Essays on the Role of Inventors on Corporate Boards

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Declaration

I hereby declare that this is my own original work and has not been submitted in any form for the award of any degree at any other university. Chapters 2 and 3 are co-authored with P. Boyallian and M. Ghaly.

Mohamed Badawy

Acknowledgment

First of all, I would like to express my gratitude to Almighty, **ALLAH**, for granting me the patience and ability to complete my thesis, as well as for the countless blessings he has given me in life.

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To my Father,

Today, I am remembering my father and the wonderful moments we shared. He was my closest friend in life. There is not a day or a moment that goes by when I do not think of him and smile. He served as my most significant source of encouragement and my ultimate source of inspiration. I deeply wish he could be here with me today. Life is different without him, but I am profoundly thankful that I had the privilege of calling him my dad.

Abstract

This thesis consist of two self-contained studies in the area of empirical corporate finance. The first essay examines how directors with patenting expertise affect corporate innovation. We find strong evidence of a positive relation between inventor-directors and firm innovation. Firms with inventors on their boards spend more on R&D, generate more patents, and their patents receive a higher number of citations and have greater economic value. The effects are stronger when inventor-directors are active and more influential. Additionally, we find that firms with inventor-directors are more likely to engage in radical and explorative innovations across a wider array of technology classes. Our results shed light on the importance of directors' innovation experience in facilitating firms' innovation efforts.

The second essay studies the impact of female inventor-directors on the performance of female inventors within firms. We find that female directors with innovation (patenting) experience are positively related to the patenting performance of a firm's female inventors as measured by the number, citations, value, and importance of patents they file. Firms with female inventor-directors employ more female inventors, who are more productive, and have a greater contribution to firm innovation. Further results show that the innovation productivity gender gap between male and female inventors shrinks with the presence of female inventor-directors. These effects are more pronounced when the female director is a star inventor.

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Chapter 1

Introduction

The different skills, attributes, and experiences of directors could have great impact on a firm's decisions, performance, and shareholders' wealth (Güner et al., 2008; Dass et al., 2014; Huang et al., 2014; Field and Mkrtchyan, 2017; Drobetz et al., 2018; Faleye et al., 2018; Chen et al., 2020; Gopalan et al., 2021). Therefore, and to achieve a more transparent corporate governance, on the 16th December 2009, the U.S. Securities and Exchange commission (SEC) approved new rules to improve the disclosure on risk, compensation, and corporate governance.[1] The new rules require companies to disclose the skills, experiences, and qualifications of their directors' and nominees for directorships.

By inspecting proxy statements of public companies, it becomes evident that many of these companies emphasise the patenting expertise of their directors and directorship candidates. For instance, in its 2018 proxy statement, Corning Inc. highlights that Dr Daniel Huttenlocher, a member in its board, contributes valuable patenting and innovation experience. Likewise, Intuitive Surgical Inc.'s 2011 proxy statement spotlights that Dr Barratt, a directorship nominee, holds a number of patents in wireless communication and medical imaging. Cisco systems, in its 2014 proxy statement, showcases Dr Johnson,

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[1] https://www.sec.gov/news/press/2009/2009-268.htm

one of their directors, as a holder of many patents. Furthermore, in its 2016 proxy statement, Silicon Laboratories Inc., highlights that Dr Kim, a director nominee is an inventor.

Daniel P. Huttenlocher

Dean and Vice Provost, Cornell Tech

Dr. Huttenlocher is the founding dean of Cornell Tech, the technology graduate school of Cornell University located in New York City, a position he has held since 2012. In addition to positions as a professor and dean at Cornell, Dr. Huttenlocher has served as chief technology officer at Intelligent Markets, Inc. and as a principal scientist and member of the senior leadership team at the Xerox Palo Alto Research Center.

Dr. Huttenlocher holds a Ph.D. in computer science and a Master of Science degree in Electrical Engineering, both from the Massachusetts Institute of Technology. He is a renowned computer science researcher and educator, and a prolific inventor with two dozen U.S. patents. He brings to the board extensive experience in technology innovation and commercialization, and expertise in developing next-generation products and services.

Age	Director Since
59	2015

Committees
- **Audit**
- **Finance**

Current Public Company Directorships
- **Amazon.com, Inc.**

Public Company Directorships Held During the Past 5 Years
- **None**

Skills and Qualifications

— **Extensive experience in innovation and commercialization**
— **Expertise in information technology and computer software**
— **Experience with emerging technologies and customer experience**

Source: Corning Inc. 2018 Proxy Statement

Hill and Davis (2017) report interesting findings from their discussions with CEOs and directors about their boards' ability to nurture innovation. Across different industries, a common obstacle encountered by most boards is the directors' lack of innovation experience. Most CEOs were not satisfied with the limited innovation experience of directors. This limitation impedes boards from properly evaluating innovation proposals. CEOs expressed their desire of having more directors with innovation experience, as those directors will have a more comprehensive grasp of innovation complexities that will enable them to provide a more informed guidance on innovation matters.

An expanding literature examines the relation between different board characteristics and corporate innovation. These include board independence (Balsmeier et al., 2017; Lu and Wang, 2018), directors' industry expertise (Faleye et al., 2018; Fan, 2020), directors' tenure (Jia, 2017), board connectedness (Kang et al., 2018; Chang and Wu, 2021), and board diversity (Chen et al., 2018; An et al., 2021; Cao et al., 2021; Griffin et al., 2021; Genin et al., 2023). Surprisingly, the literature overlooks the most relevant directors' experience when it comes to innovation, which is their hands-on patenting expertise.

My doctoral thesis consists of two studies designed to explore the directors' innovation experience (i.e., patenting expertise). These studies aim to provide a novel evidence on the significance of this distinctive form of experience. Figure 1.1 depicts the yearly percentage of firms with inventors in the boardroom during the study sample period. The percentage increased from 21.79% in 2000 to 37.01% in 2017. Additionally, the figure illustrates the percentage of firms with inventor-CEO, showing an increase from 11.97% in 2000 to 16.54% in 2017. Thus, from 2000 t 2017, it is clear that firms were more inclined to add innovation experience to the board rather than replace the CEO with an inventor. This trend indicates how companies are increasingly valuing the innovation experience of directors. Chapter 2 titled "Inventors in the boardroom: Does it matter to have directors with innovation experience on your board?", shows a strong evidence of a positive relation between the presence of inventor-directors in the boardroom and firm innovation. Chapter 3 titled "Female inventors' performance: The role of female inventor-directors", focuses on female inventor-directors, and finds that female directors with innovation experience have positive spillover effects on a firm's female inventors as measured by the number, citations, value, and importance of patents these female inventors file.

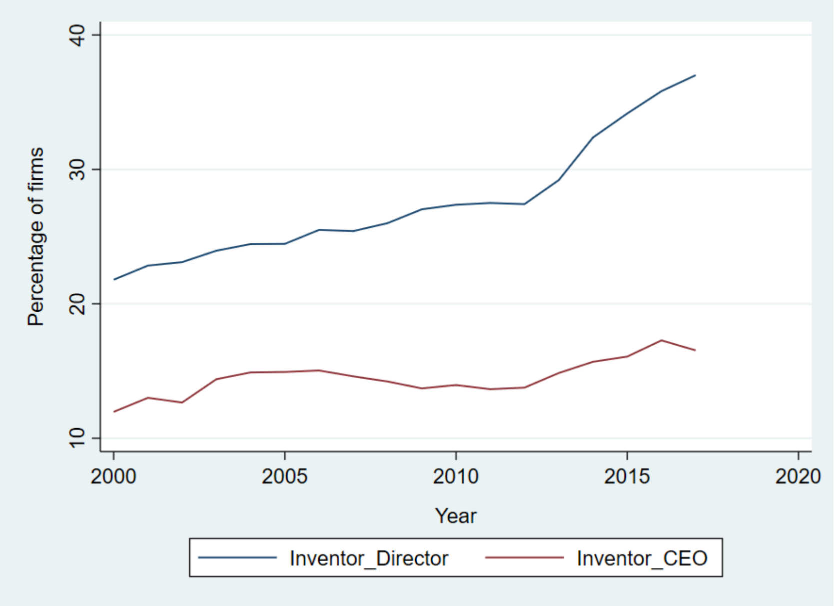

Figure 1.1: Percentage of firms with inventor-directors and inventor-CEO

Chapter 2 examines the association between the presence of inventor-directors in the boardroom and firm-level innovation. According to the resource dependence theory, board human capital (e.g., education and expertise) and relational capital (e.g., social and political connections) play a role in aiding the board to carry out its advisory responsibilities (Boyd, 1990; Hillman and Dalziel, 2003; Dalziel et al., 2011). Expertise is a crucial component of a board's human capital, which directors gain through their experience within a specific field (Kor and Sundaramurthy, 2009). Therefore, directors who have prior hands-on experience in the field of innovation, should have superior technical expertise that would enable them to provide a better advisory role on innovation initiatives and projects, through their valuable insights and deeper understanding of the innovation complexities, processes, and its long-term nature.

To investigate the relationship between the presence of inventors in the boardroom and corporate innovation, we assemble a novel dataset that tracks the patenting activities of directors in U.S. public companies. This is achieved by matching directors' information from BoardEx to that of inventors from the United States Patent and Trademark Office (USPTO)'s PatentsView database. Specifically, we employ a fuzzy matching technique on the names of directors and inventors, as well as on the names of patent assignees and the companies and institutions in the directors' employment histories. The probable inventor-director matches are manually verified by reviewing a director's employment history on LinkedIn, Wikipedia, Crunchbase, Bloomberg, newspaper interviews, and their biographies on the websites of companies in their employment history. Further details of the matching process are discussed in Appendix 2.B.

We find a strong evidence on the relation between inventor-directors and firm innovation. Firms with inventors on their boards spend more on R&D, file more patents, and their patents have greater economic value, and receive a higher number of citations. In addition, we find that firms with inventors in the boardroom tend to patent across a diverse spectrum of technology classes. Notably, firms engage in radical and breakthrough innovations, as demonstrated by the higher likelihood of filing patents in the 95th percentile of technology and year citations distribution. Firms are also more likely to engage in exploratory innovation activities that are less reliant on their existing knowledge. Moreover, our results indicate that directors who are star, active, and more influential inventors have a more pronounced impact on innovation. These results showcase how inventor-directors can motivate firms to pursue innovation, that ultimately could lead to better competitiveness and long-term value creation.

Further results investigate how the role of inventor-directors interacts with that of CEOs with innovation experience (i.e., inventor-CEOs). Our findings reveal that inventor-directors contribute positively to firm innovation in both scenarios, where inventor-CEOs are present or not.

Board composition is endogenous and it can be claimed that innovative firms are more likely to appoint inventor-directors to their boards. However, it should be noted that this matching between firms and directors is consistent with our argument that inventor-directors bring valuable innovation experience to the firms appointing them. To mitigate endogenity, we implement an instrumental variable (IV) analysis where we use the supply of inventor-CEOs near firms' headquarters as an instrumental variable for inventor-directors. The findings indicate that inventor-directors in firms' boards have causal effects on these firms' innovation activities.

Chapter 2 contributes to the expanding literature examining the effects of different directors' characteristics on corporate innovation, such as independence (Balsmeier et al., 2017; Lu and Wang, 2018), diversity (Chen et al., 2018; Griffin et al., 2021; An et al., 2021; Genin et al., 2023), networks (Kang et al., 2018; Chang and Wu, 2021), and industry expertise (Faleye et al., 2018). Our unique contribution lies in our focus on directors' experience closely related to corporate innovation, specifically their patenting expertise, and how it can facilitate firms' innovation efforts and shape their innovation strategies.

In Chapter 3, we study the impact of female inventor-directors in the boardroom on female inventors within firms. Female inventors represent only 15% of USPTO population of inventors between 1976 and 2021. Several studies examine the under-representation of female inventors in the economy and the factors contributing to this phenomenon (Kahler, 2011; Hunt et al., 2013; Fechner and Shapanka, 2018; Jensen and Meckling, 1976; Cook et al., 2022). One of these factors is the lack of female inventors serving as mentors and role models. Therefore, we investigate the influence of female inventors who managed to break through the glass ceiling and assumed roles as directors in public companies on female inventors within these firms.

According to the gender spillover literature, female representation at higher levels in the firm has a positive impact on gender-specific outcomes within the firm (e.g., Cornell and Welch, 1996; Athey et al., 2000; Cardoso and Winter-Ebmer, 2010; Dalvit et al., 2022). For example, Athey et al. (2000) argue that women serving as mentors and role models in senior positions of a firm will have positive influence on women at lower levels. The theoretical model by Dalvit et al. (2022) suggests that women at the top of a company will have gender-specific effects at various organisational levels, with these effects propagating in a top-down manner throughout the organisation. In addition, Dezsö and Ross (2012) argue that the increased representation of women at upper levels will boost the motivation of women in mid-level roles.

Chen et al. (2018) and Griffin et al. (2021) find a positive relation between board gender diversity in corporate boards and firm-level innovation. However, they do not explore the effects on female inventors in these companies. Hence, we examine the impact of the presence of female directors in general on gender-specific innovation outcomes (e.g., the output, representation, and productivity of female inventors in firms). According to Kim and Starks (2016), female directors who possess unique skills could contribute positively to the advisory effectiveness of the board. Specific skills acquired through prior experience represents a core element of a board's human capital (Kor and Sundaramurthy, 2009). Therefore, the main focus of the study goes beyond just examining the impact of female directors in general. More specifically, we study the impact of female inventors serving as directors in public companies on their fellow female counterparts, who are also inventors within these firms.

We find that female inventors in the boardroom have a positive impact on a firm's female inventors' patenting performance, as measured by the number, citations, value, and importance of patents they file. Additionally, firms with female inventors on their boards tend to create a more supportive and inclusive environment, leading to a greater participation of female inventors in the innovation activities within these firms. Additionally, we observe a boost in the productivity of a firm's female inventors when female inventor-directors are part of the board. Furthermore, these female inventors contribute more to the overall innovation efforts of the firm. Notably, our findings indicate that the presence of female inventor-directors contributes to narrowing the productivity gap between male and female inventors.

While examining the effects of female directors who lack the patenting expertise, we observe a positive relation between their presence and the patenting output of female inventors. However, this effect is comparatively less pronounced than what we observe for female inventor-directors.

In contrast to female inventor-directors, those female directors without innovation experience, do not have an impact on the productivity of female inventors or their contributions to the firm's innovation output. Moreover, they do not contribute to narrowing the gender gap in innovation productivity.

Chapter 3 contributes to the literature concerning female inventors, addressing their importance, under-representation, and the challenges they face in innovation (Kahler, 2011; Hunt et al., 2013; Fechner and Shapanka, 2018; Cook et al., 2022). Additionally, it contributes to the literature on female leaders and their potential positive effects on their female peers within organisations (Dalvit et al., 2022; Athey et al., 2000; Flabbi et al., 2019; Cardoso and Winter-Ebmer, 2010; Matsa and Miller, 2011; Kunze and Miller, 2017). Our research studies the significance of female inventors holding directorship positions, and explores how they can positively influence the patenting performance of female inventors within firms.

This thesis is organised as follows: Chapter 2 studies directors' patenting expertise and its relation to corporate innovation, Chapter 3 explores the impact of the presence of female inventor-directors on the patenting performance of female inventors within firms, Chapter 4 presents the conclusion.

Chapter 2

Inventors in the boardroom: Does it matter to have directors with innovation experience on your board?

> "Our Board's leadership has been critical to our portfolio transformation, and with the addition of Ellen de Brabander we're adding new expertise to help power our growth. Ellen brings a broad scientific background and deep R&D and innovation experience in human nutrition, life sciences and animal health – which align well with many of the growth opportunities ADM is pursuing. She has co-authored more than 60 publications in scientific journals, holds 18 patents, and has received multiple awards for her research." – Juan Luciano, ADM Chairman and CEO.[1]

2.1 Introduction

Innovation plays a crucial role in a company's long-term competitiveness and success. Even though directors are not directly engaged in the daily operations of the company, their influence can still shape the company's innovation efforts. Hill and Davis (2017), through their discussions with CEOs and directors from

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[1] The quote is from ADM's press release on 14th March 2023 announcing the nomination of Ellen de Brabander, Executive VP for Innovation and Regulatory Affairs at Elanco, to stand for election to the board of ADM at the Annual Stockholders' Meeting. ADM is an S&P 500 company specializing in human and animal nutrition and was recently ranked 35th in the 2023 Fortune 500 list of the largest U.S. companies.

various industries about their boards' ability to foster innovation, identified lack of directors' innovation expertise as a common hurdle faced by most boards. Most CEOs they interviewed expressed dissatisfaction over outside directors' insufficient innovation-related experience, which hindered their boards' ability to make knowledgeable evaluations of the risks and rewards associated with innovation proposals. One CEO stated that they refrained from discussing innovation matters with the board because they believed the directors lacked the necessary insight to accurately assess the potential value of innovation projects. The majority of CEOs that Hill and Davis (2017) spoke with wanted more directors with innovation experience on their boards, as they believed those directors would possess a deeper understanding of the complexities associated with innovation and be better equipped to provide well-informed guidance on addressing them.

Despite the importance that CEOs attach to directors with innovation experience, their impact on firms' innovation activities has so far been unexplored in the literature. A growing body of research investigates the impact of director characteristics on innovation. Director attributes that have been shown to affect corporate innovation include independence (Balsmeier et al., 2017; Lu and Wang, 2018), industry expertise (Faleye et al., 2018), gender (Chen et al., 2018; Griffin et al., 2021), connectedness (Kang et al., 2018; Chang and Wu, 2021), and educational background (Hsieh et al., 2022). Also, An et al. (2021) and Genin et al. (2023) show that board diversity, measured through a multidimensional index, has an impact on innovation. Surprisingly, the effect of directors' innovation experience, which is arguably the most relevant experience for firm innovation, has so far been overlooked. In this study, we aim to fill this gap by examining the relationship between inventor-directors (i.e., directors with patenting expertise) and firms' innovation.

Resource dependence theory emphasizes the role that board human capital (e.g., education and expertise) and relational capital (e.g., social and political connections) play in enabling the board to fulfil its advisory responsibilities (Boyd, 1990; Hillman and Dalziel, 2003; Dalziel et al., 2011). Enhanced levels of human capital are valuable to the board, as directors need to swiftly grasp extensive volumes of complex information. Possessing cognitive frameworks that facilitate this process significantly enhances directors' job performance (Carpenter and Westphal, 2001). Expertise constitutes an important aspect of a board's human capital, that is acquired through directors' past experiences within a particular domain (Kor and Sundaramurthy, 2009). Boards with expertise in a particular domain should be in a better position to help firms address strategic challenges related to that domain. This is especially true for innovation where a wider gap in knowledge and insight about a firm's innovation activities could exist between executives and outside directors, as highlighted by the survey evidence in Hill and Davis (2017).

The complex and long-term nature of innovation and the high risk associated with it often makes it difficult to accurately assess the expected returns to innovative projects compared to other types of investments (Chang and Wu, 2021). Inventor-directors with prior hands-on innovation experience are likely to have superior innovation and technical expertise compared to other directors. As a result, they may be better able to advise executives on the identification, evaluation, and exploitation of R&D opportunities. They may also provide better oversight of management's R&D spending because their technical expertise enhances their understanding of research, its development phases, and feasibility.[2] Inventor-directors may also have greater tolerance for failure through their inherent appreciation of innovation. This allows them to foster innovation by restricting potential myopic behavior by executives and encouraging them to pursue R&D opportunities that lead to value creation in the long term.[3]

Taken together, the abovementioned arguments suggest that boards with inventor-directors may have superior ability in spurring corporate innovation. To test this, we compile a novel dataset of inventor-directors that tracks the patenting history of directors in U.S. public firms. The dataset is assembled by matching directors' information from Boardex with information on patenting inventors from the United States Patent and Trademark Office (USPTO)'s PatentsView database. During our sample period, around 40% of companies have inventors serving as directors on their boards.

Using a sample of 44,006 firm-year observations over the 2000-2018 period, we find strong evidence of a positive relation between inventor-directors and corporate innovation. Firms with inventors on their boards spend more on R&D, generate more patents, and their patents receive a higher number of citations and have greater economic value. Economically, firms with inventor-directors

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[2] Arrow (1962) seminal paper in the learning by doing literature laid the groundwork for understanding how accumulated hands-on experience is crucial for improved performance and productivity. Subsequent studies examine the learning by doing and hands on experience in individual settings (e.g., Mazur and Hastie, 1978; Jovanovic and Nyarko, 1995; Waldman et al., 2003).

[3] In their discussions with Hill and Davis (2017), many directors acknowledged executives' bias for short-term results and that boards should do more to encourage management to pursue riskier innovation endeavours that would keep their companies competitive.

produce 25.73% more patents and have 26.62% more citations relative to firms without inventor-directors.

In terms of innovation strategy, firms with inventor-directors patent across a wider array of technology classes, which indicates that their innovation efforts are more diverse. They also generate patents that have higher originality (i.e., citing a wider array of technology classes) and a broader impact across various technology fields (i.e., being cited by a wider array of technology classes). Importantly, we find that firms with inventor-directors are more likely to engage in radical and breakthrough innovations, as evident by their higher tendency to produce patents that are in the top 5th percentile of the technology-year citations distribution. They are also more likely to engage in explorative innovation activities through the development of new technologies that are less dependent on their existing knowledge. Taken together, the results on radical and explorative innovation efforts are in line with the view that inventor-directors, through their better understanding of the risk and long-term nature of innovation and their greater tolerance for failure, can encourage firms to pursue riskier innovation endeavors that lead to value creation and competitiveness over the long-term. Further evidence shows that firms with inventor-directors are also more engaged in exploitative innovation efforts that take advantage of their existing knowledge and technologies.

If inventor-directors affect firm innovation through their superior abilities, we should expect those with better innovation skills to have a stronger impact on firm innovation. To test this, we classify inventor-directors based on their productivity and the quality of their patents as star inventors, if they are in the top 1% of the population of inventors in terms of productivity (Moretti and

Wilson, 2017), and as more influential if they have more than two patents with citations above the 99th percentile of technology class and year citations distribution. In line with our predictions, we find that star and more influential inventor-directors have a significantly more pronounced effect on firm innovation across all our innovation measures, which gives further support to our central argument about the importance of directors' innovation expertise in fostering corporate innovation.

Additionally, we argue that active inventor-directors, who engage in patenting activities while serving on boards, are more likely to possess up-to-date knowledge about recent innovation advancements and should, therefore, have a stronger influence on firm innovation. Indeed, our results show that active inventor-directors have a more pronounced effect on patent count, citations, value, and radical innovation relative to non-active inventor-directors.

To provide additional evidence on the relation between inventor-directors and firm innovation, we examine how the appointment of new directors with patenting experience affects innovation. Our analysis, comparing appointments of inventor-directors to appointments of non-inventor-directors, shows a significant increase in all innovation measures for firms appointing inventor-directors relative to firms appointing directors with no innovation experience.

A potential concern with a causal interpretation of the relation between inventor-directors and corporate innovation is the endogenous matching between firms and directors. For instance, a firm with superior innovation capabilities in a particular area may choose to appoint a director with innovation expertise in that area to facilitate its innovation efforts. It is also possible that a firm that plans to increase its focus on a certain innovation area but lacks experience in that area may choose to appoint a director with relevant experience in that particular area. It is important to note that any such matching is still consistent with our central argument that inventor-directors possess superior innovation expertise that is useful to companies appointing them, which we believe is a novel contribution that our paper makes to the literature.

Still, in order to establish a causal effect of inventor-directors on firm innovation, we conduct an instrumental variable (IV) analysis where we use the supply of inventor-CEOs near firms' headquarters as an instrumental variable for inventor-directors. The rationale behind this instrument is that firms are likely to appoint directors from the local pool of executives, and even though they may endogenously determine how their boards are structured, it is less likely that they would have an impact on how external director markets are structured (Knyazeva et al., 2013; Wang et al., 2015; Field and Mkrtchyan, 2017; Bernile et al., 2018; Ellis et al., 2018). Therefore, the geographic distribution of inventor-CEOs across the U.S. could provide a source of exogenous variation in the presence of inventor-directors on firms' boards. Our two-stage least squares (2SLS) analysis using the local supply of inventor-CEOs as an instrument for inventor-directors provides strong evidence supporting our original results.

However, we recognize that local director markets, particularly in industries where technology clusters are likely to develop, may be affected by firms' location choices. This clustering would potentially attract executives with innovation experience to move closer to the region, which would endogenously affect the supply of inventor-CEOs in the local market and violate the exclusion restriction. A further concern could be that due to knowledge spillovers (e.g., through local alliances within industries or across related industries), local directors with innovation experience might influence a firm's innovation activities without necessarily serving on the firm's board. To tackle this issue, we undertake the following: Firstly, our main instrument excludes from the local supply of inventor-CEOs any executives working in the same four-digit SIC industry. Secondly, we put further restrictions by constructing an instrument that excludes executives working in the same two-digit SIC industry. Thirdly, we exclude from our analysis firms headquartered in the top five innovative cities during our sample period (i.e., cities with the most filed patents). These restrictions mitigate concerns about industry clustering and knowledge spillovers affecting the exclusivity of our instrument. Our tests using the main instrument, the refined instrument, and the exclusion of most innovative cities all give support to our main finding of a positive impact of inventor-directors on corporate innovation.

Our study contributes to a growing literature examining the interaction between different directors' attributes and corporate innovation (Balsmeier et al., 2017; Lu and Wang, 2018; Chen et al., 2018; Griffin et al., 2021; Faleye et al., 2018; Kang et al., 2018; Chang and Wu, 2021; Hsieh et al., 2017; An et al., 2021; Genin et al., 2023). Our findings provide novel evidence on the importance of directors' innovation experience in facilitating firms' innovation efforts and shaping their innovation strategies.

We also contribute to a broader line of research that investigates how directors' domain-specific knowledge and experiences can affect firm outcomes related to that domain. For example, Field and Mkrtchyan (2017) and Huang et al. (2014) show that the acquisition and investment banking experience of directors can help firms make better acquisitions. Agrawal and Chadha (2005) find that directors with financial expertise can provide better monitoring of firms' financial reporting and lower their propensity to commit accounting fraud. Similarly, Gilani et al. (2021) show that the financial expertise of directors can also guide banks' capital decisions and promote their financial stability. Whitler et al. (2018) provide evidence that directors with marketing experience can provide better governance of a firm's marketing function. Our results complement this literature by showing how directors' innovation-specific knowledge and experiences can positively contribute to firms' innovation performance.

