

Board industry expertise and innovation input: evidence on the curvilinear relationship and the moderating effect of CEO

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Abstract

Purpose – The study empirically investigates whether the board of directors' expertise in the focal firm's industry has implications for innovation input. Additionally, it explores how this relationship is shaped by the CEO's educational level and background in the technology area.

Design/methodology/approach – The article tests the hypothesized relationships through the Arellano–Bond generalized method of moment estimators, proxying innovation input by R&D to total sales. Moreover, it analyses a sample of privately-held Italian medium and large high-tech companies observed over four years by relying on a unique hand-collected dataset.

Findings – The research documents an inverted U-shaped relationship between board industry expertise and innovation input and shows that such curvilinear effect is moderated by the CEO's educational level and technology background. Specifically, while the curvilinear slope is less steep for highly educated CEO, it becomes steeper in the presence of technology trained CEO.

Practical implications – The paper recommends how to shape the board human capital as a meaningful driver of board effectiveness and innovation. Additionally, it calls the managerial attention towards the interaction and the interplay between board industry expertise and CEO education as able to influence the above-mentioned outcome.

Originality/value – While previous studies have focused on the linear and positive effect of board industry expertise on innovation, this research advances current knowledge in innovation management literature by testing the presence of a curvilinear relationship. Moreover, by exploring the moderating effect of CEO education, the paper provides a comprehensive picture on the interplay among board industry expertise, CEO educational training and innovation input.

Keywords Innovation input, Board of directors, CEO, Industry expertise, Education, U-shaped relationship

Paper type Research paper

1. Introduction

In today's hypercompetitive and changing environments innovation input, meant as the financial resources invested in R&D activities for the exploration and exploitation of new products, technology, system, or technique (Freeman, 1974; Adams *et al.*, 2006; De Massis *et al.*, 2013), has become one of the most important target for companies (Dess and Picken, 2000; Cardinal, 2001; Duran *et al.*, 2016). Indeed, it not only allows to achieve a competitive advantage (Iqbal *et al.*, 2022) but it also fosters the sustainable development in the long-run

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(He and Shen, 2019; Liu *et al.*, 2019; Rejeb *et al.*, 2020; Zhong *et al.*, 2021). Thereby, it is not surprising that scholars have sought to shed light into its drivers (Cumming, 1998).

In this regard, when studying the governance antecedents of such kind of investment, the attitude of the board of directors to contribute to innovation input has widely appeared on the researchers' agenda (Guldiken and Darendeli, 2016; Rejeb *et al.*, 2020; Sarto *et al.*, 2020; Zhong *et al.*, 2021). This circumstance is rooted into the assumption that "it is difficult for firms to develop effective R&D capabilities without effective guidance" like that provided by the board of directors (Dalziel *et al.*, 2011, p. 1218). Indeed, literature enlightens that the effectiveness of board roles is strongly interconnected with company innovation activities, above all in terms of R&D investments (Van Ees *et al.*, 2003; Wu and Wu, 2014; Galia *et al.*, 2015; Abebe and Myint, 2018). According to the agency theory, when supervising managers, the board can stimulate executives to invest in innovation projects to gain long-term outcomes for shareholders (Fama and Jensen, 1983). This is also true according to the resource dependence view. Indeed, following this approach, when providing counsel to top managers, the board can bring strategic advice on strategic projects by prompting the allocation of company resources in innovation investments (Berraies and Rejeb, 2019; Sarto *et al.*, 2020).

Grounding on the above mentioned theoretical frameworks, a number of empirical studies have tried to shed light into the board's structure and composition that could support the fulfillment of its roles and therefore may influence innovation investments. For instance, some articles have investigated the R&D implications of several board demographic characteristics, such as the presence of outside (Kor, 2006) and independent (Guldiken and Darendeli, 2016) directors, the level of interlocking directorship (Han *et al.*, 2015; Helmer *et al.*, 2017) and the board gender diversity (Terjesen *et al.*, 2016; Ain *et al.*, 2021). However, more interesting to our research are studies based on the human capital theory (Becker, 1962) and upper-echelon view (Hambrick and Mason, 1984) that have explored the effects of directors' human capital on innovation input (Vandenbroucke *et al.*, 2016; Sarto *et al.*, 2020; Valenti and Horner, 2020a). Building on the assumption that the board's attitude to perform its governing tasks relies on skills, knowledge and perspectives that directors collectively bring to the board (Hillman and Dalziel, 2003), such studies have recently tested the effect of directors educational level (Dalziel *et al.*, 2011) and professional background in specific functional area (Vandenbroucke *et al.*, 2016; Valenti and Horner, 2020a) on R&D investments, by also catching their combination in terms of heterogeneity (Midavaine *et al.*, 2016; Sarto *et al.*, 2020).

Despite the increasing interest in innovation input by board human capital proponents, to date less attention has been devoted to the role that board industry expertise can play for such outcome. Literature suggests that having previous experiences in the focal firm's industry leads directors to better decision-making (Dass *et al.*, 2014). Indeed, the expertise in a given sector is widely recognized as able to foster the proper interpretation of industry practices and trends as well as the timely identification of opportunities and risks (Wang *et al.*, 2015; Oehmichen *et al.*, 2017). Therefore, it might influence the company functioning, the roles' fulfillment by the firm's governing bodies and the related performance. In line with these conclusions, previous studies have provided empirical evidence on the positive implications of industry expertise for a number of organizational outcomes, namely internationalization (Barroso *et al.*, 2011; Volontè and Gantenbein, 2016), company growth (Kor and Sundaramurthy, 2009) and firm value (Dass *et al.*, 2014; Sundaramurthy *et al.*, 2014).

While there are reasons to believe that board industry expertise can also affect firm innovation input, such implication is still at issue and some gaps need to be addressed.

First of all, the empirical evidence on the effects of board industry expertise is far from conclusive because it has only considered the positive arguments, neglecting the drawbacks of having sector expert directors sitting on the board (Chen, 2014; Dass *et al.*, 2014; Faleye *et al.*, 2018; Valenti and Horner, 2020b). Indeed, literature emphasizes that board industry expertise can be leading determinant of innovation investments because it

improves the directors' ability to properly assess the evolving sector's conditions (Sundaramurthy *et al.*, 2014), encouraging top managers to invest in R&D. In this regard, board members monitor the executives' choices related to such kind of expenditures (Wang *et al.*, 2015; Guldiken and Darendeli, 2016) and advise them on additional R&D projects to pursue (Oehmichen *et al.*, 2017; Faleye *et al.*, 2018). However, from a different standpoint, the board industry expertise can also play as a 'double-edged sword'. Indeed, too much industry expert directors can make the board firmly anchored to the sector norms and lead to the background similarity between board and top managers. Therefore, this circumstance can limit the effectiveness of board roles with negative implications for investments in innovation projects (Faleye *et al.*, 2018). Second, academics have separately investigated the board industry expertise implications for one single board role (monitoring or advising) (Chen, 2014; Guldiken and Darendeli, 2016), while exploring both roles in combination might improve our understanding of the phenomenon. Finally, research has not assessed whether the board industry expertise implications for R&D investments are influenced by additional human capital elements at CEO level. Indeed, it is also possible that such relationship could be shaped by the CEO education, as he/she drives the strategic choices and directions of the top management team (Chen *et al.*, 2013).