Finally, our paper contributes to recent papers examining how CEOs' innovation experience affects corporate innovation. In two recent papers, Islam and Zein (2020) and Bostan and Mian (2019) document the benefits of having inventor-CEOs and how they can foster innovation at the firms they lead. In contrast, Byun et al. (2021) show that, although inventor-CEOs are in general beneficial for firm innovation, they might create agency costs that manifest in other firm policies like cash management and leverage. Similarly, Liu et al. (2023) find that CEOs' participation in the patenting activities of their firms could be costly to innovation quality if they seek private benefits and distort inventors' incentives. A natural question that follows from these papers is how the innovation experience of CEOs interacts with that of outside directors in affecting corporate innovation. Therefore, in our paper, we also investigate whether the role of inventor-directors is complementary to inventor-CEOs or whether inventor-directors are beneficial only in the absence of inventor-CEOs. We find that inventor-directors serve both roles. We show that inventor-directors are important for firm innovation even in the presence of an inventor-CEO, highlighting how their direct patenting experience helps firms in enhancing their innovation activities alongside the CEO. However, their effect on all our innovation measures is significantly more pronounced when the CEO lacks innovation experience, suggesting that firms could boost their innovation by appointing such inventors to the board. This approach can be less disruptive than changing the CEO, particularly when firms prefer generalist CEOs.[4]

2.2 Sample selection and summary statistics

2.2.1 Sample selection

The sample includes all U.S. public companies in BoardEx over the period between 2000 and 2018. BoardEx provides information about board compositions, the employment history and personal details of directors and managers, directors' networks, and details about committees. Firm-level accounting and financial data are from CRSP-COMPUSTAT merged database.

We rely on two main sources for innovation data. The first is PatentsView

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[4] In untabulated results, we also examine the association between inventor-directors and corporate innovation in light of CEO power (as captured by CEO duality). The results show that inventor-directors are important for firm-level innovation regardless of the CEO power (i.e., inventor-directors contribute positively to innovation whether the CEO is the chairman of the board or not).

which is a database for patents that comes from the United States Patent and Trademark Office (USPTO) chief economist's office.[5] It covers over 7 million patents granted between 1976 and 2021. In addition, the database employs sophisticated algorithms and provides disambiguated patent assignees,[6] disambiguated inventors in addition to all relationships between patents.[7] The second dataset that we rely on is Kogan et al. (2017) patents dataset[8] where they estimate and provide the economic value of patents and map CRSP pemrco and permno to patents.

We utilise PatentsView database to construct firm-level innovation measures. However, and due to the absence of a common identifier with CRSP-COMPUSTAT merged database, we merge it with the dataset provided by Kogan et al. (2017) using patents IDs. This merging allows us to associate each CRSP's permco to each patent in PatentsView. We are interested in the application date of a patent as this date better takes into account the real time of innovation. For any patent to appear in PatentsView, it must have been granted and on average there is around two years lag between the application and grant dates. Therefore, as the two datasets cover patents till the end of 2020 and those filed in 2019 and 2020 might not show up,[9] we restrict the

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[5] The data can be downloaded from `http://www.patentsview.org`. The data for this study were downloaded in September 2021 and we rely on the 29th June 2021 update.

[6] A patent assignee is the innovating firm that files the patent under its name. PatentsView covers all public and private assignees which could be fuzzy matched to firms appearing in the employment histories of directors from BoardEx, and hence, this enables us to identify directors with patents filed against their names.

[7] PatentsView provides a backward citations table. In this table, there are two patent IDs. The first one is the *main patent* number while the second one is the number of the patent that is being cited (*cited patent*) by the *main patent*. From this table, we are able to calculate how many forward citations the *cited patent* receives.

[8] The data could be downloaded from `https://github.com/KPSS2017/Technological-Innovation-Resource-Allocation-and-Growth-Extended-Data`

[9] There is a significant drop in patents' applications after 2018.

sample till 2018. Our sample starts in 2000 because BoardEx coverage is limited prior to this year. We exclude financial firms (SIC 6000-6999) and utilities (4900-4999), resulting in a final sample of 44,006 firm-year observations between 2000 and 2018.

2.2.2 Identifying inventor-directors

First, we start by identifying companies appearing at the intersection of BoardEx/COMPUSTAT/CRSP and then we extract the full employment history of all non-executive directors from BoardEx. Second, the names of the extracted companies where directors were employed are cleaned and standardised.[10] The same process for cleaning and standardising company names is executed on all assignees of patents appearing in PatentsView.[11] Third, we fuzzy match the names of directors and companies in BoardEx to the names of inventors and assignees in PatentsView. Additionally, and to augment the matching output, we run a fuzzy matching on the names of directors and inventors with the restriction of CRSP permco of the patent's assignee[12] to be the same as that of the director's employer. This will help in identifying directors who patented while working in public companies and were not detected when fuzzy matching the companies'/assignees' names. Fourth, we manually verify the probable matches, which is a crucial step to identify directors with patenting expertise. This involves checking a director's employment history on Linkedin, Wikipedia, Crunchbase, Bloomberg, newspapers interviews, and their biographies on the websites of companies

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[10] Stata *reclink2* command is used to clean and standardise company names.

[11] It covers patents granted in 1976 and onwards.

[12] CRSP permco is added to PatentsView using Kogan et al. (2017) patents dataset.

they currently work for or serve as a directors on their boards. Finally, we end up with 2446 inventors sitting on boards as directors in our baseline analysis. Further details of the matching process could be found in appendix 2.B.

2.2.3 Firm-level innovation measures

We measure firm-level innovation in multiple ways. We use an accounting based measure such as annual R&D expenses scaled by total assets, but more importantly we also rely on alternative innovation measures based on patents as a direct measure of the output of innovation activities: Patent count (innovation quantity), patent citations, economic value of patents, number of radical patents (innovation quality), originality, generality, exploration, and exploitation ratios (innovation strategy).

2.2.3.1 Innovation quantity

Following the innovation literature, the first innovation metric is *Patent Count* which is the total number of patents filed (that are eventually granted) by each company in a year (Atanassov, 2013; He and Tian, 2013; Tian and Wang, 2014; Luong et al., 2017; Bhattacharya et al., 2017; Custódio et al., 2019). This measure reflects innovation *quantity*. In computing the number of patents filed for each firm-year observation, our focus is on the date of filing rather than the grant date as it reflects the actual timing of innovation.

2.2.3.2 Innovation quality

Patent Citations are the total number of forward citations that patents filed by a company in a year receive which is a measure of innovation *quality*. A truncation bias might arise due to patents filed toward the end of our sample period receiving less citations. For instance, a patent filed in 2018 will most likely receive less citations compared to a patent filed in 2001. Therefore, following Hall et al. (2001), we scale patent citations by the average citations of all patents filed in the same year and four-digit Combined Patent Classification (CPC) technology class. Then, we add up scaled citations of all patents filed by a firm in a specific year to construct the citations measure.

Another proxy for innovation quality is the *economic Value of patents* as measured by Kogan et al. (2017). A patent's economic value depends on the stock market reaction on the grant date of the patent. Accordingly, we compute the *Value* measure of patents as the total value of all patents filed by a company in a given year.

We develop a third measure which is the number of *Radical Patents* filed in a year. It distinguishes significant and breakthrough innovations from incremental ones. A patent is considered to be radical when it is in the *95th* percentile of four-digit CPC technology class and year citations distribution.

2.2.3.3 Innovation strategy

To capture the technological knowledge embedded within patents, we construct *Originality* and *Generality* indices, as defined by Hall et al. (2001). A patent that *cites* a wide variety of technology classes of patents is deemed to be an original patent while one that is *cited* by a wider variety of technology classes is considered to be a general patent.

A patent's *generality* index is one minus the Herfindhal index of the four-digit CPC technology classes of patents that cite the patent. It can be defined as

$$Generality_i = 1 - \sum_{j=1}^{J} \left(\frac{C_{ij}}{C_i} \right)^2$$

where C_{ij} is the number of forward citations that patent i receives from patents in technology class j. C_i is the total number of forward citations received by patent i. Then, an average generality index is computed for all patents filed by a firm in a year.

A patent's *originality* index is one minus the Herfindhal index of the four-digit CPC technology classes that the patent cites. This can be defined by the following expression

$$Originality_i = 1 - \sum_{j=1}^{J} \left(\frac{B_{ij}}{B_i} \right)^2$$

where B_{ij} is the number of backward citations that patent i makes to patents in technology class j. B_i is the total number of backward citations made by patent i. Then, an average originality index is computed for all patents filed by a firm in a specific year.

We also develop the *Diversity* measure. A company that files patents in different technology classes will have a high diversity score. The diversity measure is one minus the Herfindhal index of the number of patents in different technology classes that a firm files in a specific year.

Another set of measures that capture the innovation strategies are the exploration and exploitation ratios. Following Manso (2011), Almeida et al. (2013), Brav et al. (2018), and Custódio et al. (2019), we classify patents as exploitative or explorative patents. A patent is classified as exploitative if at least 60% of its citations are based on the firm's existing knowledge and it is classified as explorative if at least 60% of its citations are based on new knowledge. The existing knowledge of a firm consists of its patent portfolio and all patents referenced by the firm in its filed patents during the previous five years. Next, we compute the number of exploitative patents in a year for each firm, and then a firm's *Exploitation_ratio* is calculated as the number of exploitative patents to the total number of patents filed by the firm during the year. Similarly, the *Exploration_ratio* at the firm-year level is also calculated as the number of explorative patents to the total number of patents.

2.2.4 Control variables

Following the innovation literature, we control for a vector of firm characteristics that may affect innovation. We control for firm size, profitability, research and development (R&D), leverage, capital expenditures, and firm age. We also control for product market competition as measured by the Herfindhal index (HHI) and growth opportunities as captured by Tobin's Q.

In addition to firm characteristics, we control for the innovation experience of the CEO. We apply the same name matching approach used to identify inventor-directors on CEOs. We match the names of CEOs from BoardEx to inventors' names in PatentsView and then verify whether they are correctly matched or not.

We also control for board-level characteristics including board size, average age of directors in the boardroom, average tenure, directors' qualifications, percentage of directors holding PhDs and MBAs. Moreover, we control for directors' prior experience as chief executive officers and chief technology officers. Variables definitions and data sources could be found in appendix 2.A.

2.2.5 Summary statistics

Table 2.1 presents the summary statistics of the main variables at the firm-level and the directorship-level. Panel A displays the firm-level summary statistics. Columns (2) and (3) show the mean and standard deviation for the full sample. Column (5) displays the mean for firm-year observations where no inventors are present on the board while column (7) displays the mean for those observations when there are inventor(s) in the boardroom. The mean differences between observations with and without inventors are presented in column (8) while t-statistics are in column (9).

Firms with inventors on their boards spend more on R&D and with regard to innovation output, they file on average 36.71 patents which is more than double the patent count of firms without inventor-directors. The same applies to patent citations (49.04 versus 17.47). Additionally, the total value of patents filed by firms with inventor-directors is over three times the value of patents filed by firms without inventor-directors. Similarly, firms with inventors on board file more than twice the radical patents filed by those without inventors in the boardroom. Moreover, the originality, generality, and diversity indices are respectively 92%, 67%, and 116% higher for firms with inventor-directors relative to firms with no inventors on their boards. Furthermore, firms with inventors in the boardroom file a higher number of explorative patents in addition to an increased number of exploitative ones.

According to the difference of means, firms without inventor-directors are larger, more leveraged, and more profitable. In contrast, firms with inventor-directors are younger and have more growth opportunities.

Next, we examine a more homogeneous sample where we focus on high-tech industries. Firms in these industries are driven by innovation and seek to enhance their leadership skillset with those who have hands-on innovation experience (Islam and Zein, 2020). Panel B reports the summary statistics for these high-tech industries.[13] We find that this subset of firms exhibits similar differences to those shown in Panel A, but the differences are even larger in magnitude. For instance, high-tech firms with inventors in the boardroom file on average 34.69 more patents than those without inventor-directors, compared to the full sample in Panel A, where the difference is 22.06.

Panel C displays descriptive statistics at directors' level. The first three columns are for the full sample. Columns (4), (5), and (6) provide statistics for non-inventor-directors, while columns (7), (8), and (9) report results for inventor-directors. Relative to non-inventor-directors, inventor-directors are younger, less tenured, and hold fewer MBAs. In addition, they hold more qualifications and more PhDs. Furthermore, they are more experienced as

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[13] We follow Loughran and Ritter (2004) in their definitions of the high-tech industries. They define high-tech stocks as those in the following industries: computer hardware, communications equipment, electronics, navigation equipment, measuring and controlling devices, medical instruments, telephone equipment, communications services, and software.

chief executive officers (CEO) and chief technology officers (CTO).

[Insert Table 2.1 here]

Table 2.2 provides the sample distribution of inventor-directors by year. During our sample period, we identified 2446 inventors serving as non-executive directors in 2205 firms. The percentage of companies with directors who have patenting expertise ranges from 21.79% in 2000 to 37% in 2017, indicating that around one in every three companies has inventor(s) on their boards. This upward trend is an indication of how companies are increasingly valuing the innovation experience of directors, as having inventor-directors on their boards could potentially enhance a firm's innovation activities.

[Insert Table 2.2 here]

Table 2.3 highlights the distribution of firm-year observations across two-digit Standard Industrial Classification (SIC) industries. The table shows the distribution of firm-year observations where there are inventors on the board (column (1)), alongside those observations where there are no inventors in the boardroom (column (2)). The top five industries where inventors serve as directors are Chemicals & Allied Products, Insturment & related products, Electronic & Other Electrical equipment, Business Services, and Industrial Machinery & Equipment. For each industry, column (3) displays the percentage of observations in that industry where inventors serve as directors. It is noteworthy that inventors are serving as directors not only in high-tech industries but also in the boardrooms of other industries that might not be known for high innovation levels.[14] Finally, column (4) gives the average percentage of inventors on board in each industry.[15]

[Insert Table 2.3 here]

2.3 Empirical model and results

2.3.1 Inventor-directors and corporate innovation

We start by testing how the presence of an inventor in the boardroom is related to different measures of firm-level innovation. This is done by estimating a baseline linear model expressed as follows:

$$y_{i(t)} = \beta\ Inventor\_Director_{i(t-1)} + X_{i(t-1)} + \gamma_s + \mu_t + \epsilon_{it} \tag{2.1}$$

where i indexes firm, s indexes industry, t indexes time. $y_{i(t)}$ refers to the measure of innovation which could be $log(1 + \#\ patents)$, $log(1 + patent\ citations)$, $log(1 + patent\ value)$, $log(1 + \#\ radical\ patents)$, or $R\&D$. $Inventor\_Director$ is a dummy variable which takes the value of one if there is at least one inventor serving as a non-executive director on the board of firm i in year $(t-1)$ and zero otherwise.[16] $X_{i(t-1)}$ are the time varying control

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[14] That is why our study does not only focus on high-tech industries as it is the case in Islam and Zein (2020). However, the results hold if we restrict our analyses to those high-tech industries.

[15] For each firm-year observation, we calculate the percentage of inventors on board as the number of inventor-directors to the total number of directors. Then, we calculate the average percentage in each industry.

[16] Our results hold for two and three lagged independent variables.

variables while γ_s and μ_t are industry and year fixed effects where industries are classified at two-digit SIC level, and ϵ_{it} is the error term. We include industry fixed effects to account for the inter-industry differences in patenting. Standard errors are clustered at the firm-level.

Tables 2.4 and 2.5 report baseline results that indicate there is a positive and significant relation between the presence of a director with patenting expertise in the boardroom and a firm's innovation outcomes.

Table 2.4 reports the results of estimating equation 2.1. Model (1) displays the results where $log(1 + \#\ patents)$ is the main dependent variable. The Inventor_Director coefficient is 0.229 and it is statistically significant at 1%, suggesting a positive association between having inventors on board and corporate innovation. Firms with inventor-directors file 25.73%[17] more patents relative to firms without inventors on their boards. Model (2) shows the impact on the quality of patents ($log(1 + patent\ citations)$) and suggests that having an inventor-director is associated with an increase in patent citations by 26.62% (the coefficient is 0.236). The positive and significant coefficients in models (3) & (4) indicate how the presence of inventors on boards is correlated not only with normal innovation activities but also with valuable and radical innovations. Firms with inventor-directors file patents that are 49.03% more valuable and 7.47% more radical compared to firms without inventor-directors. Model (5) shows that the presence of inventor-directors has a positive relation with R&D expenditures.

[Insert Table 2.4 here]

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[17] The marginal effect could be calculated as $e^{0.229} - 1 = 25.73\%$

In table 2.5, we study the association between the presence of an inventor-director in the boardroom and various measures of innovation strategy. We find the presence of at least one inventor-director is positively and significantly related with firms filing more original patents that cite patents in a wider array of technology classes (an increase in *Originality*). In addition, firms' filed patents have a broader impact across different technology fields where they are cited by patents from a wider variety of technology classes (an increase in *Generality*). Moreover, the innovation efforts are more diverse where firms produce patents in various technology classes (an increase in *Diversity*).

As companies with inventors on boards file more patents, we are interested in examining the trade-off between exploration and exploitation activities. Inventors on boards could direct companies towards better deployment of their resources, leading firms to produce more patents in their fields of expertise. This, in turn, results in a higher number of exploitative patents. In contrast, those inventor-directors might redirect companies' innovation toward new technological domains, resulting in a greater number of patents that rely less on existing knowledge. Following Manso (2011), Almeida et al. (2013), Brav et al. (2018), and Custódio et al. (2019), we classify patents as being exploitative or explorative. A patent is classified as exploitative if at least 60% of its citations are based on the firm's existing knowledge and it is classified as explorative if at least 60% of its citations are based on new knowledge.[18] Models (4) and (5) display the results for exploitation and exploration ratios. The coefficients for the *Exploitation_ratio* and the *Exploration_ratio* are positive

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[18] We also test 80% threshold and the results remain the same.

and significant. The results indicate that firms engage in explorative innovation through the development of new technologies that are less dependent on their existing knowledge. This aligns with the view that inventor-directors exhibit more failure tolerance and have better understanding of the long-term nature of innovation. As a result, they encourage firms to pursue riskier innovation activities, which in turn, contribute to long-term value creation and competitiveness. Additionally, firms with inventor-directors engage in exploitative innovation, leveraging their existing knowledge to their advantage.

[Insert Table 2.5 here]

2.3.2 Extensive and intensive margins

In tables 2.4 and 2.5, the main independent variable addresses the extensive margin where it is a dummy indicating the presence of at least one inventor-director on board. However, we expect different outcomes for firms at different levels of relative participation of inventor-directors at their respective boards (i.e., the higher the percentage of inventors on board, the more innovative the company will become). In table 2.6, we explore the intensive margin with the main independent variable being the percentage of inventors on board (calculated as the number of inventor-directors to the total number of directors). The coefficient in model (1) is 0.987 and significant at 1% suggesting that one standard deviation increase in the percentage of inventors on board is associated with 9.3%[19] increase in the number of patents filed.

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[19] The standard deviation of the Inventors% is 0.09. As the coefficient is 0.987, the logarithm of one plus the number of patents will increase by $0.987 \times 0.09 = 0.089$ for one standard deviation increase in the percentage of inventors. Then, we take the exponential of the result and subtract one to find that the number of patents will increase by 9.3%).

Model (2) indicates that one standard deviation increase in the percentage of inventors on board will improve citations by 9.6%. Model (3) shows that the value of patents will increase by 17% with one standard deviation increase in the percentage of inventors in the boardroom. Consistently, the estimates are also significant for the number of radical patents and R&D as shown in models (4) and (5). Overall, the results show a positive and significant relationship between the relative importance of inventor-directors in a board and the main innovation measures.

[Insert Table 2.6 here]

2.3.2.1 Classification of inventors

We have documented that there is a positive relationship between the presence of inventors in the boardroom and corporate innovation. We take this further hypothesizing that the effect will be more pronounced when the director is a relatively more successful inventor. In this context and similar to Moretti and Wilson (2017), we identify *star* inventors as inventors whose number of patents filed in the last 10 years places them in the 99^{th} percentile. Models (2), (4), (6), (8), and (10) of panel A in table 2.7 present the results when the inventor on board is a *star*. The variable *Inventor_Director* is a dummy variable that takes the value of one if the inventor on board is a *star* and zero if there are no inventors on board. Models (1), (3), (5), (7), and (9) display results when the inventor on board is *not a star*. *Inventor_Director* is a dummy variable that takes the value of one if the inventor on board is not a star and zero if none of the directors is an inventor. The effects on the log(1+ # patents) and log(1+patent citations) are positive and significant. Coefficients of the number of patents and citations are greater than those in the baseline results and they are about 170% and 220% greater than their counterparts when the inventor on board is not a star. The p-values of the F-test of equal coefficients are reported in the last row of the table and show that the differences between estimates for patent count and citations are statistically significant at 1%. Regarding value, radical patents, and R&D, the coefficients for the subset of star inventors are positive and significant at 1% and they are respectively more than two, three, and four times the coefficients of the subset where the inventor on board is not a star. The p-values of the coefficients for equality tests indicate a significant statistical difference between these two subsets.

Next, we classify inventors based on whether they have *influential patents* and these are patents with citations in the top 1% of the technology class and year citations distribution. Inventors with more than two patents above the 99^{th} percentile of the technology class-year citations distribution are designated as *more influential* inventors and those with two or fewer are considered *less influential* inventors. Hence, we expect the effect on a firm's innovation will be greater when the inventor is a more influential one. The results are reported in Panel B of table 2.7 and they are in the expected direction. Models (1), (3), (5), (7), and (9) display results for the subset of firms with *Less influential inventors* while models (2), (4), (6), (8), and (10) report estimates for the subset of firms with *More influential* inventor-directors. Across all specifications, *More influential* coefficients are positive and significantly higher than the coefficients of *less influential* inventor-directors. Patent count, citations, and value coefficients when the director is a *more influential* inventor are around three times those of the subsample when the inventor is less influential. Similarly, *More influential* subsample coefficients for radical patents and R&D are around four times those of the less influential subset. In all pair of estimates, the p-values of the tests for coefficients equality are significant at either 1% or 5%.

Finally, in Panel C of table 2.7, we present similar results when we split the sample between *active* and *non-active* inventors. We expect that active inventor-directors, who engage in patenting activities while serving on boards, are more likely to maintain current knowledge about recent innovation advancements and, therefore, should have a stronger impact on firm innovation. In a given year (t), an inventor-director is considered as active if he/she has at least one patent filed in his/her name over $(t-2 : t+2$ window$)$. In models (2), (4), (6), (8), and (10), the main independent variable takes the value of one if there is an active inventor on board and zero if none of the directors is an inventor at $(t-1)$. In models (1), (3), (5), (7), and (9), the main independent variable takes the value of one if the inventor on board is not active and zero if none of the directors is an inventor at $(t-1)$. Regarding patent count, citations, value, and radical patents, the coefficients for the active inventor-directors' subsample are significant and are at least two times those of the subsample with non-active inventor-directors (the p-values of the coefficients equality tests are significant at 1%). Overall, the results in table 2.7 support our central argument about the importance of directors' innovation expertise in spurring corporate innovation.

[Insert Table 2.7 here]

2.3.3 Directors versus CEOs

Islam and Zein (2020) and Bostan and Mian (2019) establish that a firm engages in greater innovation when its CEO is an inventor with a history of patenting. Conversely, Byun et al. (2021) show that while inventor-CEOs contribute positively to firm innovation, they may create agency costs that become evident in other firm policies like cash management and leverage. Similarly, Liu et al. (2023) find that the participation of CEOs in their firms' patenting activities could potentially come at the expense of innovation quality if those CEOs seek private benefits and distort inventors' incentives. A natural question that arises from these studies is how the innovation experience of CEOs interacts with that of outside directors in affecting corporate innovation.

In this section, we examine whether the role of inventor-directors is complementary to inventor-CEOs or they are primarily advantageous in the absence of those inventor-CEOs. The results for our tests are reported in table 2.8. We split our main sample into two based on whether the CEO is an inventor or not. Models (1), (3), (5), (7), and (9) show the results for the subsample when the CEO is an inventor while models (2), (4), (6), (8), and (10) report results for non-inventor-CEOs.

The results highlight two important features of inventor-directors. First, there is a positive contribution to the main outcome variables from the presence of an inventor-director, even when the firm already has an inventor-CEO. This result implies that even when the CEO has some expertise, the presence of a director with patenting experience can help release the full inventing potential of the firm. On the other hand, the inventor-directors' expertise becomes of greater value for the firm when the CEO does not have a patenting experience himself. These results highlight the importance of the variety of skills in the boardroom and how the selection of board members can empower and increase the capacity of a CEO, beyond the board's monitoring role. It also opens an alternative strategy for firms that prefer to retain a CEO with a more generalist expertise, while reinforcing the firm's innovation activities by introducing specialized innovation expertise through board composition.[20]

[Insert Table 2.8 here]

2.4 Inventor-directors' appointments

The preceding cross-sectional analyses shed light on how the presence of an inventor who serves as a director is related to the innovation output at the firm-level. In this section, we extend our examination of this relationship by exploring the effect of inventor-directors' appointments on innovation outcome variables.

This analysis highlights how corporate innovation changes subsequent to the appointments of inventor-directors. From this appointment analysis, we are able to investigate the effect on corporate innovation by comparing appointments of inventor-directors with those of non-inventor-directors and

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[20] In the context of CEO power, prior theoretical and empirical studies have shown mixed results regrading CEO duality (as a proxy for CEO power). Some suggest negative outcomes as CEO duality might hinder the proper functioning of the board (e.g., Daily and Dalton, 1994; Aktas et al., 2019), while other research indicate positive outcomes (e.g., Finkelstein and D'aveni, 1994; Yang and Zhao, 2014). Therefore, we examine the influence of inventor-directors in light of CEO power. Our sample is divided into two subsamples based on whether the CEO of the firm also serves as the chairman of the board. Our untabulated results indicate that inventor-directors have positive impact on innovation, regardless of whether the CEO is the chair of the board or not.

those where the boards are not going through any changes (i.e., no appointments). Hence, we show how bringing this type of experience to the board affects innovation. We expect that corporate innovation increases following the appointment of inventor-directors. Table 2.9 reports the results of inventors' appointments. Panel A reports the findings for the full sample where the main independent variable is *Inventor_Appointment* which takes the value of one when there is at least one inventor appointee and zero when the appointee is not an inventor or there are no appointments in the year. Models (1) and (2) report estimates for patent count and citations respectively. Relative to observations with non-inventor appointments or no appointments, the number of filed patents will increase by 11.52% (the coefficient is 0.109 and significant), citations will increase by 13.88% (the coefficient is 0.130 and significant), the value of patents and the number of radical patents filed will go up by 19.12% and 6.18% respectively following the appointment of directors with innovation experience. The impact on R&D is also positive and significant at 5%.

In panel B of table 2.9, we restrict the sample to observations where non-executive directors are appointed (i.e., we exclude observations when there are no appointments). In this context, we examine what is the effect on innovation when the appointed director is an inventor relative to the appointments of directors without innovation experience. Across all models, the coefficients are positive and significant and the estimates indicate that the number of patents, citations, value, and radical patents are expected to increase by 9.97%, 12.30%, 16.65%, and 4.6% respectively following the appointment of a director with a patenting expertise.

Next, we match each firm appointing an inventor-director in year t with a firm not appointing an inventor-director from the same year and two-digit SIC industry using nearest-neighbour propensity score matching. The propensity score is estimated using firm size, profitability, and Tobin's Q at $(t-1)$. Panel C of table 2.9 reports the results for the analysis based on the sample of firms appointing inventor-directors and the control group. Consistent with the findings in panels A and B, we observe that firms appointing inventors to their boards experience an increase of 11.74%, 13.20%, and 26.62% in the number of patents, citations, and value respectively, compared to control firms. Overall, the results in table 2.9 highlight how firm-level innovation improves following the appointment of inventor-directors.

[Insert Table 2.9 here]

2.5 The causal effect of inventor-directors on firm-level innovation

Board composition is endogenous and it can be claimed that innovative firms who are already setting a new innovation path or pursuing their current patenting strategy are more likely to appoint inventors to their boards. In this regard, we deal with the endogenous board composition by implementing a two-stage least squares (2SLS) analysis where we use the supply of inventor-CEOs (i.e., CEOs with patenting experience) near firms' headquarters as an instrumental variable for inventor-directors.

The instrument is expected to meet the relevance restriction, as argued by

Knyazeva et al. (2013), in which current or former CEOs of other companies constitute a key source in supplying directors for boards. Directors are more likely to join proximate firms and this approach of appointing directors from the local market has been applied in studies conducted by Wang et al. (2015), Ellis et al. (2018), Kang et al. (2018), Bernile et al. (2018), and Fahlenbrach et al. (2010). We argue that inventor-CEOs in the local market would affect the firm's innovation by being appointed to the board, as it is less likely that an inventor-CEO from a local public company joins the firm in another position and hence affects its innovation.

The instrument for the 2SLS analysis is the logarithm of one plus the number of inventor-CEOs in the local market. We match CEOs in BoardEx to inventors in PatentsView with the same matching techniques used for directors. The local market for any firm includes all other firms within 100 miles of its headquarter and any nearby firm must be in a different four-digit SIC industry as companies cannot directly hire from their competitors.

Panel A of table 2.10 presents the 2SLS findings where column (1) displays the first stage and the second stage results are in columns (2)-(6). Regarding the relevance of the instrument, the coefficient in the first stage is positive and significant confirming that the greater the number of CEOs with patenting expertise in the local market, the higher the percentage of inventors on board. The first stage F-statistic is reported which is large and exceeds the weak instrument threshold as proposed by Stock and Yogo (2005). Moreover, the coefficients in the second stage are positive and significant across all specifications which indicate that having inventors on board has a positive impact on firm-level innovation. A one standard deviation increase in the percentage of inventors on board is associated with 56.08%,[21] 59.84%, 134.78%, and 16.56% increase in the number of filed patents, total citations, value, and the number of radical patents respectively.

A shortcoming for the instrument in Panel A is that an increase in the number of nearby firms with inventor-CEOs might indicate an increase of the overall innovation activity in the region that might create spill-overs between companies beyond the supply of skill for the board (e.g., through local alliances within industries or across related industries) and this could be a potential violation of the exclusion restriction. However, even in the extreme case of the existence of regional or state-level policy (such as tax incentives) to promote the settlement or development of innovative firms in a given area, what this would create is an attenuation bias: all firms would respond to this change in policy and hence all firms would experience a homogenous change in their outcome variables rendering our main variable of interest (appointing inventor-directors) completely insignificant. Yet, this is not observed in our results.

To tackle the spill-over issue, we construct a more conservative instrument where the local market for any firm is defined as all other firms within 100 miles of its headquarter and any nearby firm must be in a *different* two-digit SIC industry. This restrictive condition reduces the concern over spill-overs between companies assuming that such spill-over effects are less likely to happen across industries. Hence, if inventor CEOs sit on the boards of

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[21] The standard deviation of the predicted values of Inventor_Director% from the first stage is 0.038. As the coefficient in the second stage is 11.716, the logarithm of one plus the number of patents will increase by $11.716 \times 0.038 = 0.445$ for one standard deviation increase in the percentage of inventors. Then, we take the exponential of the result and subtract one to find that the number of patents will increase by 56.08%.

companies in different industries and there are increases in these companies innovation, this could be linked to the technical skill set of these inventor-directors. Panel B of table 2.10 reports the results. The coefficient from the first stage is positive and significant and, additionally all estimates from the second stage remain positive and significant.

Furthermore, the local supply of directors could be affected by the location of firms, especially in industries where technology clusters are more likely to develop. This clustering could result in more executives with patenting experience moving to the region, which will endogenously affect the supply of inventor-CEOs. In this regard, and by employing the same instrument as in panel B, we drop observations of firms headquartered in the top five innovative cities (these are top five cities with most filed patents during our sample period).[22] Panel C reports the results where the first stage coefficient is still positive and significant. The second stage estimates are significant for the number of patents filed, total citations, value, and R&D expenditure.

In summary, the findings from the instrumental variable analysis presented in table 2.10 support our hypothesis that the appointment of inventor-directors to firms' boards leads to an increase in the innovation activities of these firms.

[Insert Table 2.10 here]

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[22] The five cities are Armonk, Santa Clara, San Jose, Redmond, and Dallas

2.6 Conclusion

In this paper, we examine the relationship between the presence of directors with innovation experience on corporate boards and the level of corporate innovation. Analysing data from 2000 to 2018, we find that approximately 40% of public companies in our sample have inventors on their boards. Our baseline results indicate a positive relationship, with firms having inventor-directors investing more in R&D, filing more patents, receiving more patent citations, and generating more valuable patents. The results are more pronounced when the directors are highly successful inventors (star and influential inventors).

We find that firms with inventors in the boardroom patent across a wide array of technology classes and engage more in radical and breakthrough innovations. Moreover, these firms are more engaged in both explorative innovation, which relies less on existing knowledge, and exploitative innovation, which leverages their existing expertise.

We study how inventor-directors interact with inventor-CEOs to influence firm-level innovation. Our findings reveal that inventor-directors contribute positively to corporate innovation, whether or not the CEO is an inventor. The results highlight the importance of having a diverse skill set in the boardroom, as evidenced by the directors' hands-on innovation experience. This suggests an alternative strategy for firms to retain a generalist CEO while enhancing innovation by adding specialized expertise to the board.

Beyond the cross sectional analysis of the presence of inventor-directors and corporate innovation, we also examine the impact on innovation following the appointment of inventors to boards. We find that both the quantity and quality innovation increase following inventor-directors' appointments. Instrumental variable (IV) results support our hypothesis that inventors in the boardroom lead to an increase in corporate innovation. These results confirm the importance of directors' patenting expertise in promoting firms' innovation, thereby contributing to broader economic growth.

Table 2.1: Summary statistics

This table presents summary statistics of the main variables of the study over the period 2000-2018. Panel A presents summary statistics of variables at the firm-level for all industries. Columns (1) to (3) show statistics for the full sample. Columns (4)-(5) and (6)-(7) display statistics for the subsamples without and with inventors in the boardroom respectively. The differences between means and t-statistic are reported in columns (8)-(9). Panel B reports summary statistics at the firm-level for high-tech industries as defined in Loughran and Ritter (2004). Panel C reports summary statistics at the directors' level. Columns (1)-(3) in panel C display statistics for all Non-executive directors. Statistics for Non-executive directors who are not inventors are shown in columns (4)-(6) while those of inventors are in columns (7)-(9). Mean differences and t-statistic are in columns (10) to (11). Appendix 2.A provides definitions of all variables.

Panel A: Firm-level summary statistics

	Full Sample			Without Inventors		With Inventors		Difference	
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
Variable	N	Mean	Std. Dev.	N	Mean	N	Mean	(7)-(5)	t-stat
# patents	44006	20.79	168.07	31772	14.66	12234	36.71	22.06***	12.36
Total Citations	44006	26.25	195.95	31772	17.47	12234	49.04	31.57***	15.18
Total Value	44006	679.42	5336.17	31772	400.22	12234	1404.51	1004.29***	17.75
# Radical Pat.	44006	1.26	9.14	31772	0.85	12234	2.34	1.48***	15.29
Originallity	44006	0.15	0.24	31772	0.12	12234	0.23	0.12***	46.56
Generality	44006	0.07	0.16	31772	0.06	12234	0.10	0.05***	27.68
Diversity	44006	0.16	0.29	31772	0.12	12234	0.26	0.14***	46.18
Exploitation_ratio	44006	0.14	0.28	31772	0.09	12234	0.25	0.16***	54.40
Exploration_ratio	44006	0.18	0.33	31772	0.15	12234	0.26	0.11***	30.91
Firm_Size	44006	6.29	2.03	31772	6.32	12234	6.23	-0.09***	-4.31
ROA	44006	0.04	0.52	31772	0.07	12234	-0.04	-0.11***	-19.73
R&D	44006	0.07	0.18	31772	0.04	12234	0.13	0.09***	47.79
Leverage	44006	0.21	0.26	31772	0.23	12234	0.18	-0.05***	-17.92
Capex	44006	0.05	0.07	31772	0.06	12234	0.04	-0.02***	-24.49
HHI	44006	0.19	0.18	31772	0.20	12234	0.15	-0.05***	-28.88
Tobin's_Q	44006	2.27	2.72	31772	2.12	12234	2.67	0.55***	19.13
Firm_Age	44006	2.83	0.73	31772	2.84	12234	2.79	-0.06***	-7.26
Inv_CEO	44006	0.15	0.35	31772	0.11	12234	0.25	0.15***	39.73
Board_Size	44006	8.18	2.26	31772	8.10	12234	8.39	0.30***	12.39
Board_Avg_Age	44006	59.72	5.07	31772	59.79	12234	59.53	-0.25***	-4.68
Board_Avg_Tenure	44006	7.69	4.56	31772	7.89	12234	7.19	-0.70***	-14.36
Independence_ratio	44006	0.73	0.15	31772	0.72	12234	0.76	0.04***	26.21
No_Qualifications	44006	17.02	6.83	31772	16.24	12234	19.04	2.80***	39.11
PhD%	44006	0.10	0.13	31772	0.07	12234	0.16	0.09***	71.14
MBA%	44006	0.31	0.19	31772	0.31	12234	0.33	0.02***	11.43
CEO%	44006	0.54	0.18	31772	0.53	12234	0.57	0.04***	18.67
CTO%	44006	0.01	0.04	31772	0.01	12234	0.03	0.02***	44.47

Panel B: Firm-level summary statistics for high-tech industries

	Full Sample			Without Inventors		With Inventors		Difference	
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
Variable	N	Mean	Std. Dev.	N	Mean	N	Mean	(7)-(5)	t-stat
# patents	9752	41.94	183.39	5747	27.69	4005	62.38	34.69***	9.23
Total Citations	9752	52.10	242.18	5747	36.76	4005	74.10	37.34***	7.51
Total Value	9752	1150.63	7641.21	5747	726.79	4005	1758.81	1032.01***	6.58
# Radical Pat.	9752	2.54	11.14	5747	1.75	4005	3.67	1.92***	8.39
Originallity	9752	0.23	0.25	5747	0.19	4005	0.28	0.09***	18.05
Generality	9752	0.12	0.18	5747	0.11	4005	0.14	0.04***	10.30
Diversity	9752	0.26	0.33	5747	0.21	4005	0.34	0.13***	19.70
Exploitation_ratio	9752	0.20	0.31	5747	0.15	4005	0.28	0.13***	21.34
Exploration_ratio	9752	0.30	0.37	5747	0.27	4005	0.35	0.08***	10.42
Firm_Size	9752	5.86	2.06	5747	5.70	4005	6.10	0.41***	9.62
ROA	9752	0.03	0.31	5747	0.05	4005	0.01	-0.04***	-5.59
R&D	9752	0.10	0.13	5747	0.09	4005	0.12	0.03***	12.77
Leverage	9752	0.14	0.20	5747	0.15	4005	0.13	-0.02***	-4.81
Capex	9752	0.04	0.04	5747	0.04	4005	0.04	0.00	-0.61
HHI	9752	0.09	0.08	5747	0.09	4005	0.08	-0.01***	-3.24
Tobin's_Q	9752	2.45	2.44	5747	2.31	4005	2.64	0.32***	6.49
Firm_Age	9752	2.74	0.65	5747	2.72	4005	2.77	0.05***	3.64
Inv_CEO	9752	0.26	0.44	5747	0.21	4005	0.32	0.11***	12.19
Board_Size	9752	7.59	2.06	5747	7.35	4005	7.93	0.58***	13.76
Board_Avg_Age	9752	58.99	5.31	5747	58.96	4005	59.02	0.06	0.52
Board_Avg_Tenure	9752	7.67	4.44	5747	7.70	4005	7.62	-0.09	-0.95
Independence_ratio	9752	0.74	0.14	5747	0.72	4005	0.75	0.03***	9.72
No_Qualifications	9752	16.43	6.41	5747	15.39	4005	17.92	2.54***	19.62
PhD%	9752	0.12	0.14	5747	0.09	4005	0.16	0.07***	23.46
MBA%	9752	0.32	0.19	5747	0.32	4005	0.33	0.01	1.61
CEO%	9752	0.55	0.19	5747	0.53	4005	0.57	0.03***	8.16
CTO%	9752	0.03	0.07	5747	0.02	4005	0.04	0.02***	18.22

Panel C: Directors’ summary statistics

	All Non-Executive Directors			Non-Inventor-Directors			Inventor-Directors			Difference	
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)
Variable	N	Mean	Std. Dev.	N	Mean	Std. Dev.	N	Mean	Std. Dev.	(8)-(5)	t-stat
Age	285631	60.85	9.39	269319	60.88	9.42	16312	60.32	8.92	-0.56***	-7.44
Tenure	294586	7.24	7.03	278245	7.28	7.04	16341	6.69	6.85	-0.58***	-10.31
No. Qual.	294586	2.14	1.21	278245	2.12	1.19	16341	2.57	1.31	0.45***	46.15
CEO	294586	0.49	0.50	278245	0.48	0.50	16341	0.63	0.48	0.14***	35.39
CTO	294586	0.01	0.10	278245	0.00	0.07	16341	0.09	0.29	0.09***	114.64
PhD	294586	0.10	0.30	278245	0.08	0.28	16341	0.38	0.49	0.30***	127.50
MBA	294586	0.33	0.47	278245	0.33	0.47	16341	0.22	0.41	-0.11***	-29.90

Table 2.2: Sample distribution of inventor-directors by year

This table reports the number of unique inventors in the boardroom in column (1), the number of unique companies with inventors on their boards in column (2), the total number of companies in column (3), and the percentage of companies with inventors on their boards in column (4).

Year	No. of unique Inventors (1)	No. of unique companies with Inventors (2)	No. of all companies (3)	% of Companies with Inventors (4)
2000	263	255	1170	21.79%
2001	312	302	1322	22.84%
2002	345	323	1398	23.10%
2003	686	659	2751	23.95%
2004	760	740	3027	24.45%
2005	761	737	3013	24.46%
2006	800	751	2945	25.50%
2007	777	722	2841	25.41%
2008	786	713	2742	26.00%
2009	764	692	2560	27.03%
2010	762	698	2550	27.37%
2011	769	695	2527	27.50%
2012	774	689	2513	27.42%
2013	859	747	2558	29.20%
2014	949	846	2613	32.38%
2015	986	869	2544	34.16%
2016	997	883	2465	35.82%
2017	1036	913	2467	37.01%
Full sample	2446	2205	5501	40.08%

Table 2.3: Sample distribution of observations by two-digit Standard Industrial Classification (SIC) industries

This table presents the distribution of two-digit SIC industries. For each industry, the number of observations where there are inventor(s) in the boardroom is reported in column (1), while column (2) shows the number of observations without inventors on board. The percentage of observations with inventor-directors for each industry is displayed in column (3). For each industry, the average percentage of inventors on board is reported in column (4).

Industry	#Obs. w/ Inventors (1)	#Obs. w/o Inventors (2)	% of Obs. w/ Inventrs (3)	Inventors% on board (4)
Chemicals & Allied Products	3045	2582	54.11%	10.84%
Instruments & Related Products	1686	1574	51.72%	9.66%
Electronic & Other Electrical Equipment	1572	2535	38.28%	7.00%
Business Services	1502	4239	26.16%	4.22%
Industrial Machinery & Equipment	983	1809	35.21%	5.72%
Communications	327	1044	23.85%	2.98%
Engineering & Management Services	278	732	27.52%	4.60%
Transportation Equipment	258	899	22.30%	2.89%
Oil & Gas Extraction	222	1812	10.91%	1.46%
Wholesale Trade - Durable Goods	205	833	19.75%	2.49%
Miscellaneous Retail	161	768	17.33%	2.57%
Health Services	133	781	14.55%	2.30%
Food & Kindred Products	127	958	11.71%	1.34%
Printing & Publishing	123	396	23.70%	2.90%
Primary Metal Industries	118	437	21.26%	3.29%
Fabricated Metal Products	103	554	15.68%	2.22%
Miscellaneous Manufacturing Industries	100	244	29.07%	4.01%
Rubber & Miscellaneous Plastic Products	97	270	26.43%	2.96%
Metal Mining	94	853	9.93%	1.31%
Paper & Allied Products	73	370	16.48%	1.75%
Apparel & Accessory Stores	71	554	11.36%	1.23%
Furniture & Fixtures	68	243	21.86%	2.54%
Wholesale Trade - Nondurable Goods	58	620	8.55%	1.16%
Apparel & Other Textile Products	55	363	13.16%	1.61%
Eating & Drinking Places	52	733	6.62%	0.62%
Trucking & Warehousing	52	314	14.21%	1.62%
Amusement & Recreation Services	51	406	11.16%	1.28%
Stone, Clay, Glass, & Concrete Products	46	162	22.12%	3.14%
Petroleum & Coal Products	44	312	12.36%	1.89%
Motion Pictures	42	169	19.91%	2.62%
General Merchandise Stores	33	283	10.44%	0.97%
Textile Mill Products	33	98	25.19%	3.10%
Leather & Leather Products	31	166	15.74%	2.09%
Nonmetallic Minerals, Except Fuels	30	116	20.55%	2.80%
Water Transportation	30	183	14.08%	1.36%
Heavy Construction, Except Building	29	201	12.61%	2.00%
Food Stores	28	185	13.15%	1.07%

Nonclassifiable Establishments	28	94	22.95%	2.12%
Transportation Services	24	196	10.91%	1.12%
Furniture & Homefurnishings Stores	24	215	10.04%	0.96%
Automotive Dealers & Gasoline Service Stations	21	306	6.42%	0.96%
Educational Services	21	221	8.68%	1.06%
Lumber & Wood Products	20	227	8.10%	0.91%
Pipelines, Except Natural Gas	19	104	15.45%	2.23%
Hotels & Other Lodging Places	17	165	9.34%	1.01%
Transportation by Air	16	297	5.11%	0.50%
General Building Contractors	14	293	4.56%	0.44%
Special Trade Contractors	14	96	12.73%	1.74%
Railroad Transportation	12	137	8.05%	0.69%
Coal Mining	12	154	7.23%	1.08%
Personal Services	11	130	7.80%	0.85%
Building Materials & Gardening Supplies	10	78	11.36%	0.96%
Auto Repair, Services, & Parking	5	81	5.81%	0.89%
Tobacco Products	4	54	6.90%	0.73%
Miscellaneous Repair Services	2	7	22.22%	2.78%
Social Services	0	75	0.00%	0.00%
Legal Services	0	17	0.00%	0.00%
Local & Interurban Passenger Transit	0	27	0.00%	0.00%
Full Sample	12234	31772	27.80%	4.69%

Table 2.4: Presence of inventor-directors and corporate innovation

This table presents the estimates of OLS regressions to examine how the presence of inventor-directors affects innovation. The main independent variable is *Inventor_Director* which is a dummy variable that takes the value of one if there is at least one inventor on board and zero otherwise at $(t-1)$. *Count* is the log(1+total number of filed patents at (t)). *Citations* is the log(1+total forward citations of filed patents at (t)). *Value* is the log(1+total value of all patents filed by a company at (t)) as estimated by Kogan et al. (2017). *Radical Pat.* is the log(1+number of radical patents filed at (t)). A patent is considered to be radical when it is in the top 5% of technology-year citations distribution. See appendix 2.A for the definitions of all variables. *R&D* is the total research and development expenditures divided by total assets. All models include year and industry fixed effects. Standard errors are clustered at the firm-level. *t* statistics are in parentheses. *,**, and *** represent significance at the 10%, 5%, and 1% levels, respectively.

	(1) Count	(2) Citations	(3) Value	(4) Radical Pat.	(5) R&D
Inventor_Director	0.229***	0.236***	0.399***	0.072***	0.016***
	(5.98)	(5.69)	(6.21)	(3.54)	(4.97)
Firm_Size	0.333***	0.338***	0.666***	0.138***	-0.008***
	(21.31)	(20.65)	(27.56)	(13.98)	(-6.22)
ROA	0.151***	0.181***	0.372***	0.064***	-0.216***
	(6.26)	(7.03)	(8.46)	(5.56)	(-12.76)
R&D	0.684***	0.690***	1.077***	0.243***	
	(6.86)	(6.50)	(7.32)	(5.96)	
Leverage	-0.363***	-0.373***	-0.677***	-0.161***	-0.044***
	(-5.96)	(-5.82)	(-5.68)	(-5.38)	(-3.87)
Capex	0.381**	0.401**	0.440	0.225**	-0.078***
	(2.19)	(2.20)	(1.49)	(2.46)	(-4.05)
HHI	0.133	0.142	0.341*	0.013	-0.055***
	(1.20)	(1.20)	(1.79)	(0.23)	(-9.89)
Tobin's_Q	0.056***	0.066***	0.139***	0.026***	0.004**
	(8.99)	(9.41)	(10.13)	(8.25)	(2.25)
Firm_Age	0.148***	0.116***	0.279***	0.049***	-0.008***
	(4.81)	(3.57)	(5.47)	(3.05)	(-3.57)
Inv_CEO	0.503***	0.531***	0.767***	0.181***	0.028***
	(10.14)	(9.69)	(9.81)	(6.15)	(5.38)
Board_Size	-0.020*	-0.023*	-0.034*	-0.009	-0.000

	(-1.68)	(-1.75)	(-1.68)	(-1.40)	(-0.48)
Board_Avg_Age	-0.011***	-0.013***	-0.024***	-0.006***	-0.001**
	(-3.45)	(-3.78)	(-4.22)	(-3.55)	(-2.38)
Board_Avg_Tenure	-0.004	-0.002	-0.005	-0.001	0.000
	(-1.03)	(-0.36)	(-0.63)	(-0.68)	(0.35)
Independence_Ratio	0.136	0.136	0.398**	-0.055	0.035***
	(1.44)	(1.36)	(2.43)	(-1.17)	(4.57)
No_Qualifications	0.015***	0.017***	0.031***	0.007***	0.001***
	(3.62)	(3.73)	(4.31)	(2.92)	(3.23)
PhD%	0.776***	0.791***	1.190***	0.300***	0.120***
	(5.41)	(5.06)	(5.12)	(3.85)	(7.33)
MBA%	-0.106	-0.141*	-0.199	-0.134***	0.004
	(-1.39)	(-1.66)	(-1.52)	(-3.26)	(0.63)
CEO%	0.172**	0.190**	0.341***	0.091**	0.012*
	(2.26)	(2.27)	(2.66)	(2.27)	(1.84)
CTO%	1.019***	1.099***	1.496***	0.229	0.109***
	(2.93)	(2.78)	(2.70)	(1.19)	(3.03)
Observations	44006	44006	44006	44006	44005
Adjusted R^2	0.448	0.403	0.473	0.278	0.350
Industry FE	Yes	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes	Yes

Table 2.5: Presence of inventor-directors and innovation strategy

This table presents the estimates of OLS regressions to examine how the presence of inventor-directors affects different measures of innovation quality and strategies. The main independent variable is *Inventor_Director* which is a dummy variable that takes the value of one if there is at least one inventor on board and zero otherwise at $(t-1)$. The dependent variables are Originality, Generality, Diversity, Exploitation_ratio, and Exploration_ratio at (t). A patent's originality index is one minus the Herfindhal index of the four-digit Combined Patent Classification (CPC) classes that the patent cites. Then, an average index is computed for all patents filed by a firm in a year. A patent's generality index is one minus the Herfindhal index of the four-digit CPC classes of patents that cite the patent. Then, the average is computed for all patents filed by a firm in a year. Diversity measure is one minus the Herfindhal index of the number of patents in different technology categories that a firm files in a specific year. Following Manso (2011), Almeida et al. (2013), Brav et al. (2018), and Custódio et al. (2019), we classify patents as being exploitative or explorative. A patent is classified as exploitative if at least 60% of its citations are based on the firm's existing knowledge and it is classified as explorative if at least 60% of its citations are based on new knowledge. A firm's existing knowledge is the set of firm's patents portfolio and all patents referenced by the firm in its filed patents during the previous five years. We then compute the number of exploitative patents in a year for each firm and a firm's exploitation ratio is calculated as the number of exploitative patents to the total number of patents filed by the firm during the year. Similarly, the ratio of explorative patents at the firm-year level is also calculated as the number of explorative patents to the total number of patents. See appendix 2.A for the definitions of all variables. All models include year and industry fixed effects. Standard errors are clustered at the firm-level. t statistics are in parentheses. *,**, and *** represent significance at the 10%, 5%, and 1% levels, respectively.

	(1) Originality	(2) Generality	(3) Diversity	(4) Exploitation_ratio	(5) Exploration_ratio
Inventor_Director	0.034***	0.014***	0.038***	0.051***	0.026***
	(5.88)	(4.38)	(5.17)	(7.72)	(3.59)
Observations	44006	44006	44006	44006	44006
Adjusted R^2	0.278	0.246	0.386	0.220	0.221
Controls	Yes	Yes	Yes	Yes	Yes
Industry FE	Yes	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes	Yes

Table 2.6: Percentage of inventor-directors and corporate innovation

This table presents the estimates of OLS regressions to examine the relationship between the percentage of inventors on board and corporate innovation. The main independent variable is *Inventor_Director%* which is the number of inventor-directors to the total number of directors at $(t-1)$. *Count* is the log(1+total number of filed patents at (t)). *Citations* is the log(1+total forward citations of filed patents at (t)). *Value* is the log(1+total value of all patents filed by a company at (t)) as estimated by Kogan et al. (2017). *Radical Pat.* is the log(1+number of radical patents filed at (t)). A patent is considered to be radical when it is in the top 5% of technology-year citations distribution. *R&D* is the total research and development expenditures divided by total assets. See appendix 2.A for the definitions of all variables. All models include year and industry fixed effects. Standard errors are clustered at the firm-level. *t* statistics are in parentheses. *,**, and *** represent significance at the 10%, 5%, and 1% levels, respectively.