With this in mind, drawing upon the board human capital framework, our work intends to address the above-explained research gaps by answering the following research question: *What is the link among board industry expertise, CEO education and innovation input?* To this aim, we empirically analyze a panel of 596 firm-year observations (149 firms \times 4 years) of Italian medium and large high-tech companies and test our hypotheses on innovation input through the Arellano–Bond generalized method of moment (GMM) estimators (Arellano and Bond, 1991).

We focus on privately-held Italian medium and large high-tech companies as an interesting and specific European setting due to its innovation and board human capital peculiarities. Indeed, concerning the related unique innovation features, the firms under investigation are more likely to promote innovative initiatives than their low-tech peers (Agarwal and Audretsch, 2001; Clarysse *et al.*, 2007; Ramella, 2017) and produce a higher level of internal resources able to absorb innovation costs (Damanpour, 2010; Mazzoleni and Giacosa, 2017; Ramella, 2017). With regard to the board human capital features, their value and outcomes are mainly driven by the human capital of all staff involved in the organization as they represent a highly knowledge intensive setting (like healthcare firms) (Vandenbroucke *et al.*, 2016; Valenti and Horner, 2020a). Such effect is especially pronounced in Italy, where existing laws have encouraged to improve the level of expertise of high-tech organizations' top management teams (Sarto *et al.*, 2020).

Our evidence shows an inverted U-shaped (concave) relationship between the industry expertise of board members and innovation input. In particular, innovation input improves up to a certain level of board industry expertise, whereas after a given threshold, this human capital specification limits the outcome under examination. In addition, the analyses highlight that such curvilinear effect is moderated by the presence of a CEO characterized by advanced level of education and technology background. More specifically, while a better educated CEO makes the curvilinear slope less steep, a technology trained CEO turns the slope to be steeper.

Thereby, our paper advances the literature on innovation management and contributes to the debate on the governance antecedents of innovation input. Indeed, it fills a gap in the research and improves our understanding of the link between board sector expertise and R&D by documenting the presence of an inverted U-shaped relationship. In doing so, the article also provides a theoretical advancement of previous studies as it interprets the above mentioned relationship by combining the agency and resource dependence views, and suggesting that innovation input is the outcome of the effective fulfillment of both board

monitoring and resource provision roles. From a different standpoint, the paper advances the debate on board capital. Indeed, it extends prior empirical evidence on the performance implications of board industry expertise that is still scarce for what concerns the innovation side of firm performance. At the same time, the article contributes to the research on the CEO-board interface by exploring how the CEO education (in terms of level and background) shapes the relationship between directors' expertise and innovation input.

The remaining of the paper is structured as follows. We first present the theoretical development and the hypotheses formulation. Later, we offer an overview of the methodological approach. Then, we present the research findings. Lastly, we discuss our results and provide the conclusions by illustrating the study's limits and future lines of enquiry.

2. Theoretical development and hypothesis formulation

2.1 *The board of directors: theories, roles and implications for innovation*

The board of directors is a meaningful driver of firm innovation (De Massis *et al.*, 2013; Cirillo *et al.*, 2019; Saggese *et al.*, 2021) with respect to both its monitoring and resource provision roles.

The monitoring role (also called control role) grounds on the agency theory suggesting that the board of directors plays as primary governance mechanism to address the issue of separation between ownership and control (Jensen and Meckling, 1976; Eisenhardt, 1989; Pugliese *et al.*, 2009). In this vein, by painting the board-CEO/top managers dynamics and relationships in an adversarial manner, agency studies posit that the main board's fiduciary duty to shareholders is to protect their interests and prevent the managerial opportunistic behavior (Jensen and Meckling, 1976). As a result, the board control task encompasses the monitoring of CEO and top managers' activities (e.g. budgets definition, strategy implementation and operational decisions) (Rindova, 1999) as well as the settlement of their compensation and evaluation rewarding (Conyon and Peck, 1998). Therefore, this role has also implications for innovation. Indeed, when monitoring managers in the initiation and organization of innovation projects (Wu and Wu, 2014; Galia *et al.*, 2015; Abebe and Myint, 2018; Berraies and Rejeb, 2019), board limits the agency costs and stimulates executives to invest in risky innovation initiatives as they are beneficial to increase the shareholders' value in the long run (Fama and Jensen, 1983; Wu and Wu, 2014).

Differently, the resource provision role relies on the resource dependence theory (Pfeffer and Salancik, 1978; Hillman *et al.*, 2000) positing that a company appoints a director to the board as "it expects the individual will come to support the organization, will concern himself with its problems, will variably present it to others, and will try to aid it" (Pfeffer and Salancik, 1978, p. 163). In this regard, studies grounded on the resource dependence view interpret the board-CEO/top manager dynamics in a more collaborative manner (Boyd *et al.*, 2011) by suggesting that the board's primary role is providing the firm with access to key resources (e.g. human, physical and social capital) (Nicholson and Newton, 2010). In particular, the board task encompasses the provision of a network of ties, communication channels and contacts with the external environment that helps to build the company reputation (Pfeffer and Salancik, 1978; Zahra and Pearce, 1989). Additionally, it consists of giving advice and counsel to CEO and top managers, not only supporting them in the operational decision-making but also helping them to address critical strategic issues and proposing strategic alternatives (Zahra *et al.*, 2000; Finkelstein and Mooney, 2003; Fiegenger, 2005; Brauer and Schmidt, 2008). In this vein, as far as innovation is concerned, when performing the resource provision role and giving counsel to top managers in setting strategic priorities, directors bring advice on innovation projects and prompt the implementation of novel business models, as well as the allocation of financial resources in innovation investments (Shapiro *et al.*, 2015; Abebe and Myint, 2018; Berraies and Rejeb, 2019).

When drawing the attention to the antecedents of the effective fulfillment of such roles and the related effects on firm innovation, a well-rooted assumption in the literature suggests that the implication of the board of directors for company innovation can depend on the board human capital because it can influence the fulfillment of board tasks and the decision-making process (Hillman and Dalziel, 2003; Dalziel *et al.*, 2011).

Indeed, while some scholars highlight that the board of directors tends to alternatively perform the above mentioned roles according to their classic composition measures (e.g. directors' independence, board committees and CEO power in terms of duality and tenure) (Johnson *et al.*, 1996; Dalton *et al.*, 1998), board capital proponents consider the combination of both theories and emphasize that the board of directors could effectively and simultaneously fulfill the monitoring and resource provision tasks and this ability depends on the related human capital (i.e. directors' skills, knowledge and perspectives) (Hillman and Dalziel, 2003; Nicholson and Kiel, 2004; Minichilli *et al.*, 2012; Chen, 2014; Pérez-Calero *et al.*, 2016). This is also true according to the behavioral approach (Cyert and March, 1963) as the fulfillment of all governing tasks is mainly influenced by the board decision-making process which in turn is affected by the directors' competences, knowledge and skills (Finkelstein and Hambrick, 1996; Sarto *et al.*, 2020).