	(1) Count	(2) Citations	(3) Value	(4) Radical Pat.	(5) R&D
Inventor_Director%	0.987***	1.016***	1.748***	0.253**	0.135***
	(5.32)	(4.91)	(5.61)	(2.51)	(5.47)
Observations	44006	44006	44006	44006	44005
Adjusted R^2	0.447	0.402	0.472	0.277	0.352
Controls	Yes	Yes	Yes	Yes	Yes
Industry FE	Yes	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes	Yes

Table 2.7: Type of inventor-directors

This table presents the estimates of OLS regressions to examine how the presence of different types of inventors in the boardroom affects innovation. In panel A and similar to Moretti and Wilson (2017), we classify an inventor as a *star* in a specific year if he/she is above the 99th percentile of the number of patents filed over the last 10 years. In models (2), (4), (6), (8), and (10) of panel A, the main independent variable takes the value of one if there is a star inventor on board (499 observations) and zero if none of the directors is an inventor at $(t-1)$ (31,772 observations). In models (1), (3), (5), (7), and (9) of panel A, the independent variable takes the value of one if the inventor on board is not a star (11,735 observations) and zero if none of the directors is an inventor at $(t-1)$ (31,772 observations). In Panel B, we examine how the presence of *more influential* inventors in the boardroom affects innovation. We define *more influential* inventors as those holding more than two patents with citations above the *99th* percentile of technology class and year citations distribution. In models (2), (4), (6), (8), and (10), the main independent variable takes the value of one if there is a *more influential* inventor on board (714 observations) and zero if none of the directors is an inventor at $(t-1)$ (31,772 observations). In models (1), (3), (5), (7), and (9), the independent variable takes the value of one if the inventor on board is less influential (11,520 observations) and zero if none of the directors is an inventor $(t-1)$ (31,772 observations). In panel C, we examine how the presence of active inventors in the boardroom affects innovation. Similar to Islam and Zein (2020), in a given year (t), an inventor-director is considered to be active if he/she has at least one patent filed in his/her name over $(t-2:t+2$ window$)$. In models (2), (4), (6), (8), and (10), the main independent variable takes the value of one if there is an active inventor on board (6,177 observations) and zero if none of the directors is an inventor at $(t-1)$ (31,772 observations). In models (1), (3), (5), (7), and (9), the independent variable takes the value of one if the inventor on board is not active (6,057 observations) and zero if none of the directors is an inventor at $(t-1)$ (31,772 observations). *Count* is the log(1+total number of filed patents at (t)). *Citations* is the log(1+total forward citations of filed patents at (t)). *Value* is the log(1+total value of all patents filed by a company at (t)) as estimated by Kogan et al. (2017). *Radical Pat.* is the log(1+number of radical patents filed at (t)). A patent is considered to be radical when it is in the top 5% of technology-year citations distribution. *R&D* is the total research and development expenditures divided by total assets. See appendix 2.A for the definitions of all variables. All models include year and industry fixed effects. Standard errors are clustered at the firm-level. *t* statistics are in parentheses. P-values of the differences between coefficients are reported. *,**, and *** represent significance at the 10%, 5%, and 1% levels, respectively.

Panel A: Presence of *star* inventors

	Count		Citations		Value		Radical Pat.		R&D	
	(1) Not a Star	(2) Star	(3) Not a Star	(4) Star	(5) Not a Star	(6) Star	(7) Not a Star	(8) Star	(9) Not a Star	(10) Star
Inventor_Director	0.216***	0.583***	0.220***	0.705***	0.378***	0.900***	0.066***	0.258***	0.015***	0.069***
	(5.57)	(4.20)	(5.24)	(4.27)	(5.81)	(4.16)	(3.20)	(3.10)	(4.68)	(2.79)
Observations	43507	32271	43507	32271	43507	32271	43507	32271	43506	32270
Adjusted R^2	0.445	0.414	0.400	0.375	0.470	0.431	0.274	0.247	0.361	0.332
Controls	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Industry FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
P-Value (F-test of equal coefficient estimates)	0.008		0.003		0.015		0.022		0.026	

Panel B: Presence of *more influential* inventors

	Count		Citations		Value		Radical Pat.		R&D	
	(1) Less Influential	(2) More Influential	(3) Less Influential	(4) More Influential	(5) Less Influential	(6) More Influential	(7) Less Influential	(8) More Influential	(9) Less Influential	(10) More Influential
Inventor_Director	0.210***	0.649***	0.214***	0.741***	0.367***	1.070***	0.065***	0.256***	0.014***	0.060***
	(5.45)	(4.80)	(5.13)	(4.68)	(5.64)	(5.05)	(3.16)	(2.99)	(4.48)	(3.20)
Observations	43292	32486	43292	32486	43292	32486	43292	32486	43291	32485
Adjusted R^2	0.443	0.420	0.399	0.380	0.468	0.437	0.274	0.250	0.349	0.355
Controls	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Industry FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
P-Value (F-test of equal coefficient estimates)	0.001		0.001		0.001		0.026		0.011	

Panel C: Presence of *active* Inventors

	Count		Citations		Value		Radical Pat.		R&D	
	(1) Not Active	(2) Active	(3) Not Active	(4) Active	(5) Not Active	(6) Active	(7) Not active	(8) Active	(9) Not active	(10) Active
Inventor_Director	0.162^{***}	0.323^{***}	0.157^{***}	0.345^{***}	0.246^{***}	0.592^{***}	0.045^{*}	0.115^{***}	0.013^{***}	0.022^{***}
	(3.55)	(6.80)	(3.19)	(6.59)	(3.26)	(7.42)	(1.84)	(4.41)	(3.75)	(4.61)
Observations	37829	37949	37829	37949	37829	37949	37829	37949	37828	37948
Adjusted R^2	0.426	0.441	0.384	0.398	0.444	0.467	0.260	0.268	0.391	0.324
Controls	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Industry FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
P-Value (F-test of equal coefficient estimates)	0.001		0.001		0.000		0.009		0.054	

Table 2.8: Inventor-director role versus Inventor-CEO

This table presents the estimates of OLS regressions to examine the relationship between the presence of inventor-directors and innovation in a subsample analysis setting. We divide the main sample into two based on whether the CEO is an inventor or not. This enables us to study whether the role of inventor-directors is substituting or complementing that of the inventor-CEO. Regressions in models (1), (3), (5), (7), and (9) are based on observations where the CEO is an inventor while in models (2), (4), (6), (8), and (10), observations are those where the CEO is not an inventor. The main independent variable is *Inventor_Director* which is a dummy variable that takes the value of one if there is at least one inventor on board and zero otherwise at $(t-1)$. *Count* is the log(1+total number of filed patents at (t)). *Citations* is the log(1+total forward citations of filed patents at (t)). *Value* is the log(1+total value of all patents filed by a company at (t)) as estimated by Kogan et al. (2017). *Radical Pat.* is the log(1+number of radical patents filed at (t)). A patent is considered to be radical when it is in the top 5% of technology-year citations distribution. *R&D* is the total research and development expenditures divided by total assets. See appendix 2.A for the definitions of all variables. All models include year and industry fixed effects. Standard errors are clustered at the firm-level. t statistics are in parentheses. P-values of the differences between coefficients are reported. *,**, and *** represent significance at the 10%, 5%, and 1% levels, respectively.

	Count		Citations		Value		Radical Pat.		R&D	
	(1) Inv. CEO	(2) Non Inv. CEO	(3) Inv. CEO	(4) Non Inv. CEO	(5) Inv. CEO	(6) Non Inv. CEO	(7) Inv. CEO	(8) Non Inv. CEO	(9) Inv. CEO	(10) Non Inv. CEO
Inventor_Director	0.158^{**}	0.237^{***}	0.174^{**}	0.241^{***}	0.185^{*}	0.435^{***}	0.071^{*}	0.068^{***}	0.009	0.018^{***}
	(2.42)	(5.56)	(2.29)	(5.30)	(1.79)	(6.04)	(1.75)	(3.12)	(0.88)	(5.96)
Observations	6463	37541	6463	37541	6463	37541	6463	37541	6463	37540
Adjusted R^2	0.570	0.417	0.501	0.374	0.624	0.444	0.417	0.250	0.319	0.321
Controls	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Industry FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
P-Value (F-test of equal coefficient estimates)	0.230		0.436		0.041		0.933		0.352	

Table 2.9: Appointment of inventor-directors

This table presents the estimates of OLS regressions to examine the relationship between the appointments of non-executive inventor-directors and corporate innovation. In panel A, we present the appointment results for the full sample where in some observations firms are appointing non-executive directors and in others, there are no appointments. The main independent variable in panel A is *Inventor_Appointment* which is a dummy variable that takes the value of one when an inventor is appointed as a non-executive director and zero otherwise at $(t-1)$. In panel B, we restrict the sample to observations where there are appointments of non-executive directors only (Compared to panel A, in panel B, we drop observations where all directors appointed are executives and observations where the firm is not appointing any directors). The main independent variable in panel B is *Inventor_Appointment* which is a dummy variable that takes the value of one if the appointed non-executive director is an inventor and zero otherwise at $(t-1)$. In panel C, we match firms using nearest-neighbour propensity score matching without replacement, where the propensity score is estimated using firm size, profitability, Tobin's Q at $(t-1)$. We restrict matched firms to be in the same year and two-digit SIC industry, with no other appointments in the periods $t-1$ and $t+1$. *Count* is the log(1+total number of filed patents at (t)). *Citations* is the log(1+total forward citations of filed patents at (t)). *Value* is the log(1+total value of all patents filed by a company at (t)) as estimated by Kogan et al. (2017). *Radical Pat.* is the log(1+number of radical patents filed at (t)). A patent is considered to be radical when it is in the top 5% of technology-year citations distribution. *R&D* is the total research and development expenditures divided by total assets. See appendix 2.A for the definitions of all variables. All models include year and industry fixed effects. Standard errors are clustered at the firm-level. *t* statistics are in parentheses. *,**, and *** represent significance at the 10%, 5%, and 1% levels, respectively.

Panel A: Inventor-directors' appointments (all observations)

	(1) Count	(2) Citations	(3) Value	(4) Radical Pat.	(5) R&D
Inventor_Appointment	0.109***	0.130***	0.175***	0.060***	0.020**
	(3.64)	(3.86)	(3.36)	(3.70)	(2.57)
Observations	44006	44006	44006	44006	44005
Adjusted R^2	0.444	0.400	0.469	0.276	0.350
Controls	Yes	Yes	Yes	Yes	Yes
Industry FE	Yes	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes	Yes

Panel B: Inventor-directors' appointments (observations of non-executive directors' appointments)

	(1) Count	(2) Citations	(3) Value	(4) Radical Pat.	(5) R&D
Inventor_Appointment	0.095***	0.116***	0.154***	0.045***	0.020**
	(3.01)	(3.28)	(2.84)	(2.66)	(2.51)
Observations	19646	19646	19646	19646	19646
Adjusted R^2	0.466	0.424	0.490	0.306	0.316
Controls	Yes	Yes	Yes	Yes	Yes
Industry FE	Yes	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes	Yes

Panel C: Inventor-directors' appointments (Matched sample)

	(1) Count	(2) Citations	(3) Value	(4) Radical Pat.	(5) R&D
Inventor_Appointment	0.111**	0.124**	0.236**	0.040	0.024**
	(2.02)	(2.03)	(2.52)	(1.33)	(2.23)
Observations	2493	2493	2493	2493	2493
Adjusted R^2	0.511	0.462	0.543	0.373	0.199
Controls	Yes	Yes	Yes	Yes	Yes
Industry FE	Yes	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes	Yes

Table 2.10: Two-Stage least squares (2SLS) analysis

This table shows the relationship between the percentage of inventors on board and corporate innovation in a 2SLS framework. In panel A, the instrument (*Local_Inv_CEO*) is the log(1+number of inventor-CEOs within 100 miles distance from the headquarter in industries other than the four-digit SIC industry of the firm) at $(t-1)$. In panel B, the instrument is the log(1+number of inventor-CEOs within 100 miles distance from the headquarter who are in different two-digit SIC industries). In panel C, the instrument is the same as the one in panel B but we exclude the top five patenting cities in our sample. *Inventor_Director%* is the percentage of inventors on board which is the number of inventor-directors to the total number of directors at $(t-1)$. *Count* is the log(1+total number of filed patents at (t)). *Citations* is the log(1+total forward citations of filed patents at (t)). *Value* is the log(1+total value of all patents filed by a company at (t)) as estimated by Kogan et al. (2017). *Radical Pat.* is the log(1+number of radical patents filed at (t)). A patent is considered to be radical when it is in the top 5% of technology-year citations distribution. *R&D* is the total research and development expenditures divided by total assets. See appendix 2.A for the definitions of all variables. All models include year and industry fixed effects. Standard errors are clustered at the firm-level. The test for weak instruments is Cragg-Donald Wald F statistic. *t* statistics are in parentheses. *,**, and *** represent signficance at the 10%, 5%, and 1% levels, respectively.

Panel A: Local supply from different four-digit SIC industries

	(1) Inventor_Director%	(2) Count	(3) Citations	(4) Value	(5) Radical Pat.	(6) R&D
Local_Inv_CEO	0.004***					
	(5.33)					
Predicted_Inventor_Director%		11.716***	12.342***	22.460***	4.032*	1.357***
		(2.95)	(2.86)	(3.24)	(1.91)	(4.12)
Observations	42122	42122	42122	42122	42122	42121
Controls	Yes	Yes	Yes	Yes	Yes	Yes
Industry FE	Yes	Yes	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes	Yes	Yes
First Stage F-statistic	200.03					

Panel B: Local supply from different two-digit SIC industries

	(1) Inventor_Director%	(2) Count	(3) Citations	(4) Value	(5) Radical Pat.	(6) R&D
Local_Inv_CEO	0.004^{***}					
	(5.40)					
Predicted_Inventor_Director%		12.170^{***}	12.816^{***}	23.076^{***}	4.243^{**}	1.389^{***}
		(3.08)	(3.00)	(3.35)	(2.05)	(4.25)
Observations	42122	42122	42122	42122	42122	42121
Controls	Yes	Yes	Yes	Yes	Yes	Yes
Industry FE	Yes	Yes	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes	Yes	Yes
First Stage F-statistic	204.74					

Panel C: Local supply from different two-digit SIC industries (with excluding top five patenting cities)

	(1) Inventor_Director%	(2) Count	(3) Citations	(4) Value	(5) Radical Pat.	(6) R&D
Local_Inv_CEO	0.004^{***}					
	(4.91)					
Predicted_Inventor_Director%		7.906^{**}	8.940^{**}	17.647^{**}	2.591	1.254^{***}
		(2.04)	(2.11)	(2.53)	(1.27)	(3.68)
Observations	40138	40138	40138	40138	40138	40137
Controls	Yes	Yes	Yes	Yes	Yes	Yes
Industry FE	Yes	Yes	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes	Yes	Yes
First Stage F-statistic	170.90					

2.A Appendix-Variables definitions

Variable	Definition
Count	The natural logarithm of one plus the total number of filed patents in a given year. (Source: PatentsView & KPSS)[23]
Citations	The natural logarithm of one plus the total forward citations that filed patents in a given year receive. (Source: PatentsView & KPSS)
Value	The natural logarithm of one plus the total value of all patents filed by a company in a given year as estimated by Kogan et al. (2017). (Source: PatentsView & KPSS)
Radical Pat.	The natural logarithm of one plus the number of radical patents filed in a given year. A patent is considered to be radical when it is in the top 5% of technology-year citations distribution. (Source: PatentsView & KPSS)
R&D	Research & Development expenditures divided by total assets. (Source: Compustat)
Originality	A patent's originality index is one minus the Herfindhal index of the four-digit Combined Patent Classification (CPC) classes that the patent cites. Then, an average index is computed for all patents filed by a firm in a year. (Source: PatentsView & KPSS)
Generality	A patent's generality index is one minus the Herfindhal index of the four-digit CPC classes of patents that cite the patent. Then, the average is computed for all patents filed by a firm in a year. (Source: PatentsView & KPSS)
Diversity	One minus the Herfindhal index of the number of patents in different technology categories that a firm files in a specific year. (Source: PatentsView & KPSS)

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[23] KPSS refers to the data from Kogan et al. (2017).

Exploitation_ratio	The number of exploitative patents to the total number of patents filed by the firm during the year. Following Manso (2011), Almeida et al. (2013), Brav et al. (2018), and Custódio et al. (2019), we classify patents as being exploitative or explorative. A patent is classified as exploitative if at least 60% of its citations are based on the firm's existing knowledge and it is classified as explorative if at least 60% of its citations are based on new knowledge. A firm's existing knowledge is the set of firm's patents portfolio and all patents referenced by the firm in its filed patents during the previous five years. We then compute the number of exploitative patents in a year for each firm and a firm's exploitation ratio is calculated as the number of exploitative patents to the total number of patents filed by the firm during the year. (Source: PatentsView & KPSS)
Exploration_ratio	The number of explorative patents to the total number of patents. (Source: PatentsView & KPSS)
Inventor_Director	A dummy variable that takes the value of one if there is a non-executive director with innovation experience in the boardroom and zero otherwise. (Source: PatentsView and BoardEx)
Inventor_Director%	The number of inventor-directors to the total number of directors. (Source: PatentsView and BoardEx)
Inventor_Appointment	A dummy variable that takes the value of one when an inventor is appointed as a non-executive director and zero otherwise. (Source: PatentsView and BoardEx)
Local_Inv_CEO	The natural logarithm of one plus the number of inventor-CEOs within 100 miles distance from the headquarter in industries other than the four-digit SIC industry of the firm or the natural logarithm of one plus the number of inventor-CEOs within 100 miles distance from the headquarter who are in different two-digit SIC industries. (Source: PatentsView, BoardEx, and Compustat)
Firm_Size	The natural logarithm of the firm's total assets. (Source: Compustat)
ROA	Operating income before interest, taxes, depreciation and amortisation divided by total assets. (Source: Compustat)
Leverage	Total short- and long-term debt divided by total assets. (Source: Compustat)
Capex	Total expenditures divided by total assets. (Source: Compustat)
HHI	Herfindahl Hirschman index which is constructed by computing the share of each firm's sales to total industry sales, then squaring each firm's share and adding up all squared shares. An industry is three-digit SIC. (Source: Compustat)
Tobin's_Q	Ratio of total assets minus book value of equity plus market value of equity to total assets. (Source: Compustat)
Firm_Age	The logarithm of one plus the number of years since the firm appeared in Compustat. (Source: Compustat)

Inv_CEO	A dummy variable that takes the value of one if the CEO of the firm is an inventor and zero otherwise. (Source: PatentsView and BoardEx)
Board_Size	The total number of directors in the board. (Source: BoardEx)
Board_Avg_Age	The average age of all directors. (Source: BoardEx)
Board_Avg_Tenure	The average tenure of all directors. A director's tenure is the number of years since being in role. (Source: BoardEx)
Independence_Ratio	The total number of independent directors divided by the total number of directors. (Source: BoardEx)
No_Qualifications	The total number of qualifications of all directors. (Source: BoardEx)
PhD%	The percentage of directors who hold a doctoral degree. (Source: BoardEx)
MBA%	The percentage of directors who hold MBA. (Source: BoardEx)
CEO%	The percentage of directors with experience as CEOs. (Source: BoardEx)
CTO%	The percentage of directors with experience as chief technology officers. (Source: BoardEx)

2.B Appendix-Matching techniques

We start by identifying companies appearing at the intersection of BoardEx/ COMPUSTAT/CRSP and then we extract the full employment history of all non-executive directors from BoardEx. Next, the names of the extracted companies where directors were employed are cleaned and standardised.[24] The same process for cleaning and standardising company names is applied on all assignees of patents appearing in PatentsView.[25]

To identify directors with patenting expertise, we proceed as follows:

1. The name of the director from BoardEx will be exactly matched to an inventor's name in PatentsView with *the restriction that the standardised name of the company in the director's employment history is exactly matched to that of the patent's assignee*. In this step, we try different combinations of directors' and inventors' names: first, second (if available) and last names or first name, first initial of the second name, and last name or usual first and last names.

2. The second technique used is to incorporate CRSP *permco* in the matching. This step will identify directors who patented while working in public companies and were not detected in the step above. Similar to what we did in step 1, we do the matching with the different combinations of names, with *the restriction that the permco of the assignee is the same as that of the employer of the director*.

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[24] Stata *reclink2* command is used to clean and standardise company names.

[25] It covers patents granted in 1976 and onwards.

3. In the third technique, we restrict the *permco of the company where the director held a position to be the same exact permco of the assignee* and then we perform a *fuzzy matching* based on the names of directors and inventors. This is helpful when there are disparities between the names of inventors and directors within the two databases. Then, those possible matches are *manually verified*.

4. In the fourth technique, we restrict *the name of the company where the director held a position to be the same exact name of the assignee*, and then, similar to step 3, we perform a *fuzzy matching* based on the names of directors and inventors. Then, we *manually verify* the probable matches.

5. In the fifth step, and in order to identify any other inventor-directors not detected in the last four techniques, we relax the restriction of the *same permco* (in step 4) and the *same company/assignee name* (in step 5). Then, we run a *fuzzy matching* based on *both directors'/inventors' names* and *companies'/assignees' names*.

The algorithm provides a score to each output of steps 3 to 5. We commence the manual verification by selecting a specific threshold, and then verify *all* possible matches that surpass it. Next, we relax the barrier by choosing a smaller score and then verify all the probable matches above it. This process iterates until we find that any more verifications by lowering the score further will not result in any significant change in the number of inventor-directors. We manually verified 3,035 probable matches.[26] In addition, we manually

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[26] Those manually verified include possible inventor-directors matches and inventor-CEOs matches as we run the matching algorithm on CEOs in addition to directors. This is needed when we control for CEO patenting experience and for the instrumental variable (IV) analysis.

verified a substantial sample of individuals who match precisely in terms of their names and affiliated companies' names/permcos.

As the manual verification is a crucial step to identify directors with patenting expertise, we examine thoroughly each potential match. This involves checking the director's employment history on Linkedin, Wikipedia, Crunchbase, Bloomberg, and their biographies on the websites of companies they currently work for or serve as a directors on their boards. In some instances, we find details about their patents on these websites. In addition, we go through any available newspapers interviews with those directors where they might talk about their patents and innovation experience. Moreover, for each probable inventor-director match remaining, we retrieve all patents filed by the inventor (from PatentsView) and manually compare the assignees of these patents against the information on companies where the directors were employed (from BoardEx). In this process, we identify pairs of assignees/companies which after careful consideration, are recognised as the same firm despite not appearing in the matching algorithm output (e.g., the name of the parent company could be the one appearing in BoardEx employment history while the patent is filed under its subsidiary). Furthermore, when we suspect that the director is possibly an inventor, even though there is a difference between the two names, we use Google Patents search engine and we check the original patent publication where we could find the names extracted by PatentsView have typos (e.g., missing letters from names) or these typos could be in the directors' names from BoardEx.

Chapter 3

Female inventors' performance: The role of female inventor-directors

3.1 Introduction

Between 1976 and 2021, women have made up at least half of the United States population[1] but they have only constituted 15% of the United States Patents and Trademark Office (USPTO) population of inventors.[2] Those figures point to a clear gender innovation gap and according to Bell et al. (2019), it could take more than a century to have a gender parity in innovation. This innovation gender disparity is costly, as patents produced by female inventors exhibit high quality and are of great importance to society (Koning et al., 2021; Hochberg et al., 2023).[3]

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[1] World Bank data accessed via https://data.worldbank.org/indicator/SP.POP.TOTL.FE.ZS?end=2021&locations=US&start=1960

[2] USPTO data on patents and inventors are available through https://patentsview.org/download/data-download-tables

[3] Koning et al. (2021) find that patents filed by female inventor teams are more likely to focus on female-relevant health patents in contrast to male majority teams and therefore, the under-representation of female inventors results in a reduced supply of patents that cater to the needs of women. Hochberg et al. (2023) employ Artificial Intelligence (AI) on patents abstracts to estimate what will be the counterfactual citations that female patents would receive if they were alternatively led by male inventors and they find that female patents receive less actual citations compared to the counterfactual ones if they were male patents. Their findings suggest that females could be deterred from the innovation economy due to the less perceived quality of their innovation output. In addition, science, technology, engineering and mathematics (STEM) fields will experience more labour allocation inefficiencies. In a study on women and African

In this paper, we focus on female inventors who successfully managed to break through the glass ceiling and assumed roles as non-executive directors in public companies. We investigate whether their presence in the boardroom has a positive impact on the representation of women among inventors in the firm and on their patenting output and performance. We rely on the gender spillover literature where female representation at the top of the firm has a positive impact on gender-specific outcomes within the firm (e.g., the ability and performance of female employees) (Cornell and Welch, 1996; Athey et al., 2000; Cardoso and Winter-Ebmer, 2010; Matsa and Miller, 2011; Flabbi et al., 2019; Dalvit et al., 2022). Chen et al. (2018) and Griffin et al. (2021) study the impact of board gender diversity on firm-level innovation, but they do not investigate the spillover effects on female inventors within firms. Our study examines the broader impact of female directors and the specific influence of female inventor-directors on gender-specific innovation outcomes.

Women have been under-represented among the inventors population. A growing body of research studies the gender innovation gap (Kahler, 2011; Hunt et al., 2013; Fechner and Shapanka, 2018; Jensen et al., 2018; Cook et al., 2022). These studies explore a number of factors contributing to this under-representation of women arising from the demand side as well as the supply side.

Hunt et al. (2013) use the National Survey of College Graduates 2003 and find that part of the gender innovation gap is resulting from women holding less science and engineering (S&E) degrees and in particular less doctorates.[4]

American PhDs, Cook and Yang (2018) find that their inclusion in innovation could lead to 0.88% to 4.6% increase in the gross domestic product (GDP).

[4] National Science Foundation (NSF) 2021 report indicates that the percentage of women

However, this shortage in supply of women with technical backgrounds only partially explains the gap. The National Science Foundation (NSF) 2021[5] employment data show that women are underemployed relative to men in science and engineering (Cook et al., 2022).[6] Consistently, the study by Hunt et al. (2013) finds that among those with science and engineering degrees, females are less represented in electrical and mechanical engineering jobs and in design and development tasks.[7] All these point in the direction that women in the sector still have to confront negative stereotypes about their intellectual capabilities and lack technical skills, leading to less access to innovation resources. Moreover, this could actually be working as spiralling negative circle where the lack of women in the innovation sector leads to fewer female role models and mentors which also contributes to the dearth of female inventors (Fechner and Shapanka, 2018; Cook et al., 2022). According to the World Intellectual Property Organization (WIPO)'s report by Brant et al. (2019), there is a notable lack of female role models within the intellectual property (IP) field. As a result of this hurdle, women who successfully managed to enter the IP field, find it difficult to stay and achieve success.

An expanding literature focuses on gender spillover effects where female

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holding science and engineering degrees has improved over the past years and more specifically, women in 2018 were awarded 41.2% of the S&E doctoral degrees. By focusing on engineering degrees, women accounted for 12.26% of the doctoral degrees awarded in 1998, but by 2018, this figure doubled to 24.53% which highlights a growing emphasis on women pursuing engineering degrees.

[5] Reports by NSF could accessed through https://ncses.nsf.gov/pubs/nsb20198 and https://ncses.nsf.gov/pubs/nsf21321/report/field-of-degree-women

[6] Cook et al. (2022) explore the different potential sources of the gender innovation gap by examining gender discrimination at different phases of innovation.

[7] According to their results, females' lower likelihood of having any science and engineering degree explains only 7% of the gap while 78% of the gap is explained by the less patenting by women among those with science and engineering degrees.

leaders in an organisation have an influence on gender-specific outcomes. Athey et al. (2000) propose that women at upper-levels in the hierarchy acting as role models and mentors could have a positive impact on women at lower levels. Dalvit et al. (2022) present a theoretical model on how female representation at the top of a company could have gender-specific outcomes at different levels within the company based on the assumption that women in managerial and leadership positions would be better in assessing the skills of other females in the organisation. They argue that the effect will propagate in a top-down manner in the organisation. They test their model by relying on a French reform that mandates gender quotas on corporate boards and the results indicate that following the mandate, more females are employed within the upper and middle levels of the firm. Similarly, Flabbi et al. (2019) examine the effects of female executives on gender wage gap where they develop a theoretical model in which executives of the same gender as workers have a better ability in assessing workers' productivity. Hence, those female leaders will 'reverse the statistical discrimination' and consequently, females in the firm will receive higher wages consistent with their productivity.[8] Cornell and Welch (1996) develop a discrimination theory in job screening where candidates of the same type as employers (e.g., same gender) are more likely to be hired. Additionally, Dezsö and Ross (2012) argue that female representation at upper levels will enhance the dedication and motivation of women in middle levels.

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[8] Several studies examine the bias and discrimination against women in a business environment. For example, statistical discrimination by Phelps (1972), prejudice and taste-based discrimination by Becker (1971), and incorrect beliefs through miscalibrated stereotyping as examined by Bordalo et al. (2016) and Arnold et al. (2018).

Empirically, the findings of several studies show that women taking on leadership roles could bring about positive impact on female peers within the business environment. (Bilimoria, 2006; Cardoso and Winter-Ebmer, 2010; Matsa and Miller, 2011; Bell, 2005; Tate and Yang, 2015; Kunze and Miller, 2017; Theodoropoulos et al., 2022).[9] For example, Cardoso and Winter-Ebmer (2010) analyse data from Portugal and finds that female-led companies demonstrate less discrimination where female workers receive higher wages and the wage gap between males and females is reduced. According to Matsa and Miller (2011), there is a positive association between female representation in corporate boards and the share of females in the top executive level.[10] In contrast, Bagues et al. (2017) study the composition of scientific committees and show that the presence of women in evaluation committees does not increase the success rate of female candidates nor affects the quality of the assessment outcome. Moreover, the outcome tends to be less favourable to women mostly because the male evaluators become less favourable towards the female candidate.

Specifically related to board composition, the literature has focused both on the effect of gender diversity and the acquisition of specific skills in the board,

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[9] In a press release on 14th March 2023, ADM announced the nomination of Ellen de Brabander, an Executive VP for Innovation and Regulatory Affairs at Elanco with 18 patents under her name, for election to the board at the Annual Stockholders' Meeting. Notably, at the time of her nominsation, the board included three other female board members, one of whom served on the nomination committee.

[10] Kunze and Miller (2017) use Norwegian data and find that a reduction in gender promotion gap is observed with the presence of more female managers at the next rank in the organisation. Tate and Yang (2015) find there is a smaller wage gap between male and female workers when there are women in senior positions. Ceccarelli et al. (2023) show that there is an under-representation gap between men and women in commercial banking and find that female leaders in local banks help in reducing this gap. Egan et al. (2022) find the gender gap in punishment among financial advisers is reduced with the presence of female managers.

and their outcome on firm performance. Results on the outcomes of gender diversity are mixed. Adams and Ferreira (2009) find that women on boards have better attendance rates compared to male directors but the impact of gender diversity on firm performance is inconclusive. Ahern and Dittmar (2012) examine the board quota reform in Norway mandating 40% representation of women on boards and results show a negative impact on firm value in the short term.[11] Subsequent to the reform in Norway, Bertrand et al. (2019) findings reveal that earnings gender gap within boards of companies subject to the reform is reduced. However, they do not find conclusive evidence about the existence of spillover effects on women employed by these companies.[12] Hwang et al. (2021) investigate the recent quota reform in California using an event study analysis and find a negative impact on shareholders' value by mandating women on boards. They argue that this is attributed to female directors' supply constraints where female directors might lack the specific skills and expertise sought after by boards.

In terms of board members and their skillset, Kim and Starks (2016) suggest that female directors with unique skills appointed to a corporate board will contribute positively to the board's advisory effectiveness. Specialised expertise represents a crucial element of a board's human capital, which is obtained through prior experience (Kor and Sundaramurthy, 2009). Other studies examine directors' domain-specific knowledge and expertise and how they could affect outcomes related to that domain (e.g., Agrawal and Chadha,

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[11] Similarly, Matsa and Miller (2013) find that the profitability of firms in Norway decline following the reform as employment and labour costs increase.

[12] Similar results are documented by Maida and Weber (2022) who study board reforms in Italy.

2005; Huang et al., 2014; Field and Mkrtchyan, 2017; Whitler et al., 2018).

Related papers by Chen et al. (2018) and Griffin et al. (2021) find a positive impact of board gender diversity on innovation at the firm-level. However, they do not explore the spillover effects on female inventors within firms. *In our study*, we examine the impact of female directors more generally and female inventor-directors more specifically on gender-specific innovation outcomes (e.g., the output, representation, and productivity of female inventors in firms).

To examine the relationship between the presence of female inventor-directors in the boardroom and the patenting output and representation of female inventors within firms, we create a dataset that links female non-executive directors in U.S. public companies with the population of female inventors in USPTO. By drawing on both theoretical foundations and empirical evidence highlighting the positive spillover effects that female leaders and women in authority could have on their female counterparts in a business, as well as the evidence on the importance of directors' specific experience and skills, we argue that female directors with patenting expertise will play a role in reducing the gender stratification and bias against female inventors within firms and alleviate their under-representation (Dalvit et al., 2022; Matsa and Miller, 2011; Cardoso and Winter-Ebmer, 2010; Dalvit et al., 2022). As a result, we expect female inventors to be more represented among the innovating teams with female inventor-directors present in the boardroom. In addition, the presence of female inventor-directors' in corporate boards, serving as role models for other female inventors, will foster a more inclusive environment. Hence, we expect that female inventors will be more motivated and, in turn, their productivity will be boosted in the presence of female inventor-directors (Dezsö and Ross, 2012; Athey et al., 2000). Therefore, we anticipate that the improved representation of female inventors combined with their enhanced productivity will collectively contribute to an increased patenting output by a firm's female inventors.

We find a significant positive relation between the presence of female inventors on board and the patenting output of female inventors in the firm. The results show that the presence of female inventors on board does not only affect the quantity of innovation by female inventors but also the quality of those female patents. Relative to firms without female inventor-directors, firms with female directors who have patenting expertise file 46.81% more patents where the inventors' team has at least one female inventor. In addition, the findings show that 19.4% more patents are filed by teams with a majority of female inventors. Similarly, the citations that female patents receive increase with having a female inventor in the boardroom (44.91% more for teams with at least one female inventor, and 16.07% more for female-dominated teams). We find consistent results for the other quality measures (the value of female patents and the number of important female patents).

In addition to focusing on female inventor-directors in the boardroom, we investigate the impact of female directors *in general* (i.e., those who do not possess a patenting expertise). Our results indicate that female directors in general are positively related to the patenting output of female inventors within the firm. However, and of greater importance, we find that female directors with the *relevant patenting expertise* (*female inventor-directors*) have a more noticeable effect on the patenting output of female inventors.

Our results suggest that more female inventors are involved in innovation with the presence of female inventor-directors. Furthermore, a noteworthy relation exists between female inventor-directors and the productivity of a firm's female inventors where we get significant results across all productivity measures. Both factors collectively seem to contribute to the higher patenting output of female inventors within a firm in the presence of female inventor-directors in the boardroom. Our findings show that female directors who do not have a patenting expertise have a positive impact on the number of female inventors, but in contrast, they do not have an impact on the productivity of female inventors.

By examining the productivity of all male and female inventors who participate in innovation within firms, our sample statistics reveal that there is a productivity gap between male and female inventors. Our findings suggest that female inventor-directors help in reducing this gender productivity gap. In addition, we find that female inventors contribute more to firm innovation with female inventors present in the boardroom.[13] Consistent with the productivity results, female directors *without* any patenting expertise neither have an impact on the productivity gap nor on female inventors' contribution to the innovation activities within firms.

Furthermore, we examine the heterogeneity in the patenting expertise of female inventor-directors. If there is a positive relation between female inventors in the boardroom and the patenting output of a firm's female inventors, we expect that the impact will be more noticeable for female

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[13] We measure the contribution of female inventors to a firm's innovation by dividing female inventors' patenting output measures by total firm innovation output.

inventor-directors who achieved greater success in patenting (referred to as star inventors). These star female inventors in the boardroom will serve as more prominent role models for female inventors within firms. Consistent with our expectation, star female inventors in the boardroom are more positively associated with the patenting output and the productivity of female inventors and negatively with the gender productivity gap.

To offer additional evidence on the relationship between female inventor-directors and the output of female inventors, we study the subsequent effects of the appointment of a female inventor to the board. Our results indicate that firms that appoint female inventor-directors experience a significant subsequent increase in the innovation output of their female inventors relative to firms that do not make such appointments.

Our paper makes several contributions to literature. First, we contribute to the literature on female inventors, their importance, under-representation, and the hurdles they face in innovation (Kahler, 2011; Hunt et al., 2013; Fechner and Shapanka, 2018; Bell et al., 2019; Cook et al., 2022; Koning et al., 2021). We study the importance of female inventors serving as directors, and how they can have positive effects on the patenting performance of female inventors within firms.

Second, we contribute to the literature on how women in leadership positions could have positive effects on female peers in a business environment (e.g., Dalvit et al., 2022; Athey et al., 2000; Flabbi et al., 2019; Cardoso and Winter-Ebmer, 2010; Matsa and Miller, 2011; Tate and Yang, 2015; Kunze and Miller, 2017; Theodoropoulos et al., 2022). Our study investigates how the presence of female inventor-directors helps in a better inclusion of female inventors in a firm's innovation activity, and additionally, how this presence helps in reducing the productivity gap between male and female inventors.

Third, we contribute to the literature on women in the boardroom. Many studies examine how board gender diversity affects different aspects of the firm (Adams and Ferreira, 2009; Levi et al., 2014; Haslam et al., 2010; Chen et al., 2018; Griffin et al., 2021). Other studies investigate how mandating women on boards affect stock return, firm profitability, and shareholders' value using board quota laws from Europe and the US (e.g., Ahern and Dittmar, 2012; Matsa and Miller, 2013; Bertrand et al., 2019; Hwang et al., 2021). Kim and Starks (2016) suggest that skilled female directors could contribute value to the board. In our paper, we focus on skilled female directors with innovation experience and how their presence in the boardroom could have positive spillover effects on female inventors in the firm.

Fourth, we add to the literature on the factors contributing to corporate innovation and more specifically the corporate governance literature that examines the relationship between boardroom characteristics and firm innovation activity (Balsmeier et al., 2017; Faleye et al., 2018; Fan, 2020; Jia, 2017; Chang and Wu, 2021; Helmers et al., 2017; Chen et al., 2018; An et al., 2021; Cao et al., 2021; Griffin et al., 2021).

3.2 Sample selection and summary statistics

3.2.1 Sample selection

Our sample consists of U.S. public companies in the intersection of BoardEx, COMPUSTAT, and Center for Research in Security Prices (CRSP). BoardEx covers boards compositions and provides directors' personal information, their education, employment history, and network connections. Our sample period extends from 2000 to 2018. We control for firm-level accounting characteristics from COMPUSTAT, and stock market data through CRSP.

We rely on two main sources for innovation data. The first is PatentsView which is a database for patents that comes from the United States Patent and Trademark Office (USPTO) chief economist's office. It covers over 7 million patents granted between 1976 and 2021. In addition, the database employs sophisticated algorithms and provides disambiguated patent assignees, disambiguated inventors in addition to all relationships between patents. The second dataset that we rely on is Kogan et al. (2017) patents dataset where they estimate and provide the economic value of patents and map CRSP pemrco and permno to patents.

We focus on the filing year of a patent rather than the grant year as it reflects the real time of innovation. Following innovation literature and due to the fact there is an average of two years gap between the filing and grant dates of a patent and while PatentsView covers patents granted until 2020,[14] our sample ends in 2018. Our sample starts from 2000 due to the lack of coverage from BoardEx before that. Financial firms (SIC 6000-6999) and utilities (4900-4999) are excluded from our sample.

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[14] At the time of the paper analyses, PatentsView includes only patents granted until March 2021 and that's why we exclude 2021 and the last year with full coverage of granted patents is 2020.

3.2.2 Identifying female inventor-directors

Our initial step involves identifying companies that appear in the intersection of BoardEx/COMPUSTAT/CRSP and then we extract the full employment history of all non-executive female directors from BoardEx. Next, the names of the extracted companies where directors held positions are cleaned and standardised.[15] The same process of cleaning and standardising companies' names is executed on all assignees of patents appearing in PatentsView.[16] After the cleaning and standardising process, we run a fuzzy matching algorithm to link the names of female directors in BoardEx and their current/previous employers to those of female inventors and assignees in PatentsView database.[17]

Next, we undertake a manual verification process for potential matches. As the manual verification is a crucial step to identify female directors with patents filed under their names, for each possible match, we checked the female director's employment history on Linkedin, Wikipedia, Crunchbase, Bloomberg, and their biographies on the websites of companies they currently work for or serve as a directors on their boards. Further details of the matching process could be found in appendix 2.B.

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[15] Stata *reclink2* command is used to clean and standardise company names.

[16] It covers patents granted since 1976 and onwards.

[17] We also rely on CRSP permco in matching companies in BoardEx to assignees in PatentsView.

3.2.3 Measures of female innovation

Following the extant literature (e.g., Atanassov (2013), Bradley et al. (2017), Brav et al. (2018), Custódio et al. (2019)), we use *patents* data to construct the quantity and quality measures of innovation output by female inventors. PatentsView provides the gender of inventors and hence, for each firm we start by constructing the quantity measure of innovation as the *number of patents filed* (*that are eventually granted*) *by female inventors* in a specific year. The year of innovation is the patent application year and not the grant one as the application year better reflects the time of innovation. By applying the natural logarithm, the variable for the analysis will be *ln*(*1+# female patents*).

Ding et al. (2006) conducted interviews with females in academia and found that female inventors rely on their collaboration with male inventors to start the patenting process.[18] In addition, Milli et al. (2016) show that patents produced by mixed teams of inventors receive more citations. Similarly, more gender diverse R&D teams boost radical innovation (Diaz-Garcia et al., 2013).

We expect that female inventor-directors in public companies will create an inclusive environment that encourages women to join innovative teams and produce more valuable patents for these firms. In addition, we expect the likelihood of female inventors participating in mixed-gender teams to increase and surpass the likelihood of forming female-majority teams. The effect of female inventor-directors is expected to be particularly strong for patents filed by teams with at least one female inventor, though we also expect a significant impact for patents filed by teams with a majority of female inventors.

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[18] Sugimoto et al. (2015) find that women are less represented among inventors in firms when compared to academia and government.

Therefore, our definition of *female patents* take two forms: patents filed by a team that has at least one female inventor, and patents filed by a team with a majority of female inventors (more than 50% of the inventors are women). Hence, we construct the female innovation quantity measure based on these two definitions of female patents.

In addition to the innovation quantity measure, we employ three other measures that capture the quality of female inventors' output. First, the *number of citations that patents filed by female inventors receive*. The citations measure requires an adjustment due to time truncation bias where patents filed toward the end of the sample period are less likely to receive citations compared to those filed earlier. For instance, patents filed in 2016 are expected to receive less forward citations compared to patents filed in 2004. We mitigate this concern by scaling each patent's citations by the average patent citations in the same year and four-digit Combined Patent Classification (CPC) technology class (Hall et al., 2001, 2005).[19] Second, the total *value of patents filed by female inventors* as estimated by Kogan et al. (2017). The total value of patents is a proxy for the perceived quality of patents as value is estimated from market reaction to the announcement of the grant of the patent. Third, the total *number of important patents filed by female inventors*. A patent is considered to be important if it is in the 80% percentile of the four-digit CPC technology class and year citations distribution. Hence, the three main quality measures are *ln*(*1+female citations*), *ln*(*1+female value*), and *ln*(*1+# important female patents*). We construct the quality measures for the two different definitions of female

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[19] In untabulated results, we scale a patent's citations by the average number of citations that patents filed in the same year receive and the the results remain the same.

patents.

3.2.3.1 Measures of female productivity, productivity gap, and female contribution to innovation

In addition to the absolute female innovation quantity and quality measures constructed, and similar to Acharya et al. (2014), Mukherjee et al. (2017), and Fich et al. (2023), we construct female inventors' productivity measures where in any year, we scale the four female innovation output measures by the number of female inventors who filed these patents. Firstly, the productivity of female inventors based on the number of patents could be defined as:

$$Productivity\ (\#\ patents) = ln\left(1 + \frac{\#\ female\ patents}{\# female\ inventors}\right)$$

The same applies to the other productivity measures reflecting quality which could be defined as follows:

$$Productivity\ (citations) = ln\left(1 + \frac{total\ citations\ of\ female\ patents}{\# female\ inventors}\right)$$

$$Productivity\ (value) = ln\left(1 + \frac{total\ value\ of\ female\ patents}{\# female\ inventors}\right)$$

$$Productivity\ \ (important\ \ patents) \quad = \quad ln\left(1 + \frac{\#\ important\ female\ patents}{\# female\ inventors}\right)$$

The female inventors' productivity measures are constructed for the two variants of female patents. In addition to these female inventors' productivity measures, we construct four variables for the innovation productivity gap between male and female inventors. We start by constructing productivity measures for male inventors, similar to what we did previously for female inventors. The productivity gap is subsequently calculated as the difference between male and female innovation productivity measures, resulting in four distinct productivity gap measures.

$$Productivity\_Gap\ (\#\ patents) = ln\left(1 + \frac{\#\ male\ patents}{\#male\ inventors}\right) - ln\left(1 + \frac{\#\ female\ patents}{\#female\ inventors}\right)$$

$$\begin{aligned} Productivity\_Gap\ (citations) = ln\left(1 + \frac{total\ citations\ of\ male\ patents}{\#male\ inventors}\right) - \\ ln\left(1 + \frac{total\ citations\ of\ female\ patents}{\#female\ inventors}\right) \end{aligned}$$

$$\begin{aligned} Productivity\_Gap\ (value) = ln\left(1 + \frac{total\ value\ of\ male\ patents}{\#male\ inventors}\right) - \\ ln\left(1 + \frac{total\ value\ of\ female\ patents}{\#female\ inventors}\right) \end{aligned}$$

$$\begin{aligned} Productivity\_Gap\ (important\ patents) = ln\left(1 + \frac{\#\ important\ male\ patents}{\#male\ inventors}\right) - \\ ln\left(1 + \frac{\#\ important\ female\ patents}{\#female\ inventors}\right) \end{aligned}$$

We also construct four variables that reflect the contribution of female inventors to firm innovation. Firstly, *Fem. Patents*% refers to the percentage of female patents which is constructed as the number of female patents filed in a specific year divided by the total number of patents filed in the same year. Secondly, *Fem. Citations*% is the total citations that female patents filed in a year receive divided by the total citations that all patents filed in the same year receive. Thirdly, *Fem. Value*% is the total value of female patents filed in a specific year, divided by the total value of all patents filed in that same year. Lastly, *Fem. Imp. Pat.%* is the number of important female patents filed in a given year out of the overall number of important patents filed during that same year.

3.2.4 Control variables

Firm characteristics are controlled for including firm size, profitability, research and development (R&D), leverage, capital expenditures, and firm age. We also include controls for product market competition as captured by Herfindhal index (HHI) and growth opportunities as captured by Tobin's Q.

Furthermore, we control for the percentage of non-executive female directors on board who lack the patenting expertise (*Female_NED%*). We account for the presence of male inventor-directors and various board-level characteristics such as board size, the average age of directors in the boardroom, their average tenure, directors' qualifications, and the percentage of directors holding PhDs and MBAs. Moreover, we control for the directors' experience as chief executive officers (CEOs) and chief technology officers (CTOs). We also control for the patenting expertise of the chief executive officer (CEO). Appendix 3.A provides all the details of the variables definitions and their sources of data.

3.2.5 Summary statistics

Panels A and B of table 3.1 present summary statistics at the firm-level and directorship-level respectively. In panel A (firm-level descriptive statistics), columns (2) and (3) report the mean and standard deviation of the main variables across all firm-year observations. Column (5) reports the mean of all variables for firm-year observations where there are not any female non-executive directors with patenting expertise in the boardroom while column (7) displays the mean of the variables for firm-year observations where there is a female non-executive director with patenting expertise on board. The mean differences between the coefficients in columns (7) and (5) are reported in column (8) with the associated t-statistics for the equality of mean test displayed in column (9). The statistics for female innovation measures reported in the table are based on female patents filed by teams with at least one female inventor.

Comparing the mean values in column (7) and those in column (5) shows how *female* inventors in firms with female directors who have patenting expertise participate in filing more patents, more important patents, and these patents receive more citations and are more valuable. The mean for *ln*(*1+# female patents*) when there is a female inventor in the boardroom is more than three times the one without female inventor-directors (1.19 versus 0.36). Similarly, the trend holds for the citations female patents receive (1.16 versus 0.36), the value of female patents (2.65 versus 0.82), and the number of female important patents (0.65 versus 0.18).

In addition to the measures of female inventors' patenting output, the univariate analysis indicates that firms with female inventor-directors have a larger number of female inventors participating in filing patents. The mean for *ln*(*1+# female inv.*) is 1.18 while it is 0.35 for firms without female inventors on their boards. In addition, the percentage of female inventors is higher (8%)

when the firm has a female inventor-director relative to those without female inventor-directors where the mean is only 3%.

The productivity statistics indicate that female inventors in firms with female inventor-directors in their boardrooms are at least more than twice productive with respect to the number of patents, citations, value, and important patents compared to female inventors in firms without female inventor-directors. Moreover, Panel A reports the mean of the measures of the productivity gap between male and female inventors. Across all observations, statistics indicate that there is a productivity gap between male and female inventors and we get similar results for firms without female inventor-directors (productivity gap values are positive with respect to the number, citations, and value of patents). In contrast, the mean values of the productivity gap measures are negative in the presence of female inventor-directors, indicating that female inventors are more productive than their male counterparts in companies with female inventors in the boardroom.

Additionally, panel A reports the mean of the variables capturing the contribution of female inventors to the innovation activity of the firm. The four measures are higher when there are female inventors in the boardroom (19% versus 7% for percentage of patents filed, 17% versus 6% for percentage of citations, 19% versus 7% for percentage of patents values, 15% versus 5% for percentage of important patents).

The univariate tests suggest economic difference in female inventors' output and productivity in firms with female directors who have patenting experience. In the next section, we report results for multivariate regressions where we control for firm and board level characteristics that could potentially affect the outcomes.

Panel B of Table 3.1 presents the summary statistics for non-executive directors. Columns (1)-(3) report the statistics for all non-executive directors while columns (5) and (7) report the statistics for female non-executive directors without and with innovation experience respectively. Column (9) displays the mean of the variables for male non-inventor-directors' observations while column (11) shows the mean of the variables for male inventor-directors' observations. The statistics indicate that female inventor-directors are younger than most of the non-executive directors, spent less time on board, hold more qualifications, have less experience as chief executive officers.

[Insert Table 3.1 here]

Table 3.2 presents female inventor-directors distribution over the sample period. Column (1) displays the number of unique female inventor-directors in each year of the sample years. Column (2) shows the number of unique companies that have female inventor-directors on their boards in each year. The number of all companies and the percentage of companies with female inventor-directors in each year of our sample period are reported in columns (3) and (4) respectively. There are 167 unique female inventors who served as non-executive directors in 241 firms between 2000 and 2017. During the sample period, the number of female inventor-directors experienced an approximately eight-fold increase (from 14 in 2000 to 113 in 2017). In addition, the percentage of companies with female inventor-directors increased from 1.28% in 2000 to 5.43% in 2017 and this illustrates the progressive rise in the representation of female inventors in the boardroom overtime.

[Insert Table 3.2 here]

Table 3.3 provides the breakdown of female inventor-directors' observations across the different two-digit Standard Industrial Classification (SIC) industries. For each industry, the number of observations where there are female inventors in the boardroom is reported in column (1) while the number of observations without any female inventor-directors is shown in column (2). The top five industries where female inventors serve as directors are Chemicals & Allied Products, Insturment & related products, Business Services, Electronic & Other Electrical equipment, Industrial Machinery & Equipment.

[Insert Table 3.3 here]

3.3 Empirical model and results

3.3.1 Female inventor-directors and female innovation

We start the empirical analysis by examining the relation between the presence of female inventors in the boardroom and the patenting output of female inventors in the firm. This is established by estimating a baseline linear model expressed as follows:

$$y_{i,t} = \beta \; Female\_Inventor\_Director_{i,t-1} + X_{i,t-1} + \gamma_s + \mu_t + \epsilon_{i,t} \tag{3.1}$$

where i indexes firm, s indexes industry, t indexes time. $y_{i,t}$ will be the alternatives measures of female inventors' patenting output in a firm i at year t which could be $ln(1 + \#female\ patents)$, $ln(1 + female\ citations)$, $ln(1 + female\ value)$, or $ln(1 + \#\ female\ important\ patents)$. $Female\_Inventor\_Director$ is a dummy variable which takes the value of one if there is at least one female inventor serving as a non-executive director in the board of firm i in year $(t-1)$ and zero otherwise. $X_{i,t-1}$ are the time varying control variables at $(t-1)$, γ_s and μ_t are industry and year fixed effects respectively where industries are classified at 2-digit SIC level, and ϵ_{it} is the error term. Industry fixed effects account for the patenting differences between industries. Standard errors are clustered at the firm-level.

The baseline results of estimating equation 3.1 are reported in table 3.4. Panel A displays the results when the different dependent variables (female inventors' patenting output) are constructed for patents filed by teams with at least one female inventor. Panel B shows the findings for female patents filed by teams with a majority of female inventors.