Thereby, thanks to their human capital, directors can supply the company with critical resources, knowledge and expertise that are essential not only for the fulfillment of board tasks, but also for company innovation (Pfeffer and Salancik, 1978; Hillman and Dalziel, 2003; Ashwin *et al.*, 2016). With this in mind, the following sections aim to explore the influence of one dimension of board human capital (i.e. board industry expertise) on the firm's commitment to innovation (i.e. innovation input) and investigate the moderating implications of CEO education.

2.2 The relationship between board industry expertise and innovation input

The board human capital taxonomy embraces two main forms. The general one encompasses the set of knowledge, skills and abilities that directors collectively provide to the board thanks to their educational level (e.g. PhD, MBA) or the education awarded by high-profile universities (Bond *et al.*, 2010; Barroso *et al.*, 2011; Arena *et al.*, 2015; Kirkpatrick *et al.*, 2017; Sarto *et al.*, 2020). Differently, the specific one consists of previous expertise and experiences developed in certain industry, firm and functions (Barroso *et al.*, 2011; Ganotakis, 2012; Sundaramurthy *et al.*, 2014; Volonté and Gantenbein, 2016).

In this regard, the industry expertise, meant as the previous experience that directors develop in the sector of the focal firm, is one of the most important elements among board human capital dimensions (Oehmichen *et al.*, 2017). Literature suggests that such qualification helps directors to interpret the current dynamics and evolving conditions of the sector (Sundaramurthy *et al.*, 2014; Oehmichen *et al.*, 2017), and therefore allows the proper identification of industry opportunities, trends, and existing competitive threats (Zahra and Pearce, 1990; Bailey and Helfat, 2003; Kor, 2003). It can offer potential information channels arising from the links with other key players in the sector and can provide useful input to the board decision-making (Faleye *et al.*, 2018). As a result, the directors' industry expertise affects board tasks with positive implications for innovation (Kor and Misangyi, 2008; Balsmeier *et al.*, 2014; Dass *et al.*, 2014).

From an agency perspective, research suggests that the directors' previous industry experience improves the board monitoring task and supports the timely identification of both opportunities and risks embedded in the sector (Wang *et al.*, 2015). In this regard, when supervising managerial activities, board industry experts encourage top managers to invest in innovation by increasing their willingness to do so. Indeed, executives tend to be reluctant to R&D as they deem such initiatives too risky for the firm and their employment

(Baysinger *et al.*, 1991), and not worth to account from a financial information standpoint (Lee and O'neill, 2003). However, the presence of board members with industry expertise supports the identification of innovation input advantages and alleviate the managerial risk aversion and myopia in R&D investments (Kothari *et al.*, 2002; Guldiken and Darendeli, 2016). For instance, thanks to their previous experiences in the sector of the focal firm, industry expert directors can better appreciate the characteristics of innovation opportunities that are peculiar to the industry, especially in relation to cost requirements and payoff patterns, thus allowing greater resilience to early failures and losses (Manso, 2011). Aside the monitoring task, the resource provision role, in terms of strategic advice and innovation investment decision, can be also supported by directors with industry knowledge. Indeed, grounding on the resource dependence view, prior expertise in the firm's sector helps directors to effectively questioning strategic proposals and giving advice to managers (Carter and Lorsch, 2003; Chen, 2014). In this regard, by knowing how the organizations of a given sector can take advantage of innovation, industry expert directors can support executives in the proper identification of such kind of investment, and can also recommend additional promising R&D options to pursue (Guldiken and Darendeli, 2016).

Building on these arguments, some studies provide empirical evidence that directors with industry expertise positively affect company innovation in terms of R&D investments (Chen, 2014; Dass *et al.*, 2014; Faleye *et al.*, 2018; Valenti and Horner, 2020b).

Despite such evidence, there are a number of reasons to assume that board expertise after a given threshold can have negative implications for firm innovation because it can hamper the board effectiveness. Indeed, concerning the resource provision role, when directors strategically advise top managers, too much industry expertise can limit the board's skills to identify and propose innovation opportunities as directors tend to be too firmly anchored to sector norms and rules (Faleye *et al.*, 2018). At the same time, too much industry experts on board can increase the background similarity. As a result, it can foster the interpersonal attraction between directors and top managers, producing biases in terms of board monitoring decisions (Westphal and Zajac, 1995) and innovation investments limitations. It is worth noting that such homogeneity can also hamper the board decision-making from a different angle. The rationale is that the background similarity leads to an information overload and limits the heterogeneity of the information pool available, thus reducing the decision comprehensiveness, as well as hampering the evaluation of company innovation options and opportunities (Finkelstein and Hambrick, 1996; Gradstein and Justman, 2000; Brodbeck *et al.*, 2007; Midavaine *et al.*, 2016). Furthermore, the similarity of directors' individual cognitive schema can limit the fruitful debate among the involved parties and may hinder the exchange of different viewpoints, improving narrow-mindedness, constraining the board problem-solving attitude and diverting the attention of decision makers from critical innovation problems (Ocasio, 1997; Cannella *et al.*, 2008). As a result, the likeness of board members in respect of industry expertise might lead to suboptimal decisions, and therefore could limit the firm commitment to innovation investments (Amason, 1996; Hillman *et al.*, 2002).

Drawing upon the preceding arguments, we might expect that there is a curvilinear relationship between board industry expertise and innovation input, such that it first increases and then decreases as board industry expertise enhances. Hence, we hypothesize that:

- H1. There is an inverted U-shaped relationship between board industry expertise and innovation input.

2.3 The moderating role of CEO education

Literature enlightens that the implications of corporate teams (e.g. top management teams) can be influenced by their leader's behavior (e.g. CEO) (Hambrick, 1995). In this regard, research suggests that the effective fulfillment of both board monitoring and resource provision roles to top executives is influenced by CEO characteristics (Georgakakis *et al.*, 2019). For instance, Jizi and Nehme (2018) report that the CEO duality affects the relationship between board independence and audit fee, leading to the conclusion that the CEO influences how the board control role is effective. Focusing on the resource provision role, Haynes and Hillman (2010) document that the CEO power moderates the relationship between board members' human capital and firm strategic change.

As far as innovation is concerned, previous research suggests that the CEO is up to the task of prompting the top management's choices as he/she represents the highest decision maker of company regular and strategic activities (Chen, 2013). For instance, when the board monitors the top management team in relation to R&D investments, if the CEO disapproves the innovation team effort, he/she can obstruct the board path to R&D investments (Westphal and Fredrickson, 2001). At the same time, when the board advises top managers on innovation matters, the CEO is able to make the board and top management's debate around innovation as systematic, driving the discussion and allowing the exchange of innovative ideas (Jaw and Lin, 2009; Tharnpas and Boon-itt, 2018; Sarto *et al.*, 2020).

Building on this, there are reasons to believe that the CEO characteristics, especially in terms of education (level and area), could play a pivotal role for the above-explained relationship between board industry expertise and innovation input. Indeed, literature claims that the CEO background and education are relevant to his/her receptivity to innovative ideas and activities (Lin *et al.*, 2011).