The results in Panel A suggest that there is a positive relationship between the presence of a female director with patenting expertise and the quantity and quality of patents filed by teams with at least one female inventor. In Model (1) of panel A, $Female\_Inventor\_Director$ coefficient is positive and significant at 1% where it is 0.384 which indicates that the presence of female inventor-directors is associated with 46.81%[20] increase in the number of patents filed that have female inventors among the team relative to firms without female inventor-directors. Similarly and with respect to the quality of

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[20] This economic magnitude could be calculated as $e^{0.384} - 1 = 0.4681$

innovation, the results in models (2) and (3) of panel A indicate that the citations and value of female patents increase by 44.91% and 126.60% respectively (the coefficients are 0.371 and 0.818 and both are significant at 1%) when the board has a female inventor. In column (4), the coefficient for female important patents is 0.231 which represents a 25.99% increase. Hence, the results indicate that female inventors participate in more high quality and valuable patents when there is a female inventor in the boardroom. Across all specifications, we control for the presence of male inventor-directors. In panel A, our findings reveal that the coefficients for female inventor-directors are at least two times those coefficients for male inventor-directors. This highlights the crucial role of female inventor-directors and how their presence on corporate boards could positively impact the participation of female inventors in the innovation activities of the firm (as measured by the enhanced female inventors' patenting output).

We go beyond analysing the impact of female inventor-directors on only patents with at least one female inventor.[21] Instead, we also explore their influence on patents where female inventors make up the majority of the team. We expect that female inventor-directors will encourage female inventors within the the firm to collaborate and generate more patents that are female-dominated (more than 50% of the inventors in the team are women). The results reported in panel B pertain to patents that have a majority of female inventors in their teams and indicate that female inventors file more female-dominated patents where the coefficient is significant at 1%.[22] In

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[21] The team could be male-dominated and hence we are interested in assessing the quality for those patents with a majority of female inventors

[22] The coefficient is six times the coefficient of male-inventor-directors. Across all

addition, these female-dominated patents are of high quality as measured by the citations they receive, their value and importance.

[Insert Table 3.4 here]

In table 3.4, the main independent variable reflects the extensive margin of the presence of female directors with patenting expertise in the boardroom where it is a binary variable that takes the value of one when there is a female inventor-director and zero otherwise and in this context, we are interested in investigating the relative weight and influence that female inventor-directors could have on the innovation output of female inventors in the firm. Table 3.5 presents the results where the main independent variable is the percentage of female inventor-directors on board ($Female\_Inventor\_Director\%$) defined as the number of female inventor-directors divided by the total number of directors in the boardroom. Panel A reports the results for patents where the teams have at least one female inventor while panel B reports the results for patents with a majority of female inventors. Model (1) of panel A shows that the coefficient for the percentage of female directors with innovation experience which is positive and significant (2.49). In terms of economic significance, a one standard deviation increase in the percentage of female inventor-directors is associated with 4.32% increase in the number of patents filed by teams that

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specifications, the coefficients of female inventor-directors are statistically significant while their counterparts of male inventor-director become insignificant for the citations and important patents measures. For the baseline tests, we take a step further, and reconstruct all the dependent variables where the inventors' teams are exclusively composed of female inventors (100% of the inventors in the team are females). For these all-female patents, we expect that female inventor-directors will matter more and will have higher impact than male inventor-directors. The findings corroborate our expectation where the coefficients of male inventor-directors are insignificant for the number of female patents, citations, and important patents while coefficients of female inventor-directors are significant across all models.

have female inventors among their members.[23] We further find consistent pattern across all the innovation quality measures, showing positive and statistically significant results as reported in columns (2)-(4). The coefficients for the female citations, value, and number of important patents filed by teams with female inventors are 2.417, 5.965, and 1.432 respectively and their economic significance indicate that these innovation measures would increase by 4.19%, 10.67%, and 2.5% with one standard deviation increase in the percentage of female inventor-directors.

Additionally, we include control variables for the percentage of other female directors who do not possess a patenting expertise (*Female_NED%*), where we expect that they will have an impact on female innovation in the firm but the most significant effect is expected from the representation of female directors who have the relevant expertise (i.e., *female inventor-directors*). The results from panel A demonstrate a positive association between female directors without innovation experience and the patenting output of female inventors. However, the coefficients of female inventor-directors are notably larger, implying that having female directors with the relevant patenting expertise on board will have larger spillover effects on the output of female inventors in the firm.

Panel B presents the results concerning female patents filed by teams predominantly composed of female inventors. The presence of female inventor-directors shows a positive and significant impact across all models, highlighting their importance in influencing female inventors' patenting output.

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[23] The standard deviation for the percentage of female inventor-directors is 0.017 and hence the economic magnitude will be 4.32%

Prior studies' results indicate that female leaders and women in authority could have a positive impact on their female peers in a business environment (Cardoso and Winter-Ebmer, 2010; Matsa and Miller, 2011; Bell, 2005; Tate and Yang, 2015; Kunze and Miller, 2017; Theodoropoulos et al., 2022; Dalvit et al., 2022). For instance, Matsa and Miller (2011) find that there is a positive association between female representation on boards and the share of females in the top executives team. Consistently, our results from tables 3.4 and 3.5 suggest that women on corporate boards are positively related to the patenting output of female inventors within firms. More importantly, the positive relationship becomes even more significant when the female directors possess the relevant skills and experience, specifically the patenting expertise. Our findings underscore the importance of female inventor-directors.

[Insert Table 3.5 here]

3.3.2 Inventors' diversity and productivity

The baseline results show a positive relationship between the presence of female inventor-directors and the patenting output of female inventors in the firm. One possible explanation is that female inventor-directors might promote diversity within inventor teams, leading to an increased participation of female employees in the innovation activity of the firm. Alternatively, these female inventor-directors could empower female inventors, give them access to more resources, resulting in an improvement of their productivity. Consequently, the higher patenting output of female inventors could be attributed to either the greater number of female inventors participating in innovation (more diverse teams) or the improved productivity of female inventors, or possibly a combination of both.

Therefore, we examine the association between the presence of female inventor-directors and the number of female inventors in the firm. In addition, we study whether the proportion of female inventors among all inventors in the firm improves when there is a female inventor-director in the boardroom. This presence could have positive spillover effects on the diversity of inventor teams. Hence, we expect that the number and percentage of female inventors (measured as the number of female inventors filing patents in a firm in a specific year divided by the total number of inventors filing patents in the same year) would increase when there is a female inventor-director on board.

The results are reported in table 3.6. Models (1) and (3) respectively report results for the number and percentage of female inventors based on patents filed by teams with at least one female inventor. Models (2) and (4) respectively present the results for the number and percentage of female inventors based on patents filed by teams with a majority of female inventors. Models (1) and (2) indicate that the presence of women with innovation experience in the boardroom is significantly correlated with the number of female inventors in the firm (the coefficient is 0.399 for the number of female inventors participating in innovation and is 0.215 for the number of female inventors participating in female-dominated teams). Furthermore, models (3) and (4) report the findings when the dependent variable is the percentage of female inventors in the firm and they show that the percentage of female inventors increases with the presence of a female inventor in the boardroom. Coefficients indicate that female inventor-directors are strongly correlated with both the number and proportion of female inventors in the firm. Overall, the results presented in table 3.6 indicate that female directors, in general, and female inventor-directors, in particular, promote diversity among inventors within the firm. This is evident from the increased number of female inventors and their enhanced representation.

[Insert Table 3.6 here]

By promoting diversity and fostering an inclusive environment, female inventor-directors have the potential to empower their fellow female inventors in the firm. This could be achieved by giving them access to more resources and improving their innovation capacity, resulting in an enhanced productivity of female inventors. Therefore, we expect a positive relation between the presence of a female inventor-director and the productivity of a firm's female inventors.

Table 3.7 reports results for the alternative productivity measures. Panel A shows the results for the productivity of all female inventors in the firm in a given year (those who participated in filing patents during the year). Panel B presents the results for female inventors who participated in female-dominated teams in a specific year (where female patents are filed by teams with a majority of female inventors). Model (1) in panel A suggests that the productivity measure based on the number of patents with female participants increases by 8.22% in the presence of female inventors in the boardroom (the coefficient for *Productivity_(# patents)* is 0.079 and significant at 1%). Models (2)-(4) in panel A report results for the other productivity measures and they lead to analogous inferences where $\frac{total\ citations\ of\ female\ patents}{\#female\ inventors}$,

$\frac{total\ value\ of\ female\ patents}{\#female\ inventors}$, and $\frac{\#\ important\ female\ patents}{\#female\ inventors}$ increase by 8.11%, 55.89%, and 1.92% respectively. Panel B shows similar results for female-dominated teams. In most specifications, the findings reveal that female directors who do not possess patenting expertise (*Female_NED%*) have no impact on female inventors' productivity. Instead, female directors with the relevant patenting experience are the ones who demonstrate a positive impact on female inventors' productivity.

Overall, the results in tables 3.6 and 3.7 show how female inventor-directors promote gender diversity where in their presence, female inventors participate more in firms' innovation activities. Furthermore, and unlike female directors who do not have an experience in patenting, female inventors' productivity is enhanced with the presence of female inventor-directors in the boardroom.

[Insert Table 3.7 here]

3.3.3 Productivity gap

Female inventor-directors have a positive impact on female inventors' productivity (see results in table 3.7) but our sample summary statistics (table 3.1) indicate that there is a productivity gap between male and female inventors. In this section, we are interested in investigating whether female inventor-directors could help in reducing that gap.

To help reduce the gap between males and females specific outcomes, previous studies show that women in leadership positions could help their fellow women in this regard. For example, Tate and Yang (2015) show that the pay gap between males and females is reduced with the presence of females in leadership. Egan et al. (2022) find that, following misconduct, female advisers are more punished than male advisers and this punishment gap is reduced with the presence of female managers. Hence, we study what happens to the productivity gap between male and female inventors when there is a female inventor-director in the boardroom.

Similar to female productivity measures constructed in table 3.7, we construct the same four productivity measures for male inventors. Then, we examine the relationship between the presence of female inventors in the boardroom and the difference between male and female inventors' productivity (*Productivity_Gap*). The results are reported in table 3.8 where panel A reports results for the productivity gap between all male and female inventors in the firm. The findings in panel A indicate that the productivity gap measures based on the patent count, value of patents, and the number of important patents are *reduced* with the presence of female inventor-directors.

In addition, we restrict the productivity gap analyses to be between male inventors participating in male-dominated teams and female inventors participating in female-dominated teams and the results are reported in panel B. The findings suggest that female inventor-directors do not an have an impact on the productivity gap in this case.[24] The coefficients for female inventor-directors in panel B are not significant. These results could be potentially explained by the fact that a firm's female inventors are more likely to participate in mixed-gender teams as suggested by Ding et al. (2006). The results in 3.8 indicate that female inventor-directors could play a role in reducing the productivity gap between male and female inventors in a firm.

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[24] Their male counterparts have a significant impact on increasing the gap.

[Insert Table 3.8 here]

3.3.4 Contribution of female inventors to firm innovation

In this section, we examine whether female inventors contribute more to the firm innovation with a female inventor-director present in the boardroom. The findings are reported in table 3.9. Panel A shows the results for the contribution measures based on patents with at least one female inventor while panel B shows the results for patents with a majority of female inventors. In models (1)-(4), the dependent variables are *Fem. Patents%*, *Fem. Citations%*, *Fem. Value%*, and *Fem. Imp. Pat.%* respectively. In model (1) of panels A and B, the *Female_Inventor_Director* coefficient is positive and significant which suggests that the fraction of patents filed by female inventors increases with the presence of a female inventor-director on board. Likewise in model (2), the percentage of female patents citations to the total citations of a firm's patents is also enhanced with female inventor-directors. Models (3) and (4) report similar results for female inventors' contributions based on value and important patents respectively. Additionally, the results show that female directors without patenting expertise do not have significant impact on the contribution of female inventors to firm innovation. The most significant impact, in contrast, is observed from female directors with accumulated experience in patenting.

Overall, the results in table 3.9 indicate that female inventors in a firm contribute more to the innovation output of the firm with the presence of a female inventor-director in the boardroom .

[Insert Table 3.9 here]

3.3.5 Star female inventor-directors

The previous results show that female inventors in the boardroom are positively related to the patenting output and productivity of female inventors in the firm and negatively with the gender productivity gap. Hence, we expect that the effects will be more pronounced if the female director was *more successful* in patenting in recent years.

Following Moretti and Wilson (2017), we designate a female inventor as a *star* in a given year if her number of filed patents over the past 10 years place her in the top 10th percentile among the population of inventors in USPTO. Table 3.10 presents the findings where models (2), (4), (6), and (8) show the results when the female inventor on board is a star. The variable *Female_Inventor_Director* is a dummy variable that takes the value of one if there is a star female inventor on board and zero if none of the directors is a female inventor. Models (1), (3), (5), and (7) display results when the female inventor on board is not a star. In these models, *Female_Inventor_Director* is a dummy variable that takes the value of one if the female inventor on board is not a star and zero if none of the directors is a female inventor. Panel A reports the results for female inventors' patenting output measures based on patents filed by teams that have at least one female inventor. The findings for the productivity of female inventors, and the productivity gap between male and female inventors in the firm are also displayed in panel A.

Regarding the patenting output measures, the results indicate that female directors who are star inventors have greater impact on the patenting output of female inventors compared to non-star female directors. The coefficients of star female inventor-directors are approximately four times those of non-star female inventor-directors (the p-values of F-test for equal coefficients are reported and indicate that there are statistical differences between coefficients). With respect to the productivity measures based on count, citations and value, we get similar results where the coefficients of star female inventor-directors are higher and statistically different from the coefficients of non-star female inventor-directors. Productivity gap tests indicate that star female inventor-directors are highly correlated with the reduction in the productivity gender gap compared to non-star female directors. Panel B reports results for patents filed by teams predominantly composed of females. In line with panel A results, the patenting output and productivity of female inventors within female-dominated teams are more pronounced when the female inventor-director on board is a star inventor.

Our findings in table 3.10 affirm our initial findings, highlighting the beneficial impact of female inventor-directors as role models for other female inventors within firms. This impact is strengthened when the female director is a star inventor.

[Insert Table 3.10 here]

3.4 Appointment of female inventor-directors

In the previous section, the cross sectional analyses shed light on how the presence of a female inventor in the boardroom is correlated with the patenting output of female inventors. However, the previous analyses shed limited insights in terms of the causal effect (and potential policy implications) of the presence of a non-executive female director with patenting expertise. We partially address this by examining how the patenting output of female inventors in the firm changes after the appointment of a female inventor-director.

Table 3.11 reports the results of the appointment analysis. Panel A shows the results for patenting output based on patents filed by teams with at least one female inventor while panel B shows the results for patents filed by teams with a majority of female inventors. The appointment analysis will help in exploring the impact of female inventor-directors appointments relative to firms that do not make such appointments. This analysis helps in showing the influence of bringing skilled female directors to the board on the patenting output of female inventors.

The main independent variable in table 3.11 is *Female_Inv_Dir_Appointment* which is a dummy variable that takes the value of one in a given year if a female director with patenting expertise is appointed to the board as a non-executive director and zero if there are no female inventor-directors appointments in that year. The main independent variable is lagged one period. Model (1) of panel A reports the result for the number of patents filed by female inventors. The coefficient is 0.239 and significant indicating that the number of patents filed by female inventors increases by 27% following the appointment of a female inventor-director relative to firms that do not appoint female inventor-directors. Models (2), (3), and (4) show the results for the female inventors' output based on citations, value, and important patents where the coefficients are all positive and significant representing a respective increase of 28.8%, 62.3%, and 14.8%. Panel B shows a positive relation between the appointment of female inventor-directors and the number and value of female-dominated patents filed, where patents filed by teams with a majority of female inventors increase by 8.9% and the their values are higher by 22.7% for firms that appoint female inventor-directors relative to firms that do not.

[Insert Table 3.11 here]

Note that the use of a lagged indicator variable to flag the appointment of a female inventor-director mitigates potential concerns of reverse causality, although our setting is in limited in sorting out endogeneity concerns arising from potential omitted variables or unobserved heterogeneity.

3.5 Conclusion

In this paper, we examine whether a female director with a patenting expertise in the boardroom matters for the patenting activity of female inventors within firms. We find that female inventor-directors have a positive influence on different aspects of female inventors' patenting output, including the count, citations, value, and importance of their filed patents. Additionally, firms with female inventors on their boards foster a more supportive and inclusive environment where more female inventors are being involved in firms' innovation activities. Furthermore, we find female inventors' productivity improves with female inventor-directors present in the boardroom, and additionally, they have greater contribution to a firm's innovation.

Interestingly, our findings suggest that the presence of female inventor-directors helps in shrinking the productivity gap between male and female inventors.

Notably, our study goes beyond examining the general influence of female directors. We distinguish between the impact of female directors who do not possess a patenting expertise and the specific influence of female directors with such expertise. Although we observe that female directors in general are positively related to the patenting output of female inventors as well as their representation in the firm, this effect is not as strong as the one observed for female inventor-directors. Unlike female inventor-directors, those lacking patenting experience do not influence the productivity of female inventors, do not affect their contribution to the firm innovation, and do not contribute to the reduction of the innovation productivity gender gap.

Our results support the findings of gender spillover literature, which suggests that female leaders serving as role models can have positive impact on gender-specific outcomes in a business, and provide benefits to their fellow women. More specifically, we show that female directors with the unique and specific patenting expertise, have the most significant impact on female inventors in firms. Our findings are more pronounced when the female director is a star inventor.

Table 3.1: Summary statistics

This table presents summary statistics of the main variables of the study over the period 2000-2018. Panel A reports summary statistics of variables at the firm-level. Columns (1)-(3) show statistics for the full sample. Columns (4)-(5) show statistics when there is not any female directors with patenting expertise in the boardroom and columns (6)-(7) display statistics for the firm-year observations with female inventors in the boardroom. The differences between means and t-statistic are reported in columns (8) and (9) respectively. Panel B reports summary statistics at the directors' level. Columns (1)-(3) in panel B display statistics for all Non-executive directors. Statistics for female directors without innovation experience are shown in columns (4)-(5) while those of female inventors are in columns (6)-(7). Statistics for male directors without innovation experience are reported in columns (8)-(9) while those of male inventors are in columns (10)-(11). Appendix 3.A provides definitions of all variables.

Panel A: Firm-level summary statistics

	Full Sample			Without Fem. Inv-Dir		With Fem. Inv-Dir		Difference	
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
Variable	N	Mean	Std. Dev.	N	Mean	N	Mean	(7)-(5)	t-stat
ln(1+# female patents)	44006	0.38	0.95	43009	0.36	997	1.19	0.82***	27.17
ln(1+female citations)	44006	0.37	1.03	43009	0.36	997	1.16	0.80***	24.56
ln(1+female value)	44006	0.86	1.98	43009	0.82	997	2.65	1.84***	29.25
ln(1+# female important patents)	44006	0.19	0.61	43009	0.18	997	0.65	0.47***	24.04
ln(1+# female inv.)	44006	0.37	0.91	43009	0.35	997	1.18	0.83***	29.01
Female Inv. Percentage	44006	0.03	0.08	43009	0.03	997	0.08	0.05***	19.65
Productivity_(# patents)	44006	0.16	0.33	43009	0.15	997	0.36	0.21***	20.13
Productivity_(citations)	44006	0.16	0.43	43009	0.15	997	0.36	0.21***	15.54
Productivity_(value)	44006	0.57	1.27	43009	0.55	997	1.62	1.08***	26.64
Productivity_(important patents)	44006	0.05	0.16	43009	0.05	997	0.11	0.06***	11.63
Productivity_Gap_(# patents)	44006	0.01	0.26	43009	0.01	997	-0.08	-0.09***	-10.96
Productivity_Gap_(citations)	44006	0.02	0.35	43009	0.02	997	-0.06	-0.08***	-7.04
Productivity_Gap_(value)	44006	0.12	0.80	43009	0.12	997	-0.06	-0.18***	-6.99
Productivity_Gap_(important patents)	44006	0.00	0.14	43009	0.00	997	-0.03	-0.03***	-7.15
Fem. Patents%	44006	0.07	0.20	43009	0.07	997	0.19	0.12***	19.41
Fem. Citations%	44006	0.07	0.20	43009	0.06	997	0.17	0.11***	17.75
Fem. Value%	44006	0.07	0.20	43009	0.07	997	0.19	0.12***	19.4
Fem. Imp. Pat.%	44006	0.05	0.18	43009	0.05	997	0.15	0.10***	18.09
Firm_Size	44006	6.29	2.03	43009	6.27	997	7.34	1.07***	16.44
ROA	44006	0.04	0.52	43009	0.04	997	0.04	0.00	0.00
R&D	44006	0.07	0.18	43009	0.07	997	0.10	0.03***	5.51
Leverage	44006	0.21	0.26	43009	0.21	997	0.19	-0.02**	-2.45
Capex	44006	0.05	0.07	43009	0.05	997	0.04	-0.01***	-6.85
HHI	44006	0.19	0.18	43009	0.19	997	0.17	-0.02***	-3.86
Tobin's_Q	44006	2.27	2.72	43009	2.26	997	2.73	0.47***	5.43
Firm_Age	44006	2.83	0.73	43009	2.82	997	2.99	0.17***	7.21
Inv_CEO	44006	0.15	0.35	43009	0.15	997	0.19	0.05***	4.03
Male_Inventor_Director	44006	0.26	0.44	43009	0.26	997	0.37	0.11***	7.50
Female_NED%	44006	0.08	0.10	43009	0.08	997	0.09	0.01**	2.49
Board_Size	44006	8.18	2.26	43009	8.15	997	9.52	1.37***	18.98
Board_Avg_Age	44006	59.72	5.07	43009	59.71	997	59.90	0.19	1.16
Board_Avg_Tenure	44006	7.69	4.56	43009	7.71	997	7.05	-0.66***	-4.50
Independence_ratio	44006	0.73	0.15	43009	0.73	997	0.80	0.07***	15.17
No_Qualifications	44006	17.02	6.83	43009	16.90	997	22.23	5.33***	24.52
PhD%	44006	0.10	0.13	43009	0.09	997	0.17	0.08***	18.27
MBA%	44006	0.31	0.19	43009	0.31	997	0.37	0.06***	9.16
CEO%	44006	0.54	0.18	43009	0.54	997	0.57	0.03***	4.80
CTO%	44006	0.01	0.04	43009	0.01	997	0.02	0.01***	4.80

Panel B: Directors' summary statistics

	All Non-Executive Directors			Fem. Non-Inv. Dir.		Fem. Inv. Dir.		Male Non-Inv. Dir.		Male Inv. Dir.	
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)
Variable	N	Mean	Std. Dev.	N	Mean	N	Mean	N	Mean	N	Mean
Age	285631	60.85	9.39	32213	57.22	1020	57.37	237106	61.38	15292	60.52
Tenure	294586	7.24	7.03	32282	5.88	1024	5.02	237700	7.50	15317	6.81
No. Qual.	294586	2.14	1.21	32282	2.33	1024	2.95	237700	2.09	15317	2.54
CEO	294586	0.49	0.50	32282	0.37	1024	0.44	237700	0.52	15317	0.64
CTO	294586	0.01	0.10	32282	0.01	1024	0.08	237700	0.01	15317	0.10
PhD	294586	0.10	0.30	32282	0.12	1024	0.42	237700	0.08	15317	0.38
MBA	294586	0.33	0.47	32282	0.33	1024	0.20	237700	0.34	15317	0.22

Table 3.2: Sample distribution of female inventor-directors by year

This table reports the unique number of female directors with innovation experience each year in column (1), the number of companies with female inventor-directors in column (2), the total number of companies in column (3), and the percentage of companies with female inventors inventors on their boards in column (4).

Year	# unique Female Inventors (1)	# unique companies with Female Inventors (2)	No. of all companies (3)	% of companies with Female Inventors (4)
2000	14	15	1170	1.28%
2001	18	21	1322	1.59%
2002	18	23	1398	1.65%
2003	24	34	2751	1.24%
2004	29	39	3027	1.29%
2005	28	36	3013	1.19%
2006	28	36	2945	1.22%
2007	35	43	2841	1.51%
2008	37	46	2742	1.68%
2009	39	45	2560	1.76%
2010	38	43	2550	1.69%
2011	42	49	2527	1.94%
2012	52	61	2513	2.43%
2013	54	64	2558	2.50%
2014	68	87	2613	3.33%
2015	82	101	2544	3.97%
2016	99	120	2465	4.87%
2017	113	134	2467	5.43%
Full Sample	167	241	5501	4.38%

Table 3.3: Sample distribution of female inventor-directors observations by two-digit Standard Industrial Classification (SIC)

This table presents the distribution of observations with and without female inventor-directors across two-digit SIC industries. For each industry, the number of observations where there are female inventors in the boardroom is reported in column (1). The number of observations where there are not any female directors with innovation experience is shown in column (2).

Industry	Female Inventor-Directors (1)	Female Non-Inventor-Directors (2)
Chemicals & Allied Products	334	5293
Instruments & Related Products	139	3121
Business Services	115	5626
Electronic & Other Electrical Equipment	50	4057
Industrial Machinery & Equipment	49	2743
Wholesale Trade - Durable Goods	26	1012
Food & Kindred Products	24	1061
Miscellaneous Retail	23	906
Wholesale Trade - Nondurable Goods	21	657
Apparel & Accessory Stores	20	605
General Merchandise Stores	19	297
Engineering & Management Services	19	991
Transportation Equipment	17	1140
Rubber & Miscellaneous Plastic Products	16	351
Furniture & Fixtures	15	296
Leather & Leather Products	15	182
Amusement & Recreation Services	13	444
Nonclassifiable Establishments	12	110
Food Stores	8	205
Apparel & Other Textile Products	7	411
Heavy Construction, Except Building	7	223
Eating & Drinking Places	7	778
Primary Metal Industries	5	550
Motion Pictures	5	206
Trucking & Warehousing	5	361
Printing & Publishing	4	515
Stone, Clay, Glass, & Concrete Products	4	204
Transportation Services	3	217
Metal Mining	3	944
Oil & Gas Extraction	2	2032
Communications	2	1369
Paper & Allied Products	2	441
Fabricated Metal Products	2	655
Railroad Transportation	1	148
Furniture & Homefurnishings Stores	1	238
Lumber & Wood Products	1	246
Health Services	1	913
Building Materials & Gardening Supplies	0	88
Tobacco Products	0	58

Legal Services	0	17
Automotive Dealers & Gasoline Service..	0	327
Local & Interurban Passenger Transit	0	27
Special Trade Contractors	0	110
Water Transportation	0	213
Auto Repair, Services, & Parking	0	86
Miscellaneous Manufacturing Industries	0	344
Social Services	0	75
General Building Contractors	0	307
Petroleum & Coal Products	0	356
Educational Services	0	242
Textile Mill Products	0	131
Coal Mining	0	166
Transportation by Air	0	313
Miscellaneous Repair Services	0	9
Hotels & Other Lodging Places	0	182
Nonmetallic Minerals, Except Fuels	0	146
Pipelines, Except Natural Gas	0	123
Personal Services	0	141
Total	997	43009

Table 3.4: Presence of female directors with innovation experience and patenting output of female inventors

This tables presents the estimates of OLS regressions to examine how the presence of female inventor-directors affects the innovation output of female inventors in the firm. The main independent variable is *Female_Inventor_Director* which is a dummy variable that takes the value of one if there is a female non-executive director with patenting expertise in the boardroom and zero otherwise at $(t-1)$. *ln*(*1+# female patents*) is the natural logarithm of one plus the number of patents filed by female inventors at (t). *ln*(*1+ female citations*) is the natural logarithm of one plus the total citations that patents filed by female inventors at (t) receive. *ln*(*1+ female value*) is the natural logarithm of one plus the total value of patents filed by female inventors at (t) as estimated by Kogan et al. (2017). *ln*(*1+# female important patents*) is the natural logarithm of one plus the number of important patents filed by female inventors at (t). A patent is considered to be important if it is above the 80^{th} percentile of the technology-year citations distribution. Panel A reports results for female patents filed by teams with at least one female inventor. Panel B presents the results for female patents filed by teams with a majority of female inventors. See appendix 3.A for the definitions of all variables. All models include year and industry fixed effects. Standard errors are clustered at the firm-level. t statistics are in parentheses. *,**, and *** represent significance at the 10%, 5%, and 1% levels, respectively.