Focusing on the literature on CEO educational level, with some exceptions (e.g. Daellenbach *et al.*, 1999), most studies document that highly educated CEOs are more likely to lead innovative companies (Thomas *et al.*, 1991; Barker and Mueller, 2002). Specifically, the empirical evidence documents that CEOs with advanced science degrees are more willing to take risky choices and are more opened to innovative business ideas, increasing the efforts towards innovation in terms of new/improved products and patents (Camelo-Ordaz *et al.*, 2009) as well as R&D intensity (Barker and Mueller, 2002; Chen *et al.*, 2010; Lin *et al.*, 2011).

The reasons behind such results mainly rest on the assumption that better educated top managers are considered more intelligent and able to infer abstract principles from specific situations (Kor and Sundaramurthy, 2009; Dalziel *et al.*, 2011). Additionally, as they own sophisticated learning and knowledge structures, they can effectively interpret and group complex information (Carpenter and Westphal, 2001; Liu *et al.*, 2019), address challenging issues and make faster decisions (Wally and Baum, 1994; Barroso *et al.*, 2011). In addition, their high level of education makes CEOs particularly curious and receptive to fresh views and innovation advancements (Thomas *et al.*, 1991).

The positive implications of highly qualified CEOs could also occur when the board performs the monitoring task and gives the top management team advice on innovative investments (Reguera-Alvarado and Bravo, 2018; Sarto *et al.*, 2020). Indeed, CEOs with knowledge and skills mastered through high educational training can support boards in properly managing risks, solving complex issues and choosing innovative options (Hambrick and Mason, 1984; Barroso *et al.*, 2011; Arena *et al.*, 2015). In this vein, thanks to their structured skills, CEOs can effectively interpret and group complex information during the board discussion (Carpenter and Westphal, 2001; Liu *et al.*, 2019) and address challenging matters (Wincent *et al.*, 2010; Barroso *et al.*, 2011). This is especially true when the board monitors and gives advices on strategic issues that require long-term awareness and overall situational awareness (McDonald *et al.*, 2008).

Notwithstanding these conclusions, the high level of education may be not beneficial for innovation investments and, in many cases, could raise problems. Indeed, research documents that owning advanced educational qualifications might encourage more efficient and cost effective practices, leading to less innovative investments and hampering the level of R&D expenditures (Dalziel *et al.*, 2011; Allemand *et al.*, 2017). From a different standpoint, having a high academic degree can improve the CEO prestige (Haynes *et al.*, 2019) and produce emotional and cognitive conflicts that negatively affect both board decisions' quality and outcomes (Arena *et al.*, 2015). As a result, better educated CEOs can hamper the board problem-solving attitude because they might impose their viewpoints (Simons and Peterson, 2000; Petrovic, 2008; Arena *et al.*, 2015) to directors, with negative implications for firm innovation.

Taking together, these arguments allow to predict that CEOs with advanced degree of education could influence the relationship between board industry expertise and company innovation input. Hence, we conjecture that:

H2. The presence of CEO with high level of education moderates the inverted U-shaped relationship between board industry expertise and innovation input.

Besides the advanced level, also the CEOs' educational area can affect the board-innovation relationship because it influences the way in which top managers face corporate issues and drive the company decision-making (Hambrick and Mason, 1984; Roach and Sauermann, 2010; Sarto *et al.*, 2020). This circumstance is rooted in the assumption that the top managers' educational field shapes their knowledge (Becker, 1962), open mindedness and risk taking propensity, with implications for strategic orientation and company outcomes (Hambrick and Mason, 1984; Hitt and Tyler, 1991). In their efforts to grab how such background characteristics can influence managerial decisions and company performance, scholars suggest that the CEO's training in specific business areas plays a pivotal role in producing skills useful to gain competitive advantages (Daellenbach *et al.*, 1999). Indeed, it provides CEOs with expertise and competence able to prompt knowledge exploration and changes (da Mota Pedrosa *et al.*, 2013).

Grounding on these premises, literature offers many insights about the influence of managerial training and expertise in specific business areas on company innovation. Some studies highlight that CEOs with a training in the engineering and innovation area improve R&D investments because they own useful information and skills to properly exploit such outcome (Barker and Mueller, 2002; Dass *et al.*, 2014; Faleye *et al.*, 2018). Other research shows that CEOs characterized by degrees and training in scientific and technical fields encourage innovation investments (Datta and Guthrie, 1994; Tyler and Steensma, 1998; Barker and Mueller, 2002). In a similar vein, CEOs with technical education improve company innovation (Rothwell, 1977; Thong and Yap, 1995; Kitchell, 1997) as their specific knowledge fosters the identification and selection of innovation opportunities (Tyler and Steensma, 1998; Hambrick, 2007; Ahn *et al.*, 2017).

This reasoning suggests that such effects could also influence the interaction among CEO, top management team and board of directors, as the educational training in the technology area affects how CEOs interpret information and drive top managers' innovation decisions (Roach and Sauermann, 2010; Sarto *et al.*, 2020). Indeed, technology literate CEOs can make innovation investments more sizable for top managers. Therefore, the latter can benefit from the CEOs' information processing skills, technical knowledge, know-how and open-mindedness needed to properly address complex problems and manage the underlying risk of innovation initiatives (Qiu and Yu, 2021). As a result, CEOs with a technology training can influence the board industry experts' ability to perform the monitoring and advising tasks with implications for innovation input. Hence, drawing upon these arguments, we conjecture that:

H3. The presence of CEO with a technology educational background moderates the inverted U-shaped relationship between board industry expertise and innovation input.

3. Method

3.1 Setting and sample

Our analyses focus on privately-held Italian medium and large high-tech companies. This represents an interesting and specific European setting to explore our research question due to its innovation and board human capital peculiarities. Indeed, such firms are research-intensive organizations strongly involved in the extensive introduction of innovations (Ramella, 2017). In this vein, Italian high-tech firms present high risk of survival (Agarwal and Audretsch, 2001) and serious obsolescence problems, and therefore have stronger incentives than their low-tech peers to promote innovative initiatives (Clarysse *et al.*, 2007). Additionally, Italian medium and large high-tech firms are more likely than smaller companies to invest in innovation because they produce more internal resources and present scope economies able to absorb innovation costs and funding availability needed for innovative investments (Damanpour, 2010; Mazzoleni and Giacosa, 2017; Ramella, 2017). At the same time, differently from high-tech companies in other European countries, Italian firms tend to invest more in innovation input than output due to the presence of low patenting intensity, standing at around two-thirds of the European average (Ramella, 2017). As far as the board human capital is concerned, similarly to other highly knowledge intensive settings (like healthcare firms), the value and outcomes of firms belonging to our sample mainly depend on the human capital of their staff, not only at lower level but also at the top floor of decision-making (i.e. board of directors) (Vandenbroucke *et al.*, 2016; Valenti and Horner, 2020a). Such peculiarity is especially pronounced in Italy where existing laws (e.g. Italian Law Decree n. 179, 2012) have encouraged to foster the level of expertise of their Italian high-tech top management teams (Sarto *et al.*, 2020) and have identified the managers' educational qualification as one of the main prerequisites for starting up innovative companies. At the same time, from a different standpoint, we investigate private companies because they have received limited attention in the governance literature due to the lack of a single database providing all secondary data needed to conduct research on board human capital.