Panel A: Teams with at least one female inventor

	(1) ln(1+# female patents)	(2) ln(1+ female citations)	(3) ln(1+female value)	(4) ln(1+# female important patents)
Female_Inventor_Director	0.384***	0.371***	0.818***	0.231***
	(3.81)	(3.31)	(4.54)	(2.89)
Female_NED%	0.270**	0.255**	0.466**	0.179**
	(2.47)	(2.20)	(2.12)	(2.56)
Firm_Size	0.213***	0.210***	0.474***	0.125***
	(16.60)	(15.74)	(21.60)	(13.18)
ROA	0.092***	0.113***	0.272***	0.059***
	(6.04)	(6.71)	(7.93)	(6.04)
R&D	0.404***	0.412***	0.692***	0.238***
	(6.18)	(5.91)	(6.30)	(5.97)
Leverage	-0.190***	-0.189***	-0.409***	-0.127***
	(-4.49)	(-4.30)	(-4.40)	(-4.58)
Capex	0.291**	0.311**	0.415*	0.207**

	(2.36)	(2.38)	(1.79)	(2.53)
HHI	0.079	0.075	0.292*	0.030
	(1.00)	(0.88)	(1.82)	(0.56)
Tobin's_Q	0.035***	0.042***	0.101***	0.023***
	(8.43)	(8.85)	(9.56)	(8.08)
Firm_Age	0.105***	0.092***	0.217***	0.057***
	(4.56)	(3.82)	(5.06)	(3.70)
Inv_CEO	0.270***	0.277***	0.490***	0.153***
	(7.13)	(6.73)	(7.22)	(5.62)
Male_Inventor_Director	0.138***	0.130***	0.289***	0.065***
	(4.82)	(4.24)	(5.28)	(3.32)
Board_Size	-0.011	-0.012	-0.029*	-0.008
	(-1.22)	(-1.28)	(-1.73)	(-1.36)
Board_Avg_Age	-0.007***	-0.008***	-0.015***	-0.005***
	(-3.16)	(-3.38)	(-3.36)	(-3.37)
Board_Avg_Tenure	-0.005	-0.004	-0.007	-0.003
	(-1.60)	(-1.14)	(-1.13)	(-1.32)
Independence_Ratio	-0.062	-0.058	-0.006	-0.083*
	(-0.94)	(-0.84)	(-0.05)	(-1.92)
No_Qualifications	0.010***	0.011***	0.024***	0.006***
	(3.05)	(3.28)	(3.94)	(3.07)
PhD%	0.572***	0.576***	0.996***	0.307***
	(5.25)	(4.83)	(5.00)	(4.02)
MBA%	-0.142**	-0.155**	-0.288***	-0.120***
	(-2.54)	(-2.54)	(-2.68)	(-3.16)
CEO%	0.103*	0.137**	0.242**	0.078**
	(1.94)	(2.34)	(2.33)	(2.15)
CTO%	0.275	0.284	0.531	0.082
	(1.13)	(0.99)	(1.18)	(0.49)
Observations	44006	44006	44006	44006
Adjusted R^2	0.348	0.299	0.384	0.267
Industry FE	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes

Panel B: Teams with a majority of female inventors

	(1) ln(1+# female patents)	(2) ln(1+ female citations)	(3) ln(1+female value)	(4) ln(1+# female important patents)
Female_Inventor_Director	0.178***	0.149**	0.452***	0.073**
	(2.80)	(2.51)	(3.19)	(2.38)
Female_NED%	0.178***	0.146***	0.381***	0.077***
	(3.26)	(2.84)	(2.83)	(3.00)
Observations	44006	44006	44006	44006
Adjusted R^2	0.222	0.166	0.247	0.134
Controls	Yes	Yes	Yes	Yes
Industry FE	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes

Table 3.5: Percentage of female inventor-directors on the board and patenting output of female inventors

This tables presents the estimates of OLS regressions to examine the relationship between the percentage of female inventors in the boardroom and the innovation output of female inventors in the firm. The main independent variable is *Female_Inventor_Director%* which is the number of female non-executive inventor-directors in the boardroom divided by the total number of directors at $(t-1)$. *ln*(*1+# female patents*) is the natural logarithm of one plus the number of patents filed by female inventors at (t). *ln*(*1+ female citations*) is the natural logarithm of one plus the total citations that patents filed by female inventors at (t) receive. *ln*(*1+ female value*) is the natural logarithm of one plus the total value of patents filed by female inventors at (t) as estimated by Kogan et al. (2017). *ln*(*1+# female important patents*) is the natural logarithm of one plus the number of important patents filed by female inventors at (t). A patent is considered to be important if it is above the 80^{th} percentile of the technology-year citations distribution. Panel A reports results for female patents filed by teams with at least one female inventor. Panel B presents the results for female patents filed by teams with a majority of female inventors. See appendix 3.A for the definitions of all variables. All models include year and industry fixed effects. Standard errors are clustered at the firm-level. *t* statistics are in parentheses. *,**, and *** represent significance at the 10%, 5%, and 1% levels, respectively.

Panel A: Teams with at least one female inventor

	(1) ln(1+# female patents)	(2) ln(1+ female citations)	(3) ln(1+female value)	(4) ln(1+# female important patents)
Female_Inventor_Director%	2.490***	2.417***	5.965***	1.432**
	(3.46)	(3.00)	(4.23)	(2.53)
Female_NED%	0.256**	0.239**	0.447**	0.168**
	(2.35)	(2.07)	(2.02)	(2.40)
Observations	44006	44006	44006	44006
Adjusted R^2	0.345	0.297	0.381	0.264
Controls	Yes	Yes	Yes	Yes
Industry FE	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes

Panel B: Teams with a majority of female inventors

	(1) ln(1+# female patents)	(2) ln(1+ female citations)	(3) ln(1+female value)	(4) ln(1+# female important patents)
Female_Inventor_Director%	1.048**	0.914**	3.016***	0.436**
	(2.49)	(2.23)	(2.80)	(2.13)
Female_NED%	0.168***	0.137***	0.361***	0.072***
	(3.09)	(2.68)	(2.70)	(2.85)
Observations	44006	44006	44006	44006
Adjusted R^2	0.220	0.165	0.245	0.133
Controls	Yes	Yes	Yes	Yes
Industry FE	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes

Table 3.6: Female inventor-directors and the number and percentage of female inventors within the firm

This tables presents the estimates of OLS regressions to examine the relationship between the presence of female inventor-directors and the number/percentage of female inventors in the firm. The main independent variable is *Female_Inventor_Director* which is a dummy variable that takes the value of one if there is a female non-executive director with patenting expertise in the boardroom and zero otherwise at $(t-1)$. *ln(1+# Female Inv.)* is the natural logarithm of one plus the number of female inventors filing patents at (t). *Female Inv. Percentage* is the number of female inventors to the total number of inventors at (t). All models include year and industry fixed effects. Models (1) and (3) report results for the number and percentage of female inventors based on patents that are filed by teams with at least one female inventor. Models (2) and (4) present the results for the number and percentage of female inventors based on patents that are filed by teams with a majority of female inventors. See appendix 3.A for the definitions of all variables. Standard errors are clustered at the firm-level. t statistics are in parentheses. *,**, and *** represent significance at the 10%, 5%, and 1% levels, respectively.

	(1) ln(1+# Female Inv.)	(2) ln(1+# Female Inv.)	(3) Female Inv. Percentage	(4) Female Inv. Percentage
Female_Inventor_Director	0.399^{***}	0.215^{***}	0.023^{***}	0.006^{*}
	(4.04)	(2.98)	(3.74)	(1.93)
Female_NED%	0.280^{***}	0.200^{***}	0.016^{*}	0.008^{*}
	(2.70)	(3.27)	(1.87)	(1.91)
Observations	44006	44006	44006	44006
Adjusted R^2	0.354	0.225	0.157	0.023
Controls	Yes	Yes	Yes	Yes
Industry FE	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes

Table 3.7: Female inventor-directors and the productivity of female inventors

This tables presents the estimates of OLS regressions to examine the relationship between the presence of female inventor-directors and the productivity of female inventors in the firm. The main independent variable is *Female_Inventor_Director* which is a dummy variable that takes the value of one if there is a female non-executive director with patenting expertise in the boardroom and zero otherwise at $(t-1)$. $Productivity$ $(\# patents)$ is the female inventors' productivity measure based on the patents count and is defined as the natural logarithm of one plus (the number of patents filed by female inventors at (t) divided by the number of female inventors at (t)). $Productivity$ $(citations)$ is the female inventors' productivity measure based on patents citations and is defined as the natural logarithm of one plus (the total citations that patents filed at (t) by female inventors receive divided by the number of female inventors at (t)). $Productivity$ $(value)$ is the female inventors' productivity measure based on the value of patents and is defined as the natural logarithm of one plus (the total value of patents filed at (t) by female inventors divided by the number of female inventors at (t)). $Productivity$ $(important\ patents)$ is the female inventors' productivity measure based on important patents and is defined as the natural logarithm of one plus (the total number of important patents filed at (t) by female inventors at divided by the number of female inventors at (t)). A patent is considered to be important if it is above the 80^{th} percentile of the technology-year citations distribution.Panel A reports results for the productivity of all female inventors in the firm (those who participated in filing patents during the year). Panel B presents the results for female inventors who participated in female-dominated teams (where female patents are filed by teams with a majority of female inventors). See appendix 3.A for the definitions of all variables. All models include year and industry fixed effects. Standard errors are clustered at the firm-level. t statistics are in parentheses. *,**, and *** represent significance at the 10%, 5%, and 1% levels, respectively.

Panel A: All female inventors

	Productivity (# patents)	Productivity (citations)	Productivity (value)	Productivity (important patents)
Female_Inventor_Director	0.079^{***}	0.078^{***}	0.444^{***}	0.019^{**}
	(3.88)	(2.97)	(4.24)	(2.28)
Female_NED%	0.028	0.024	0.184	0.008
	(0.85)	(0.55)	(1.33)	(0.50)
Observations	44006	44006	44006	44006
Adjusted R^2	0.286	0.188	0.345	0.131
Controls	Yes	Yes	Yes	Yes
Industry FE	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes

Panel B: Female inventors in female-dominated teams

	(1) Productivity (# patents)	(2) Productivity (citations)	(3) Productivity (value)	(4) Productivity (important patents)
Female_Inventor_Director	0.042^{***}	0.033^{**}	0.259^{***}	0.010^{*}
	(3.30)	(2.15)	(3.23)	(1.92)
Female_NED%	0.034^{*}	0.023	0.188^{**}	0.004
	(1.94)	(1.26)	(2.16)	(0.69)
Observations	44006	44006	44006	44006
Adjusted R^2	0.174	0.089	0.222	0.055
Controls	Yes	Yes	Yes	Yes
Industry FE	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes

Table 3.8: Female inventor-directors and the productivity gap between male and female inventors

This tables presents the estimates of OLS regressions to examine the relationship between the presence of female inventor-directors and the productivity gap between male and female inventors. The main independent variable is *Female_Inventor_Director* which is a dummy variable that takes the value of one if there is a female non-executive director with patenting expertise in the boardroom and zero otherwise at $(t-1)$. Male inventors' productivity measures are constructed in the same way as female inventors' productivity in table 3.7. *Productivity_Gap* $(\# \textit{patents})$ is defined as the difference between male and female inventors' productivity based on the number of patents at (t). *Productivity_Gap* $(\textit{citations})$ is defined as the difference between male and female inventors' productivity based on the citations of patents at (t). *Productivity_Gap* $(\textit{value})$ is defined as the difference between male and female inventors' productivity based on the value of patents at (t). *Productivity_Gap* $(\textit{important patents})$ is defined as the difference between male and female inventors' productivity based on the number of important patents at (t). A patent is considered to be important if it is above the 80^{th} percentile of the technology-year citations distribution. Panel A reports results for the productivity gap between all male and female inventors in the firm. Panel B presents the results for the productivity gap between male inventors in male-dominated teams and female inventors in female-dominated teams. See appendix 3.A for the definitions of all variables. All models include year and industry fixed effects. Standard errors are clustered at the firm-level. t statistics are in parentheses. *,**, and *** represent significance at the 10%, 5%, and 1% levels, respectively.

Panel A: All male and female inventors

	(1) Productivity_Gap (# patents)	(2) Productivity_Gap (citations)	(3) Productivity_Gap (value)	(4) Productivity_Gap (important patents)
Female_Inventor_Director	-0.038***	-0.031	-0.146***	-0.013**
	(-2.77)	(-1.54)	(-3.35)	(-2.10)
Female_NED%	-0.013	-0.029	-0.098	-0.009
	(-0.53)	(-0.97)	(-1.28)	(-0.72)
Observations	44006	44006	44006	44006
Adjusted R^2	0.047	0.024	0.016	0.020
Controls	Yes	Yes	Yes	Yes
Industry FE	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes

Panel B: Male inventors in male-dominated teams and female inventors in female-dominated teams

	(1) Productivity_Gap (# patents)	(2) Productivity_Gap (citations)	(3) Productivity_Gap (value)	(4) Productivity_Gap (important patents)
Female_Inventor_Director	-0.007	0.006	0.014	-0.005
	(-0.49)	(0.25)	(0.16)	(-0.69)
Female_NED%	-0.027	-0.034	-0.130	-0.007
	(-1.18)	(-1.03)	(-1.31)	(-0.71)
Observations	44006	44006	44006	44006
Adjusted R^2	0.109	0.089	0.131	0.056
Controls	Yes	Yes	Yes	Yes
Industry FE	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes

Table 3.9: Female inventor-directors and the contribution of female inventors to firm innovation

This tables presents the estimates of OLS regressions to examine the relationship between the presence of female inventor-directors and the contribution of female inventors to the innovation activity of the firm. The main independent variable is *Female_Inventor_Director* which is a dummy variable that takes the value of one if there is a female non-executive director with patenting expertise in the boardroom and zero otherwise at $(t-1)$. *Fem. Patents%* refers to the percentage of patents filed by the firm's female inventors and it is constructed as the number of patents filed by female inventors in a specific year divided by the total number of patents filed in the same year. *Fem. Citations%* is the total citations that patents filed by female inventors received divided by the total citations that all patents filed in a year received. *Fem. Value%* is the total value of female inventors' patents divided by the total value of all patents. *Fem. Imp. Pat.%* is the number of important patents filed by female inventors divided by the total number of all important patents. A patent is considered to be important if it is above the 80^{th} percentile of the technology-year citations distribution. Panel A reports results for female patents filed by teams with at least one female inventor. Panel B presents the results for female patents filed by teams with a majority of female inventors. See appendix 3.A for the definitions of all variables. All models include year and industry fixed effects. Standard errors are clustered at the firm-level. t statistics are in parentheses. *,**, and *** represent significance at the 10%, 5%, and 1% levels, respectively.

Panel A: Teams with at least one female inventor

	(1) Fem. Patents%	(2) Fem. Citations%	(3) Fem. Value%	(4) Fem. Imp. Pat.%
Female_Inventor_Director	0.048^{***}	0.047^{***}	0.050^{***}	0.044^{***}
	(3.49)	(3.46)	(3.56)	(3.18)
Female_NED%	0.020	0.017	0.022	0.014
	(0.98)	(0.87)	(1.11)	(0.80)
Observations	44006	44006	44006	44006
Adjusted R^2	0.171	0.143	0.167	0.132
Controls	Yes	Yes	Yes	Yes
Industry FE	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes

Panel B: Teams with a majority of female inventors

	(1) Fem. Patents%	(2) Fem. Citations%	(3) Fem. Value%	(4) Fem. Imp. Pat.%
Female_Inventor_Director	0.009^{**}	0.011^{**}	0.009^{**}	0.008^{*}
	(2.24)	(2.22)	(2.23)	(1.68)
Female_NED%	0.008	0.009^{*}	0.009	0.002
	(1.53)	(1.88)	(1.61)	(0.52)
Observations	44006	44006	44006	44006
Adjusted R^2	0.025	0.018	0.024	0.016
Controls	Yes	Yes	Yes	Yes
Industry FE	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes

Table 3.10: Star female inventor-directors

This tables presents the estimates of OLS regressions to examine the relationship between the presence of *star* female inventors in the boardroom and female inventors' output, productivity, and the innovation gap between male and female inventors. Similar to Moretti and Wilson (2017), we classify an inventor as a *star* in a specific year if she is above the 90th percentile of the number of patents over the last 10 years. In models (2), (4), (6), and (8), the main independent variable takes the value of one if there is a star female inventor on board (142 observations) and zero if none of the directors is a female inventor at $(t-1)$. In models (1), (3), (5), and (7), the independent variable takes the value of one if the female inventor on board is not a star (855 observations) and zero if none of the directors is a female inventor at $(t-1)$. The dependent variables for the output, productivity, and productivity gap are the same as those defined in tables 3.4, 3.7, and 3.8 respectively. Panel A reports results for female patents filed by teams with at least one female inventor. Panel B presents the results for female patents filed by teams with a majority of female inventors. See appendix 3.A for the definitions of all variables. All models include year and industry fixed effects. Standard errors are clustered at the firm-level. t statistics are in parentheses. *,**, and *** represent significance at the 10%, 5%, and 1% levels, respectively.

Panel A: Teams with at least one female inventor

	(1) Not a Star	(2) Star	(3) Not a Star	(4) Star	(5) Not a Star	(6) Star	(7) Not a Star	(8) Star
	Female Patents (Output)		Female Citations (Output)		Female Value (Output)		Female Imp. Pat.80% (Output)	
Female_Inventor_Director	0.275***	1.074***	0.253**	1.122***	0.583***	2.309***	0.160**	0.688***
	(2.87)	(4.22)	(2.49)	(3.21)	(3.28)	(4.98)	(2.24)	(2.65)
P-Value (F-test of equal coefficient estimates)	0.002		0.012		0.000		0.038	
	Female Patents (Productivity)		Female Citations (Productivity)		Female Value (Productivity)		Female Imp. Pat.80% (Productivity)	
Female_Inventor_Director	0.064***	0.171***	0.057**	0.210**	0.323***	1.203***	0.016*	0.043*
	(3.07)	(3.33)	(2.19)	(2.52)	(2.94)	(4.89)	(1.81)	(1.66)
P-Value (F-test of equal coefficient estimates)	0.045		0.073		0.001		0.309	
	Female Patents (Gap)		Female Citations (Gap)		Female Value (Gap)		Female Imp. Pat.80% (Gap)	
Female_Inventor_Director	-0.025*	-0.117***	-0.022	-0.085*	-0.096**	-0.460***	-0.010	-0.029*
	(-1.78)	(-3.73)	(-1.12)	(-1.75)	(-2.12)	(-5.62)	(-1.60)	(-1.83)
P-Value (F-test of equal coefficient estimates)	0.004		0.178		0.000		0.262	
Observations	43864	43151	43864	43151	43864	43151	43864	43151
Controls	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Industry FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes

Panel B: Teams with a majority of female inventors

	(1) Not a Star	(2) Star	(3) Not a Star	(4) Star	(5) Not a Star	(6) Star	(7) Not a Star	(8) Star
	Female Patents (Output)		Female Citations (Output)		Female Value (Output)		Female Imp. Pat.80% (Output)	
Female_Inventor_Director	0.135**	0.453***	0.107*	0.423***	0.294**	1.465***	0.056*	0.184**
	(2.23)	(2.72)	(1.87)	(2.62)	(2.38)	(3.01)	(1.83)	(2.55)
P-Value (F-test of equal coefficient estimates)	0.050		0.047		0.016		0.071	
	Female Patents (Productivity)		Female Citations (Productivity)		Female Value (Productivity)		Female Imp. Pat.80% (Productivity)	
Female_Inventor_Director	0.033**	0.098***	0.023	0.098**	0.159**	0.895***	0.006	0.032**
	(2.53)	(3.06)	(1.44)	(2.41)	(2.29)	(3.00)	(1.22)	(2.03)
P-Value (F-test of equal coefficient estimates)	0.051		0.079		0.015		0.122	
	Female Patents (Gap)		Female Citations (Gap)		Female Value (Gap)		Female Imp. Pat.80% (Gap)	
Female_Inventor_Director	-0.001	-0.048	0.003	0.032	0.041	-0.160	-0.003	-0.016
	(-0.07)	(-1.22)	(0.12)	(0.31)	(0.46)	(-0.69)	(-0.42)	(-0.77)
P-Value (F-test of equal coefficient estimates)	0.237		0.772		0.401		0.527	
Observations	43864	43151	43864	43151	43864	43151	43864	43151
Controls	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Industry FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes

Table 3.11: Appointment of female inventor-directors

This tables presents the estimates of OLS regressions to examine how the appointment of female inventor-directors affects the innovation output of female inventors in the firm. The main independent variable is *Female_Inv_Dir_Appointment* which is a dummy variable that takes the value of one if there is a female inventor who was appointed as a non-executive director at $(t-1)$ and zero otherwise . $ln(1+\#$ *female patents*$)$ is the natural logarithm of one plus the number of patents filed by female inventors at (t). $ln(1+$ *female citations*$)$ is the natural logarithm of one plus the total citations that patents filed by female inventors at (t) receive. $ln(1+$ *female value*$)$ is the natural logarithm of one plus the total value of patents filed by female inventors at (t) as estimated by Kogan et al. (2017). $ln(1+\#$ *female important patents*$)$ is the natural logarithm of one plus the number of important patents filed by female inventors at (t). A patent is considered to be important if it is above the 80^{th} percentile of the technology-year citations distribution. Panel A reports results for female patents filed by teams with at least one female inventor. Panel B presents the results for female patents filed by teams with a majority of female inventors. See appendix 3.A for the definitions of all variables. All models include year and industry fixed effects. Standard errors are clustered at the firm-level. t statistics are in parentheses. *,**, and *** represent significance at the 10%, 5%, and 1% levels, respectively.

Panel A: Teams with at least one female inventor

	(1) ln(1+# female patents)	(2) ln(1+# female citations)	(3) ln(1+value of female patents)	(4) ln(1+# female important patents)
Female_Inv_Dir_Appointment	0.239^{***}	0.254^{***}	0.484^{***}	0.138^{**}
	(3.10)	(2.97)	(3.18)	(2.58)
Observations	44006	44006	44006	44006
Adjusted R^2	0.342	0.295	0.377	0.262
Controls	Yes	Yes	Yes	Yes
Industry FE	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes

Panel B: Teams with a majority of female inventors

	(1) ln(1+# female patents)	(2) ln(1+# female citations)	(3) ln(1+value of female patents)	(4) ln(1+# female important patents)
Female_Inv_Dir_Appointment	0.085^{*}	0.025	0.204^{*}	0.031
	(1.89)	(0.59)	(1.75)	(1.27)
Observations	44006	44006	44006	44006
Adjusted R^2	0.218	0.164	0.244	0.132
Controls	Yes	Yes	Yes	Yes
Industry FE	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes

3.A Appendix-Variables definitions

Variable	Definition
ln(1+# female patents)	The natural logarithm of one plus the total number of female patents filed in a given year. A Female patent could be defined in different forms: a patent filed by a team of inventors that has at least one female inventor, or a patent filed by a team with a majority of female inventors. (Source: PatentsView & KPSS[25])
ln(1+ female citations)	The natural logarithm of one plus total forward citations that female patents filed in a given year receive. (Source: PatentsView & KPSS)
ln(1+ female value)	The natural logarithm of one plus the total value of female patents filed in a given year as estimated by Kogan et al. (2017). (Source: PatentsView & KPSS)
ln(1+# female important patents)	The natural logarithm of one plus the number of important female patents filed in a given year. A patent is considered to be important when it is above the 80% percentile of technology-year citations distribution. (Source: PatentsView & KPSS)
ln(1+# female inv.)	The natural logarithm of one plus the unique number of female inventors in a given year. (Source: PatentsView & KPSS)
Female Inv. Percentage	The number of female inventors divided by the total number of inventors. (Source: PatentsView & KPSS)
Productivity_(# patents)	The natural logarithm of one plus the number of female patents scaled by the number of female inventors. (Source: PatentsView & KPSS)
Productivity_(citations)	The natural logarithm of one plus the number of citations that female patents receive scaled by the number of female inventors. (Source: PatentsView & KPSS)
Productivity_(value)	The natural logarithm of one plus the value of female patents scaled by the number of female inventors. (Source: PatentsView & KPSS)
Productivity_(important patents)	The natural logarithm of one plus the number of important female patents scaled by the number of female inventors. (Source: PatentsView & KPSS)
Productivity_Gap_(# patents)	The difference between male and female inventors' productivity based on the number of patents. (Source: PatentsView & KPSS)
Productivity_Gap_(citations)	The difference between male and female inventors' productivity based on the citations that their patents receive. (Source: PatentsView & KPSS)
Productivity_Gap_(value)	The difference between male and female inventors' productivity based on the value of their patents. (Source: PatentsView & KPSS)

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[25] KPSS refers to the data by Kogan et al. (2017).