To exploit the features of this setting, we explore a sample of 149 companies observed between 2012 and 2015. We focus on this time-frame to avoid any potential bias that might be induced by the Legislative Decree 139/2015 that has changed the accounting rules for the recognition in the financial statement from 2016. To construct our sample, on the basis of the OECD's (2005) definition, we first extract from the AIDA database (Bureau Van Dijk) all private Italian firms with more than 50 workers in 2012 (i.e. 11,019). Later, following prior literature (Gharbi *et al.*, 2014), we distinguish companies in information technology, electrical and electronic equipment, and telecommunications industries as belonging to the high-tech setting. This strategy leads to select 349 companies. Then, we drop firms with incomplete data for the entire time frame, leading to a final sample of 149 companies (596 observations in total).

3.2 Data and variables

To collect the needed information on innovation, governance and organizational features of the firms under investigation, we first obtain data from the AIDA database (Bureau van Dijk). At the same time, to further improve the accuracy of the gathered information on board industry expertise and CEO education, we hand-collect additional details from the personal CVs of board members and CEOs belonging to each company in our sample. Specifically, we

perform a thorough search and manually navigation on the firms' official websites and their social/professional networks accounts (i.e. LinkedIn, Twitter, Facebook).

As far as the variables employed in our econometric models, the dependent one is innovation input (*INNO_INPUT*) as proxied by the ratio of R&D expenditure to total sales, in line with prior studies (Chen and Hsu, 2009; Cirillo *et al.*, 2019). As our observation window covers the period 2012–2015, we choose this measure based on the assumption that it is not affected by the recognition rules introduced from 2016 by the Legislative Decree 139/2015.

Regarding the explanatory variable, to test H1, we operationalize the board industry expertise (*BD_IND_EXPERT*) as the numerosness of non-executive board members that, irrespective of their position as dependent or independent directors, present previous professional experience in the high-tech industry (Oehmichen *et al.*, 2017).

Lastly, concerning the moderator variables, to test H2, we focus on the level of CEO education, and proxy the related educational degree (*CEO_EDU*) by a dummy variable with a value of 1 if the CEO has an academic qualification higher than the bachelor degree (i.e. Msc, master and/or PhD) (Lin *et al.*, 2011). Moreover, to test H3, we focus on the educational area that the CEO of each company in our sample has obtained thanks to the related school and academic training, and use a binary indicator (*CEO_TECH_EDU_BACK*) with a value of 1 for firms whose CEO present an educational background in the following technology areas: engineering, informatics, mathematics (Mun *et al.*, 2020).

As shown in Table 1, to strengthen the confidence of our analyses, we control for a set of variables suggested by prior literature. Therefore, in our regression models we include: (1) the number of independent directors (*IND_DIR*) because they can improve the effectiveness of the board's monitoring role, with positive implications for company outcomes (Merendino and Melville, 2019); (2) the CEO power as proxied by the CEO-duality (*CEO_PW_DUAL*) because it can affect the ability of CEO to sway the direction of firm's strategic decisions towards innovation investments (Haynes and Hillman, 2010; Vandenbroucke *et al.*, 2016); (3) the number of directors that simultaneously sit on the board of another firm (i.e. interlocked directors) (*INTRL*) because they increase the fulfillment of the resource provision role by fostering the board's ability to obtain information and improve its strategic knowledge, with positive effects on firm innovation (Helmerts *et al.*, 2017); (4) the board size (*BRD_SIZE*) because larger boards can limit corporate performance due to greater levels of conflict and lower group cohesion (Merendino and Melville, 2019); (5) the firm leverage (*LEV*) (Sarto *et al.*, 2020) as the company initiatives and investments can be influenced by the company's financing support (Barker and Mueller, 2002); (6) the company age (*AGE*) and (7) the firm size (*FRM_SIZE*) (Zona *et al.*, 2013) because younger and smaller firms tend to present slacker resources and are more vulnerable than older and larger ones, with negative implications for company outcomes.

3.3 Empirical approach

Following prior literature, the empirical approach is based on the Arellano–Bond (Arellano and Bond, 1991) GMM estimators to avoid potential endogeneity issues and biases due to weak instruments (Roodman, 2009; Guldiken and Darendeli, 2016). In applying such methodology, all explanatory variables are treated as endogenous, except year dummies as they were considered exogenous. At the same time, we use as instruments both the endogenous variables and year-dummies in order to control for any contemporaneous effect (Guldiken and Darendeli, 2016). We also run GMM post-estimation tests to check for autocorrelation as well as over-identification issues, and we find that the empirical models are appropriate. Finally, in line with prior literature, we test the curvilinear relationship to identify the turning points of the squared term (Lind and Mehlum, 2010; Guldiken and Darendeli, 2016).

Variables	Description	Sources	Min	Mean	Max	Sd	Board industry expertise and innovation input
<i>INNO_INPUT</i>	Ratio of R&D expenditure to total sales	Bureau van Dijk	0.000	0.008	0.288	0.033	
<i>BD_IND_EXPERT</i>	Number of non-executive board members that, irrespective of their position as dependent or independent directors, had previous professional experience in the high-tech industry	Hand-collection	0.000	3.470	17.000	3.366	
<i>CEO_EDU</i>	Dummy variable with a value of 1 if the CEO had an academic qualification higher than the bachelor's degree (i.e. Msc, master and/or PhD)	Hand-collection	0.000	0.181	1.000	0.386	
<i>CEO_TECH_EDU_BACK</i>	Dummy variable with a value of 1 if the CEO had an educational background in the following technology areas: Engineering, informatics, mathematics	Hand-collection	0.000	0.109	1.000	0.312	
<i>IND_DIR</i>	Number of independent directors	Hand-collection	0.000	0.631	11.000	1.717	
<i>CEO_PW_DUAL</i>	Dummy variable assuming value of 1 if the CEO was chairman	Hand-collection	0.000	0.416	1.000	0.493	
<i>INTRL</i>	Number of interlocked directors on board	Hand-collection	1.000	3.369	16.000	2.740	
<i>BRD_SIZE</i>	Natural logarithm of total number of directors	Bureau van Dijk	0.000	2.372	3.401	0.712	
<i>LEV</i>	Total debt divided by total assets	Bureau van Dijk	0.000	0.738	10.130	1.389	
<i>AGE</i>	Number of years since firm foundation	Bureau van Dijk	3.000	21.879	65.000	10.715	
<i>FRM_SIZE</i>	Natural logarithm of total assets	Bureau van Dijk	0.741	3.469	6.794	0.990	

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Table 1.
Variables definition and descriptives

Hence, building on the above mentioned approaches, we empirically test **H1** through the following econometric model:

$$\begin{aligned}
 INNO_INPUT_i = & \beta_0 + \beta_1 * BD_IND_EXPERT_i + \beta_2 * BD_IND_EXPERT_i^2 \\
 & + \beta_3 * IND_DIR_i + \beta_4 * CEO_PW_DUAL_i + \beta_5 * INTRL_i \\
 & + \beta_6 * BRD_SIZE_i + \beta_7 * LEV_i + \beta_8 * AGE_i + \beta_9 * FRM_SIZE_i \\
 & + \beta_{10} * year_i + \beta_{11} * firm_i + \varepsilon_i
 \end{aligned}$$

At the same time, to empirically test **H2** and **H3**, we extend this model by including the interaction terms between the moderators (*CEO_EDU* and *CEO_TECH_EDU_BACK*) and *BD_IND_EXPERT* and *BD_IND_EXPERT*², as follows.

In particular, to test H2:

$$\begin{aligned} INNO_INPUT_i = & \beta_0 + \beta_1 * BD_IND_EXPERT_i + \beta_2 * BD_IND_EXPERT_i^2 \\ & + \beta_3 * CEO_EDU_i + \beta_4 * CEO_EDU_i * BD_IND_EXPERT_i \\ & + \beta_5 * CEO_EDU_i * BD_IND_EXPERT_i^2 + \beta_6 * IND_DIR_i \\ & + \beta_7 * CEO_PW_DUAL_i + \beta_8 * INTRL_i + \beta_9 * BRD_SIZE_i + \beta_{10} * LEV_i \\ & + \beta_{11} * AGE_i + \beta_{12} * FRM_SIZE_i + \beta_{13} * year_i + \beta_{14} * firm_i + \varepsilon_i \end{aligned}$$

Finally, to test H3:

$$\begin{aligned} INNO_INPUT_i = & \beta_0 + \beta_1 * BD_IND_EXPERT_i + \beta_2 * BD_IND_EXPERT_i^2 \\ & + \beta_3 * CEO_TECH_EDU_BACK_i \\ & + \beta_4 * CEO_TECH_EDU_BACK_i * BD_IND_EXPERT_i \\ & + \beta_5 * CEO_TECH_EDU_BACK_i * BD_IND_EXPERT_i^2 \\ & + \beta_6 * IND_DIR_i + \beta_7 * CEO_PW_DUAL_i + \beta_8 * INTRL_i \\ & + \beta_9 * BRD_SIZE_i + \beta_{10} * LEV_i + \beta_{11} * AGE_i + \beta_{12} * FRM_SIZE_i \\ & + \beta_{13} * year_i + \beta_{14} * firm_i + \varepsilon_i \end{aligned}$$

4. Results

4.1 Descriptives and correlations

The descriptives in Table 1 document that, in our sample, the mean value of R&D spending to total sales (*INNO_INPUT*) is 0.008 and the average number of directors that hold an industry expertise (*BD_IND_EXPERT*) is 3.47. Moreover, while CEOs with high level of education (*CEO_EDU*) are about 18.1%, CEOs with a technology educational background (*CEO_TECH_EDU_BACK*) occur in 10.9% of firms in our sample.

Table 2 reports the Pearson bivariate correlations of the variables in our regression models and documents that there are not multicollinearity concerns. Indeed, multicollinearity occurs if the pairwise correlation coefficients between two regressors are in excess of 0.75 (Mertens *et al.*, 2017). As shown in the matrix, the coefficients for each explanatory variable in the regression models range from -0.229 to 0.617. Therefore, these values are below the threshold and suggest that there are not serious correlation problems among our regressors. Table 2 also reports the results of variance inflation factor (VIF) tests for all models that we run to additionally check for multicollinearity problems. The VIF of our variables are lower than 2.00, suggesting the lack of any multicollinearity issues (i.e. VIF >10) (Mertens *et al.*, 2017).

4.2 Regressions

Table 3 shows the results of the estimates obtained by the GMM approach described above. Specifically: Model (0) only includes basic control variables; Models (1), (2) and (3) respectively report the results of H1, H2 and H3.

Turning to Model (1), the analysis documents that the proxy for board industry expertise (*BD_IND_EXPERT*) and its squared term (*BD_IND_EXPERT²*) are both significantly

Variable	VIF	1	2	3	4	5	6	7	8	9	10	11
<i>INNO_INPUT</i>		1.000										
<i>BD_IND_EXPERT</i>	1.68	0.023	1.000									
<i>CEO_EDU</i>	1.12	-0.087**	0.053	1.000								
<i>CEO_TECH_EDU_BACK</i>	1.08	0.110**	-0.054	-0.166***	1.000							
<i>IND_DIR</i>	1.26	0.047	0.335***	-0.051	0.010	1.000						
<i>CEO_PW_DUAL</i>	1.10	0.093**	-0.041	-0.008	0.011	0.015	1.000					
<i>INTRL</i>	1.19	-0.048	0.077*	-0.114***	-0.124***	-0.014	0.075*	1.000				
<i>BRD_SIZE</i>	2.00	0.022	0.617***	0.059	-0.125***	0.367***	-0.186***	0.224***	1.000			
<i>LEV</i>	1.16	0.126***	-0.182***	-0.174***	-0.038	-0.086**	0.152***	-0.136***	-0.229***	1.000		
<i>AGE</i>	1.08	-0.021	-0.017	0.118***	0.062	0.041	-0.038	-0.205***	-0.056	-0.072***	1.000	
<i>FRM_SIZE</i>	1.29	-0.092**	0.328***	0.099**	-0.084**	0.300***	-0.122***	-0.006	0.391***	-0.182***	0.120***	1.000

Note(s): *, **, and *** denote significance at the 10, 5 and 1% levels, respectively

Table 2.
Correlations

Table 3.
GMM regression
results testing H1,
H2, H3

Variables	Model 0	Model 1	Model 2	Model 3
<i>BD_IND_EXPERT</i>		0.471*** (0.110)	0.373*** (0.119)	0.395*** (0.122)
<i>BD_IND_EXPERT</i> ²		-0.038*** (0.008)	-0.031*** (0.009)	-0.029*** (0.008)
<i>CEO_EDU</i>			-6.409*** (2.461)	
<i>CEO_EDU*BD_IND_EXPERT</i>			1.896** (0.872)	
<i>CEO_EDU*BD_IND_EXPERT</i> ²			-0.145** (0.067)	
<i>CEO_TECH_EDU_BACK</i>				-0.613 (1.423)
<i>CEO_TECH_EDU_BACK*BD_IND_EXPERT</i>				1.223* (0.632)
<i>CEO_TECH_EDU_BACK*BD_IND_EXPERT</i> ²				-0.177** (0.071)
<i>IND_DIR</i>	0.087** (0.039)	0.107*** (0.038)	0.091** (0.038)	0.089* (0.048)
<i>CEO_PW_DUAL</i>	0.657 (0.408)	0.693* (0.389)	0.699* (0.402)	0.706* (0.365)
<i>INTRL</i>	-0.112 (0.072)	-0.114* (0.064)	-0.120* (0.062)	-0.085 (0.067)
<i>BRD_SIZE</i>	0.654* (0.333)	0.369 (0.258)	0.437* (0.249)	0.415 (0.312)
<i>LEV</i>	0.176*** (0.055)	0.189*** (0.051)	0.155*** (0.053)	0.222*** (0.058)
<i>AGE</i>	-0.009 (0.019)	-0.002 (0.020)	-0.002 (0.021)	-0.008 (0.022)
<i>FRM_SIZE</i>	-0.511*** (0.121)	-0.448*** (0.120)	-0.459*** (0.119)	-0.348*** (0.137)
<i>YEAR DUMMY</i>	YES	YES	YES	YES
<i>FIRM DUMMY</i>	YES	YES	YES	YES
<i>OBSERVATIONS</i>	596	596	596	596
<i>AR(2) p value</i>	-	0.310	0.442	0.422
<i>SARGAN p value</i>	-	0.000	0.000	0.000