Productivity_Gap_(important patents)	The difference between male and female inventors' productivity based on the number of important patents. (Source: PatentsView & KPSS)
Fem. Patents%	The number of female patents in a specific year divided by the total number of patents filed in the same year. (Source: PatentsView & KPSS)
Fem. Citations%	The total citations that female patents filed in a given year receive divided by the total citations that all patents filed in that same year receive. (Source: PatentsView & KPSS)
Fem. Value%	The total value of female inventors' patents divided by the total value of all patents. (Source: PatentsView & KPSS)
Fem. Imp. Pat.%	The number of female important patents filed by female inventors divided by the total number of all important patents. (Source: PatentsView & KPSS)
Female_Inventor_Director	A dummy variable that takes the value of one if there is a female non-executive director with patenting expertise in the boardroom and zero otherwise. (Source: PatentsView, KPSS, and BoardEx)
Female_Inventor_Director%	The number of female inventor-directors to the total number of directors. (Source: PatentsView , KPSS, and BoardEx)
Female_NED%	The number of female non-executive directors who do not possess patenting expertise (i.e., excluding female inventor-directors) to the total number of directors. (Source: PatentsView, KPSS, and BoardEx)
Female_Inv_Dir_Appointment	A dummy variable that takes the value of one when a female inventor is appointed as a non-executive director and zero otherwise. (Source: PatentsView, KPSS, and BoardEx)
Firm_Size	The natural logarithm of the firm's total assets. (Source: Compustat)
ROA	Operating income before interest, taxes, depreciation and amortisation divided by total assets. (Source: Compustat)
R&D	Research & Development expenditures divided by total assets. (Source: Compustat)
Leverage	Total short- and long-term debt divided by total assets. (Source: Compustat)
Capex	Total capital expenditures divided by total assets. (Source: Compustat)
HHI	Herfindahl Hirschman index which is constructed by computing the share of each firm's sales to total industry sales, then squaring each firm's share and adding up all squared shares. An industry is 3-digit SIC. (Source: Compustat)
Tobin's_Q	Ratio of total assets minus book value of equity plus market value of equity to total assets. (Source: Compustat)
Firm_Age	The logarithm of one plus the number of years since the firm appeared in Compustat. (Source: Compustat)
Inv_CEO	A dummy variable that takes the value of one if the CEO of the firm is an inventor and zero otherwise. (Source: PatentsView, KPSS, and BoardEx)

Male_Inventor_Director	A dummy variable that takes the value of one if there is a male non-executive director with patenting experience in the boardroom and zero otherwise. (Source: PatentsView, KPSS, and BoardEx)
Board_Size	The total number of directors in the board. (Source: BoardEx)
Board_Avg_Age	The average age of all directors. (Source: BoardEx)
Board_Avg_Tenure	The average tenure of all directors. A director's tenure is the number of years since being in role. (Source: BoardEx)
Independence_Ratio	The total number of independent directors divided by the total number of directors. (Source: BoardEx)
No_Qualifications	The total number of qualifications of all directors. (Source: BoardEx)
PhD%	The percentage of directors who hold a doctoral degree. (Source: BoardEx)
MBA%	The percentage of directors who hold MBA. (Source: BoardEx)
CEO%	The percentage of directors with experience as CEOs. (Source: BoardEx)
CTO%	The percentage of directors with experience as chief technology officers. (Source: BoardEx)

Chapter 4

Conclusion

This thesis examines the distinctive innovation experience of directors in U.S. corporate boards (i.e., directors' hands-on patenting expertise). In chapter 2, we study the relation between the presence of inventor-directors in the boardroom and corporate innovation. We find that firms with inventors on their boards, spend more on R&D, file more patents, and their patents are move valuable and receive a higher number of citations. In addition, we find firms engage more in radical innovation and patent across a wide array of technology classes when inventors are present in the boardroom. Further results indicate that these firms engage more in explorative innovation that rely less on their existing knowledge. Our results are more pronounced for inventor-directors with better innovation skills (i.e., star and more influential inventors). We provide further evidence on this relationship by showing how firm-level innovation improves subsequent to the appointment of inventor-directors. To mitigate endogenous matching between firms and directors, we implement IV analysis where we use the supply of inventor-CEOs near firms' headquarters as an instrumental variable for inventor-directors. The IV results reinforce our findings of a positive impact of inventor-directors on corporate innovation.

Chapter 2 contributes to the literature on the interplay between director characteristics and corporate innovation. Existing studies have documented positive effects of different director attributes on innovation, including independence (Balsmeier et al., 2017), diversity (Chen et al., 2018; Griffin et al., 2021; An et al., 2021; Genin et al., 2023), industry expertise (Faleye et al., 2018), connectedness (Kang et al., 2018; Chang and Wu, 2021), and education (Hsieh et al., 2017). Our contribution lies in our emphasis on directors' experience directly tied to innovation, and how it can influence firms' innovation efforts and shape their innovation strategies.

In chapter 3, we study the impact of female inventor-directors on the performance of female inventors within firms. We find that female inventor-directors have a positive impact on different aspects of female inventors' patenting output, as measured by the number, citations, value, and importance of patents they file. Firms with inventor-directors in the boardroom create a more inclusive environment where female inventors are more represented in firms' innovation activities. In addition, female inventors experience a boost in their productivity and contribute more to firm innovation, when there is a female inventor in the boardroom. Further results indicate that innovation productivity gender gap between male and female inventors narrows with the presence of female inventor-directors. While our results indicate that female directors who do not possess innovation experience, have a positive impact on female inventors' patenting output, their influence is not as pronounced as that of female inventor-directors. In contrast to female directors with patenting expertise, those without such expertise do not have an impact on female inventors' productivity and their contribution to firm innovation. Furthermore, they do not contribute to narrowing the innovation productivity gender gap.

Chapter 3 contributes to the literature on female inventors, under-representation, importance, and obstacles they face in the innovation sector (Kahler, 2011; Hunt et al., 2013; Fechner and Shapanka, 2018; Cook et al., 2022; Koning et al., 2021). In addition, we contribute to the literature on potential effects of women in authority on their female counterparts within firms (Athey et al., 2000; Dalvit et al., 2022; Cardoso and Winter-Ebmer, 2010; Matsa and Miller, 2011; Kunze and Miller, 2017). The study investigates the importance of female inventor-directors and how their presence could have a positive impact on the patenting performance of firms' female inventors.

While this thesis emphasises the significance of the role of inventors on corporate boards, the findings are still subject to limitations. First, in chapter 2, to establish causality between inventor-directors and firm-level innovation, we are unable to rely on the unexpected exogenous deaths of directors. The reason for this limitation is the scarcity of cases involving inventors who suddenly die while serving as directors on corporate boards.

Second, in chapter 3, board composition is endogenous and it can be argued that firms wishing to enhance the patenting performance of their female inventors are more likely to appoint female inventor-directors to their boards. In an ideal setting, we would randomly assign female directors with patenting expertise to boards and then observe what happens to female inventors' patenting output. However, this is not feasible. An alternative setting that could be exploited is the California board quota reform, which firms are required to comply with as of 2021. It could be used to investigate what happens to female inventors' performance in California-based firms that appoint female inventor-directors. However, current innovation data do not allow us to check this due to patents' time truncation bias. This will become possible by 2024 when patents data are updated, and hence patents filed in 2022 are incorporated in PatentsView database.

Third, the sample period of the two studies starts from 2000. Although PatentsView coverage of granted patents starts from 1976, the availability and quality of data in BoardEx are limited prior to 2000. Therefore, the analyses start from the year 2000.

Due to the novelty of the inventor-directors' dataset assembled for this thesis, there is a potential for future research to explore the role of these inventor-directors in other firms' decisions. For instance, I could research the role of inventor-directors in Mergers and Acquisitions (M&A). This research could involve investigating whether the presence of inventors in the boardroom helps firms in selecting more innovative targets. In addition, I could examine the level of innovation and their related strategies within the combined firm after the completion of the deal when inventor-directors are part of the board. Furthermore, the likelihood of a merger pair formation could be examined in light of the technological overlap between the inventor-directors' prior/current experience and the target.

Given the importance of directors on firms' decisions and shareholders' wealth, further research could delve into directors' job insecurity. Recent study by Hsu et al. (2023) offers insights into how a plausibly exogenous shock to directors' job security can potentially affect corporate innovation. They utilise the staggered adoption of majority voting legislation in eleven U.S. states, which is expected to heighten directors' job insecurity. They find a negative impact on innovation subsequent to the legislation adoption. This myopic behaviour of firms, prioritising short-term results, could potentially lead to instances of labour and environmental violations by these firms. The Violation Tracker database, covering these violations, compiled by Good Jobs First organisation, could be used to investigate the relation between directors' job insecurity and corporate misconduct.

Bibliography

Acharya, V. V., Baghai, R. P., and Subramanian, K. V. (2014). Wrongful Discharge Laws and Innovation. *Review of Financial Studies*, 27(1):301–346.

Adams, R. B. and Ferreira, D. (2009). Women in the boardroom and their impact on governance and performance. *Journal of Financial Economics*, 94(2):291–309.

Agrawal, A. and Chadha, S. (2005). Corporate governance and accounting scandals. *The Journal of Law and Economics*, 48(2):371–406.

Ahern, K. R. and Dittmar, A. K. (2012). The Changing of the Boards: The Impact on Firm Valuation of Mandated Female Board Representation. *The Quarterly Journal of Economics*, 127(1):137–197.

Aktas, N., Andreou, P. C., Karasamani, I., and Philip, D. (2019). CEO Duality, Agency Costs, and Internal Capital Allocation Efficiency. *British Journal of Management*, 30(2):473–493.

Almeida, H., Hsu, P.-H., and Li, D. (2013). Less is more: Financial constraints and innovative efficiency. *Working Paper, University of Illinois Urbana-Champaign*.

An, H., Chen, C. R., Wu, Q., and Zhang, T. (2021). Corporate Innovation: Do Diverse Boards Help? *Journal of Financial and Quantitative Analysis*, 56(1):155–182.

Arnold, D., Dobbie, W., and Yang, C. S. (2018). Racial Bias in Bail Decisions. *The Quarterly Journal of Economics*, 133(4):1885–1932.

Arrow, K. J. (1962). The Economic Implications of Learning by Doing. *The Review of Economic Studies*, 29(3):155–173.

Atanassov, J. (2013). Do Hostile Takeovers Stifle Innovation? Evidence from Antitakeover Legislation and Corporate Patenting. *The Journal of Finance*, 68(3):1097–1131.

Athey, S., Avery, C., and Zemsky, P. (2000). Mentoring and Diversity. *American Economic Review*, 90(4):765–786.

Bagues, M., Sylos-Labini, M., and Zinovyeva, N. (2017). Does the Gender Composition of Scientific Committees Matter? *American Economic Review*, 107(4):1207–1238.

Balsmeier, B., Fleming, L., and Manso, G. (2017). Independent boards and innovation. *Journal of Financial Economics*, 123(3):536–557.

Becker, G. S. (1971). *The Economics of Discrimination*. University of Chicago Press, Chicago, 2d edition.

Bell, A., Chetty, R., Jaravel, X., Petkova, N., and Reenen, J. V. (2019). Who Becomes an Inventor in America? The Importance of Exposure to Innovation. *The Quarterly Journal of Economics*, 134(2):647–713.

Bell, L. A. (2005). Women-led firms and the gender gap in top executive jobs. *IZA discussion paper*.

Bernile, G., Bhagwat, V., and Yonker, S. (2018). Board diversity, firm risk, and corporate policies. *Journal of Financial Economics*, 127(3):588 – 612.

Bertrand, M., Black, S. E., Jensen, S., and Lleras-Muney, A. (2019). Breaking the Glass Ceiling? The Effect of Board Quotas on Female Labour Market Outcomes in Norway. *The Review of Economic Studies*, 86(1):191–239.

Bhattacharya, U., Hsu, P.-H., Tian, X., and Xu, Y. (2017). What Affects Innovation More: Policy or Policy Uncertainty? *Journal of Financial and Quantitative Analysis*, 52(5):1869–1901.

Bilimoria, D. (2006). The relationship between women corporate directors and women corporate officers. *Journal of Managerial Issues*, pages 47–61.

Bordalo, P., Coffman, K., Gennaioli, N., and Shleifer, A. (2016). Stereotypes. *The Quarterly Journal of Economics*, 131(4):1753–1794.

Bostan, I. and Mian, G. M. (2019). Inventor Chief Executive Officers and Firm Innovation. *International Review of Finance*, 19(2):247–286.

Boyd, B. (1990). Corporate linkages and organizational environment: A test of the resource dependence model. *Strategic Management Journal*, 11(6):419–430.

Bradley, D., Kim, I., and Tian, X. (2017). Do Unions Affect Innovation? *Management Science*, 63(7):2251–2271.

Brant, J., Marathe, K., McDole, J., and Schultz, M. (2019). *Policy Approaches to Close the Intellectual PropertyGender Gap - Practices to Support Access to the Intellectual Property System for Female Innovators, Creators and Entrepreneurs*. World Intellectual Property Organization.

Brav, A., Jiang, W., Ma, S., and Tian, X. (2018). How does hedge fund activism reshape corporate innovation? *Journal of Financial Economics*, 130(2):237–264.

Byun, S., Fuller, K., and Lin, Z. (2021). The costs and benefits associated with inventor CEOs. *Journal of Corporate Finance*, 71:102094.

Cao, C., Li, X., Li, X., Zeng, C., and Zhou, X. (2021). Diversity and inclusion: Evidence from corporate inventors. *Journal of Empirical Finance*, 64:295–316.

Cardoso, A. R. and Winter-Ebmer, R. (2010). Female-Led Firms and Gender Wage Policies. *ILR Review*, 64(1):143–163.

Carpenter, M. A. and Westphal, J. D. (2001). The strategic context of external network ties: Examining the impact of director appointments on board involvement in strategic decision making. *Academy of Management Journal*, 44(4):639–660.

Ceccarelli, M., Herpfer, C., and Ongena, S. (2023). Gender, performance, and promotion in the labor market for commercial bankers. *Working Paper*.

Chang, C.-H. and Wu, Q. (2021). Board Networks and Corporate Innovation. *Management Science*, 67(6):3618–3654.

Chen, J., Leung, W. S., and Evans, K. P. (2018). Female board representation, corporate innovation and firm performance. *Journal of Empirical Finance*, 48:236–254.

Chen, S.-S., Chen, Y.-S., Kang, J.-K., and Peng, S.-C. (2020). Board structure, director expertise, and advisory role of outside directors. *Journal of Financial Economics*, 138(2):483–503.

Cook, L. D., Gerson, J., and Kuan, J. (2022). Closing the Innovation Gap in Pink and Black. *Entrepreneurship and Innovation Policy and the Economy*, 1:43–66.

Cook, L. D. and Yang, Y. (2018). Missing Women and Minorities: Implications for Innovation and Growth. *American Economics Assciation conference presentation*.

Cornell, B. and Welch, I. (1996). Culture, Information, and Screening Discrimination. *Journal of Political Economy*, 104(3):542–571.

Custódio, C., Ferreira, M. A., and Matos, P. (2019). Do General Managerial Skills Spur Innovation? *Management Science*, 65(2):459–476.

Daily, C. M. and Dalton, D. R. (1994). Bankruptcy and Corporate Governance: The Impact of Board Composition and Structure. *Academy of Management Journal*, 37(6):1603–1617.

Dalvit, N., Patel, A., and Tan, J. (2022). Intra-firm hierarchies and gender gaps. *Labour Economics*, 77:102029.

Dalziel, T., Gentry, R. J., and Bowerman, M. (2011). An Integrated Agency-Resource Dependence View of the Influence of Directors' Human and Relational Capital on Firms' R&D Spending. *Journal of Management Studies*, 48(6):1217–1242.

Dass, N., Kini, O., Nanda, V., Onal, B., and Wang, J. (2014). Board Expertise: Do Directors from Related Industries Help Bridge the Information Gap? *Review of Financial Studies*, 27(5):1533–1592.

Dezsö, C. L. and Ross, D. G. (2012). Does female representation in top management improve firm performance? a panel data investigation. *Strategic Management Journal*, 33(9):1072–1089.

Diaz-Garcia, C., Gonzalez-Moreno, A., and Saez-Martinez, F. J. (2013). Gender diversity within R&D teams: Its impact on radicalness of innovation. *Innovation*, 15(2):149–160.

Ding, W. W., Murray, F., and Stuart, T. E. (2006). Gender Differences in Patenting in the Academic Life Sciences. *Science*, 313(5787):665–667.

Drobetz, W., von Meyerinck, F., Oesch, D., and Schmid, M. (2018). Industry expert directors. *Journal of Banking & Finance*, 92:195–215.

Egan, M., Matvos, G., and Seru, A. (2022). When Harry Fired Sally: The Double Standard in Punishing Misconduct. *Journal of Political Economy*, 130(5):1184–1248.

Ellis, J. A., Fee, C. E., and Thomas, S. (2018). Playing Favorites? Industry Expert Directors in Diversified Firms. *Journal of Financial and Quantitative Analysis*, 53(4):1679–1714.

Fahlenbrach, R., Low, A., and Stulz, R. M. (2010). Why do firms appoint CEOs as outside directors? *Journal of Financial Economics*, 97(1):12–32.

Faleye, O., Hoitash, R., and Hoitash, U. (2018). Industry expertise on corporate boards. *Review of Quantitative Finance and Accounting*, 50(2):441–479.

Fan, Y. (2020). Board Diversity of Industry Expertise: Impacts on Investment, R&D, and Product Markets. *Working Paper*.

Fechner, H. and Shapanka, M. S. (2018). Closing Diversity Gaps in Innovation: Gender, Race, and Income Disparities in Patenting and Commercialization of Inventions. *Technology & Innovation*, 19(4):727–734.

Fich, E. M., Nguyen, T., and Petmezas, D. (2023). The effects of terrorist attacks on inventor productivity and mobility. *Research Policy*, 52(1):104655.

Field, L. C. and Mkrtchyan, A. (2017). The effect of director experience on acquisition performance. *Journal of Financial Economics*, 123(3):488–511.

Finkelstein, S. and D'aveni, R. A. (1994). CEO Duality as a Double-Edged Sword: How Boards of Directors Balance Entrenchment Avoidance and Unity of Command. *Academy of Management Journal*, 37(5):1079–1108.

Flabbi, L., Macis, M., Moro, A., and Schivardi, F. (2019). Do Female Executives Make a Difference? The Impact of Female Leadership on Gender Gaps and Firm Performance. *The Economic Journal*, 129(622):2390–2423.

Genin, A., Ma, W., Bhagwat, V., and Bernile, G. (2023). Board experiential diversity and corporate radical innovation. *Strategic Management Journal*.

Gilani, U., Keasey, K., and Vallascas, F. (2021). Board financial expertise and the capital decisions of US banks. *Journal of Corporate Finance*, 71:102091.

Gopalan, R., Gormley, T. A., and Kalda, A. (2021). It's not so bad: Director bankruptcy experience and corporate risk-taking. *Journal of Financial Economics*, 142(1):261–292.

Griffin, D., Li, K., and Xu, T. (2021). Board Gender Diversity and Corporate Innovation: International Evidence. *Journal of Financial and Quantitative Analysis*, 56(1):123–154.

Güner, A. B., Malmendier, U., and Tate, G. (2008). Financial expertise of directors. *Journal of Financial Economics*, 88(2):323–354.

Hall, B. H., Jaffe, A., and Trajtenberg, M. (2005). Market value and patent citations. *RAND Journal of Economics*, pages 16–38.

Hall, B. H., Jaffe, A. B., and Trajtenberg, M. (2001). The NBER patent citation data file: Lessons, insights and methodological tools. *NBER Working paper 8498*.

Haslam, S. A., Ryan, M. K., Kulich, C., Trojanowski, G., and Atkins, C. (2010). Investing with prejudice: The relationship between women's presence on company boards and objective and subjective measures of company performance. *British Journal of Management*, 21(2):484–497.

He, J. J. and Tian, X. (2013). The dark side of analyst coverage: The case of innovation. *Journal of Financial Economics*, 109(3):856–878.

Helmers, C., Patnam, M., and Rau, P. R. (2017). Do board interlocks increase innovation? Evidence from a corporate governance reform in India. *Journal of Banking & Finance*, 80:51–70.

Hill, L. A. and Davis, G. (2017). The board's new innovation imperative. *Harvard Business Review*, 95(6):102–109.

Hillman, A. J. and Dalziel, T. (2003). Boards of Directors and Firm Performance: Integrating Agency and Resource Dependence Perspectives. *Academy of Management Review*, 28(3):383–396.

Hochberg, Y. V., Kakhbod, A., Li, P., and Sachdeva, K. (2023). Inventor Gender and Patent Undercitation: Evidence from Causal Text Estimation. *Working Paper*.

Hsieh, T.-S., Kim, J.-B., Wang, R., and Wang, Z. (2017). Educate to Innovate: Evidence from STEM Directors and Corporate Innovation. *Working Paper*.

Hsieh, T.-S., Kim, J.-B., Wang, R. R., and Wang, Z. (2022). Educate to innovate: STEM directors and corporate innovation. *Journal of Business Research*, 138:229–238.

Hsu, P.-H., Lü, Y., Wu, H., and Xuan, Y. (2023). Director Job Security and Corporate Innovation. *Journal of Financial and Quantitative Analysis*, pages 1–38.

Huang, Q., Jiang, F., Lie, E., and Yang, K. (2014). The role of investment banker directors in M&A. *Journal of Financial Economics*, 112(2):269–286.

Hunt, J., Garant, J.-P., Herman, H., and Munroe, D. J. (2013). Why are women underrepresented amongst patentees? *Research Policy*, 42(4):831–843.

Hwang, S., Shivdasani, A., and Simintzi, E. (2021). Mandating women on boards: Evidence from the United States. *Kenan Institute of Private Enterprise Research Paper No. 18-34*.

Islam, E. and Zein, J. (2020). Inventor CEOs. *Journal of Financial Economics*, 135(2):505–527.

Jensen, K., Kovács, B., and Sorenson, O. (2018). Gender differences in obtaining and maintaining patent rights. *Nature biotechnology*, 36(4):307–309.

Jensen, M. C. and Meckling, W. H. (1976). Theory of the firm: Managerial behavior, agency costs and ownership structure. *Journal of Financial Economics*, 3(4):305–360.

Jia, N. (2017). Should Directors Have Term Limits?–Evidence from Corporate Innovation. *European Accounting Review*, 26(4):755–785.

Jovanovic, B. and Nyarko, Y. (1995). The transfer of human capital. *Journal of Economic Dynamics and Control*, 19(5–7):1033–1064.

Kahler, A. I. (2011). Examining exclusion in woman-inventor patenting: a comparison of educational trends and patent data in the era of computer engineer barbie. *American University Journal of Gender, Social Policy & the Law*, 19:773.

Kang, J.-K., Liu, W.-L., Low, A., and Zhang, L. (2018). Friendly boards and innovation. *Journal of Empirical Finance*, 45:1–25.

Kim, D. and Starks, L. T. (2016). Gender diversity on corporate boards: Do women contribute unique skills? *American Economic Review*, 106(5):267–271.

Knyazeva, A., Knyazeva, D., and Masulis, R. W. (2013). The Supply of Corporate Directors and Board Independence. *Review of Financial Studies*, 26(6):1561–1605.

Kogan, L., Papanikolaou, D., Seru, A., and Stoffman, N. (2017). Technological innovation, resource allocation, and growth. *The Quarterly Journal of Economics*, 132(2):665–712.

Koning, R., Samila, S., and Ferguson, J.-P. (2021). Who do we invent for? patents by women focus more on women's health, but few women get to invent. *Science*, 372(6548):1345–1348.

Kor, Y. Y. and Sundaramurthy, C. (2009). Experience-Based Human Capital and Social Capital of Outside Directors. *Journal of Management*, 35(4):981–1006.

Kunze, A. and Miller, A. R. (2017). Women Helping Women? Evidence from Private Sector Data on Workplace Hierarchies. *The Review of Economics and Statistics*, 99(5):769–775.

Levi, M., Li, K., and Zhang, F. (2014). Director gender and mergers and acquisitions. *Journal of Corporate Finance*, 28:185–200.

Liu, G., Lu, D., and Yang, J. (2023). Innovation for promotion: The effect of executive involvement on inventors' innovation choice. *Journal of Corporate Finance*, 80:102394.

Loughran, T. and Ritter, J. (2004). Why has IPO underpricing changed over time? *Financial Management*, 33(3):5–37.

Lu, J. and Wang, W. (2018). Managerial conservatism, board independence and corporate innovation. *Journal of Corporate Finance*, 48:1–16.

Luong, H., Moshirian, F., Nguyen, L., Tian, X., and Zhang, B. (2017). How Do Foreign Institutional Investors Enhance Firm Innovation? *Journal of Financial and Quantitative Analysis*, 52(4):1449–1490.

Maida, A. and Weber, A. (2022). Female leadership and gender gap within firms: Evidence from an Italian board reform. *ILR Review*, 75(2):488–515.

Manso, G. (2011). Motivating Innovation. *The Journal of Finance*, 66(5):1823–1860.

Matsa, D. A. and Miller, A. R. (2011). Chipping away at the Glass Ceiling: Gender Spillovers in Corporate Leadership. *American Economic Review*, 101(3):635–639.

Matsa, D. A. and Miller, A. R. (2013). A Female Style in Corporate Leadership? Evidence from Quotas. *American Economic Journal: Applied Economics*, 5(3):136–169.

Mazur, J. E. and Hastie, R. (1978). Learning as accumulation: A reexamination of the learning curve. *Psychological Bulletin*, 85(6):1256–1274.

Milli, J., Williams-Baron, E., Berlan, M., Xia, J., and Gault, B. (2016). Equity in innovation: women inventors and patents. *Institute for Women's Policy Research*.

Moretti, E. and Wilson, D. J. (2017). The Effect of State Taxes on the Geographical Location of Top Earners: Evidence from Star Scientists. *American Economic Review*, 107(7):1858–1903.

Mukherjee, A., Singh, M., and Žaldokas, A. (2017). Do corporate taxes hinder innovation? *Journal of Financial Economics*, 124(1):195–221.

Phelps, E. S. (1972). The Statistical Theory of Racism and Sexism. *The American Economic Review*, 62(4):659–661.

Stock, J. and Yogo, M. (2005). *Testing for Weak Instruments in Linear IV Regression*, pages 80–108. Cambridge University Press, New York.

Sugimoto, C. R., Ni, C., West, J. D., and Larivière, V. (2015). The Academic Advantage: Gender Disparities in Patenting. *PLOS ONE*, 10(5):e0128000.

Tate, G. and Yang, L. (2015). Female leadership and gender equity: Evidence from plant closure. *Journal of Financial Economics*, 117(1):77–97.

Theodoropoulos, N., Forth, J., and Bryson, A. (2022). Are Women Doing It for Themselves? Female Managers and the Gender Wage Gap. *Oxford Bulletin of Economics and Statistics*, 84(6):1329–1355.

Tian, X. and Wang, T. Y. (2014). Tolerance for Failure and Corporate Innovation. *Review of Financial Studies*, 27(1):211–255.

Waldman, J. D., Yourstone, S. A., and Smith, H. L. (2003). Learning curves in health care. *Health Care Management Review*, 28(1):41–54.

Wang, C., Xie, F., and Zhu, M. (2015). Industry Expertise of Independent Directors and Board Monitoring. *Journal of Financial and Quantitative Analysis*, 50(5):929–962.

Whitler, K. A., Krause, R., and Lehmann, D. R. (2018). When and how Board Members with Marketing Experience Facilitate Firm Growth. *Journal of Marketing*, 82(5):86–105.

Yang, T. and Zhao, S. (2014). CEO duality and firm performance: Evidence from an exogenous shock to the competitive environment. *Journal of Banking & Finance*, 49:534–552.