Note(s): *, ** and *** denote significance at the 10, 5 and 1% levels, respectively. Robust Standard errors in brackets

related to innovation input from a statistical standpoint. In detail, while the coefficient for board industry expertise is positive ($\beta = 0.471, p < 0.01$), the squared term presents a negative sign ($\beta = -0.038, p < 0.01$). These findings show a curvilinear relationship (inverse U-shaped) between the level of board industry expertise and innovation input, providing support for H1. To further test the curvilinear relationship and identify the turning point of the curve where the relationship from positive becomes negative, we also perform the *utest* (Lind and Mehlum, 2010). The findings confirm the existence of a U-shaped relationship and document that the turning point is equal to 7.33. This suggests that, when the board has a number of members with industry expertise higher than such value, the positive effect becomes negative.

Turning the attention to the moderating effect of CEO education on the relationships between board industry expertise and innovation input, Models (2) and (3) in Table 3 show the results of the GMM estimation, respectively testing H2 and H3.

First, to empirically test H2, we extend Model (1) by including our proxy for the CEO level of education (*CEO_EDU*) and its interactions with both board industry expertise (*CEO_EDU*BD_IND_EXPERT*) and the related squared term (*CEO_EDU*BD_IND_EXPERT²*). As shown in Model (2), this strategy documents that the CEO level of education (*CEO_EDU*) has a negative and statistically significant influence on our proxy for innovation input ($\beta = -6.409, p < 0.01$). Moreover, looking at the moderating effect, results show that, while the *CEO_EDU*BD_IND_EXPERT* variable has a positive and statistically significant coefficient ($\beta = 1.896, p < 0.05$), the *CEO_EDU*BD_IND_EXPERT²* term has a negative and statistically significant beta ($\beta = -0.145, p < 0.05$). Thus, the estimates support the predicted moderating effect of the CEO educational level on the relationship between board industry expertise and innovation input.

Similarly, to test H3 we run Model (3) including the dummy variable catching the CEO educational background in the technology area (*CEO_TECH_EDU_BACK*) and its interactions with the board industry expertise (*CEO_TECH_EDU_BACK*BD_IND_EXPERT*) and the related squared value (*CEO_TECH_EDU_BACK*BD_IND_EXPERT²*). Findings document that, while the coefficient for the *CEO_TECH_EDU_BACK* is not statistically significant, the beta of the variables measuring the moderating effect are both significant. Specifically, the coefficient for *CEO_TECH_EDU_BACK*BD_IND_EXPERT* is positive and statistically significant ($\beta = 1.223, p < 0.1$). Differently, the related interaction between the CEO educational area and the square of board industry expertise (*CEO_TECH_EDU_BACK*BD_IND_EXPERT²*) is negative and statistically significant ($\beta = -0.177, p < 0.05$). These findings confirm the presence of a moderating effect of the CEO educational background in the technology field on the curvilinear relationship between board industry expertise and our proxy for innovation input.

With regard to the control variables our analyses document that, in line with previous research (Merendino and Melville, 2019), the number of independent directors (*IND_DIR*) is positively and significantly related from a statistical standpoint to our proxy for innovation input in all models. Similar conclusions are reported for the coefficient of CEO power in terms of duality (*CEO_PW_DUAL*) that, consistently with prior research, is positive and statistically significant (Vandenbroucke *et al.*, 2016). Differently, unlike previous literature (Helmerts *et al.*, 2017; Merendino and Melville, 2019), findings highlight that the number of interlocked directors (*INTRL*) negatively influences the R&D to total sales ratio, and the board size (*BRD_SIZE*) has positive implications for the above-mentioned dependent variable. Finally, with regard to the control variables at the organizational level, the regressions show that the coefficient for company leverage (*LEV*) is positive and statistically significant (Sarto *et al.*, 2020), while the beta for the firm size variable (*FRM_SIZE*) appears negative and statistically significant.

4.3 Additional analyses and robustness tests

For each estimated GMM model, we also perform two diagnostic tests. Specifically, we first carry out the Arellano–Bond test for second order autocorrelation in the first difference errors (Arellano and Bond, 1991). As illustrated in Table 3, this test shows no significant evidence of serial correlation as p -values range from 0.310 to 0.442. Then, we run the Sargan test to assess whether the instrumental variables are uncorrelated with the error term and find that the null hypothesis of zero correlation can be rejected (Roodman, 2009).

To improve our analysis and provide an easier way to interpret the above-mentioned findings, we plot the estimated relationships and elaborate figures depicting the curvilinear and moderation effects. In this regard, Figure 1 confirms a U-shaped relationship between the level of board industry expertise and R&D to total sales ratio.

With regard to H2, Figure 2 shows that the curvilinear slope is less steep for highly educated CEO. This circumstance suggests that the positive (negative) effect of board industry expertise on R&D to total sales ratio at lower (higher) levels of board industry expertise is weaker in the presence of CEO with higher level of education.

Different conclusion can be drawn for H3, as Figure 3 highlights that the curvilinear slope for the relationship between board industry expertise and innovation input is steeper in the presence of a technology trained CEO. This result supports the conclusion that the positive (negative) effect of board industry expertise on innovation input at lower (higher) levels of board industry expertise is stronger (more negative) in the presence of technology trained CEO.

In order to assess the reliability of our results, we also perform robustness analyses. First of all, we re-run Models (1), (2) and (3) by employing an alternative measure of our main explanatory variable. Specifically, we catch the board industry expertise through the strength of the directors' sector experience proxied by the average number of years of experience in the focal firm's sector (*BD_IND_EXPERT_STR*). As shown in Table 4 the analyses are run by still employing the GMM approach and confirm the curvilinear relationship between the strength of board industry expertise and innovation input (H1), as well the moderating effects played by the presence of a CEO with high level of education (H2) and a technology educational background (H3).

Finally, we re-run the regression model testing H2 by using as moderator the length of CEO educational training (*CEO_EDU_LENIGHT*) proxied by the number of years of CEO

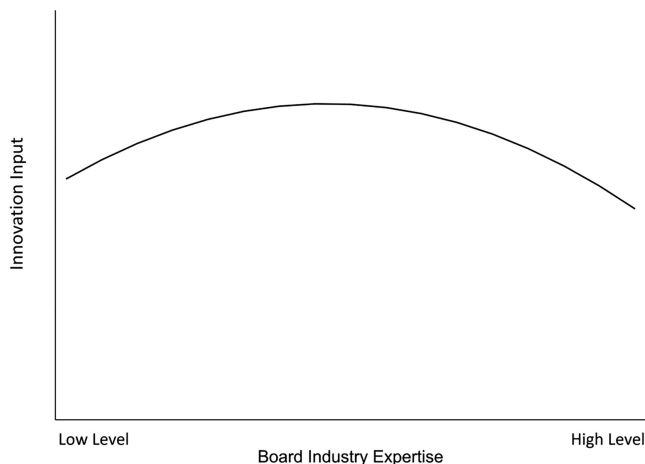


Figure 1.
The relationship
between board
industry expertise and
innovation input (H1)

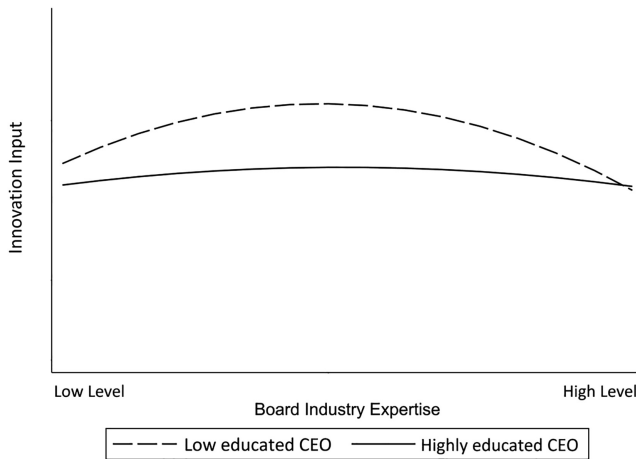


Figure 2. The moderating effect of CEO educational level (H2)

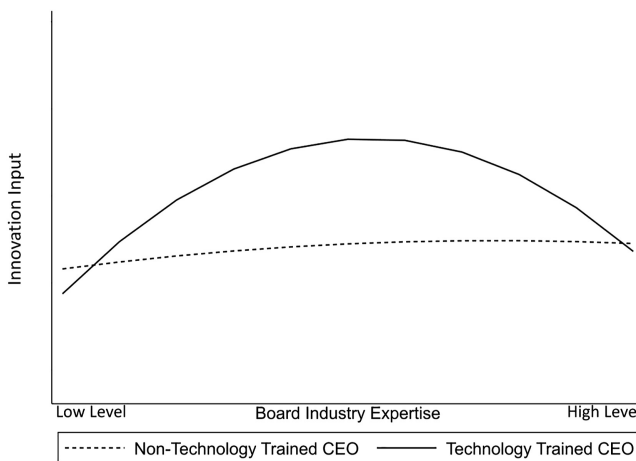


Figure 3. The moderating effect of CEO educational background in the technology area (H3)

education. As illustrated in Table 5, the GMM analysis confirms that the presence of a CEO with high level of education moderates the inverted U-shaped relationship between board industry expertise and innovation input.

5. Discussion

Based on a sample of privately-held Italian high-tech companies observed over the 2012–2015 period, this research applies the Arellano-Bond GMM estimators and examines the link among board industry expertise, CEO education and innovation input.

First of all, our results highlight the presence of an inverted U-shaped relationship between the industry expertise of board members and innovation input (H1). In particular, in line with our expectations, results show that innovation input improves up to a certain level of board industry expertise, whereas after a given threshold, having expertise in the sector of the focal firm limits innovation investments. As a first step, findings suggest that the board

Table 4.
GMM regression
results testing H1, H2,
H3 with strength of
board industry
expertise as
independent variable

Variables	Model 1	Model 2	Model 3
<i>BD_IND_EXPERT_STR</i>	11.764*** (3.244)	11.521*** (3.758)	8.269*** (1.725)
<i>BD_IND_EXPERT_STR</i> ²	-0.999*** (0.290)	-0.986*** (0.345)	-0.681*** (0.151)
<i>CEO_EDU</i>		-2007.966*** (15.022)	
<i>CEO_EDU*BD_IND_EXPERT_STR</i>		764.783*** (0.089)	
<i>CEO_EDU*BD_IND_EXPERT_STR</i> ²		-72.794*** (0.544)	
<i>CEO_TECH_EDU_BACK</i>			
<i>CEO_TECH_EDU_BACK*BD_IND_EXPERT_STR</i>			-1386.393*** (7.526)
<i>CEO_TECH_EDU_BACK*BD_IND_EXPERT_STR</i> ²			503.972*** (1.574)
<i>IND_DIR</i>			-45.676*** (0.198)
<i>CEO_PW_DUAL</i>	0.074* (0.040)	0.039 (0.042)	0.136*** (0.034)
<i>INTRL</i>	0.802* (0.418)	0.753* (0.395)	1.238*** (0.320)
<i>BRD_SIZE</i>	-0.076 (0.711)	-0.085 (0.065)	-0.064 (0.070)
<i>LEV</i>	0.819** (0.340)	0.845 (0.300)	0.658* (0.359)
<i>AGE</i>	0.234*** (0.049)	0.197*** (0.052)	0.229*** (0.049)
<i>FRM_SIZE</i>	-0.015 (0.018)	-0.009 (0.018)	1.238*** (0.320)
<i>YEAR DUMMY</i>	-0.015 (0.107)	-0.544*** (0.120)	-0.428*** (0.124)
<i>FIRM DUMMY</i>	YES	YES	YES
<i>OBSERVATIONS</i>	596	596	596
<i>AR(2) p value</i>	0.206	0.021	0.019
<i>SARGAN p value</i>	0.000	0.000	0.000

Note(s): *, **, and *** denote significance at the 10, 5 and 1% levels, respectively. Robust Standard errors in brackets

Variables	Model	Board industry expertise and innovation input
<i>BD_IND_EXPERT</i>	0.200 (0.143)	
<i>BD_IND_EXPERT</i> ²	-0.020 (0.014)	
<i>CEO_EDU LENGHT</i>	-0.179* (0.100)	
<i>CEO_EDU LENGHT *BD_IND_EXPERT</i>	0.111*** (0.033)	
<i>CEO_EDU LENGHT *BD_IND_EXPERT</i> ²	-0.007* (0.003)	
<i>IND_DIR</i>	0.085** (0.038)	
<i>CEO_PW_DUAL</i>	0.555 (0.405)	
<i>INTRL</i>	-0.115* (0.067)	
<i>BRD_SIZE</i>	0.300 (0.264)	
<i>LEV</i>	0.198*** (0.052)	
<i>AGE</i>	-0.004 (0.021)	
<i>FRM_SIZE</i>	-0.550*** (0.119)	
<i>YEAR DUMMY</i>	YES	
<i>FIRM DUMMY</i>	YES	
<i>OBSERVATIONS</i>	596	
<i>AR(2) p value</i>	0.022	
<i>SARGAN p value</i>	0.000	

Note(s): *, ** and *** denote significance at the 10, 5 and 1% levels, respectively. Robust Standard errors in brackets

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Table 5.
GMM regression results testing H2 with length of CEO educational training as moderator

members' industry experience enhances the monitoring of top managers and the effectiveness of the resource provision role in terms of strategic advice (Wang *et al.*, 2015; Guldiken and Darendeli, 2016). Therefore, we can argue that the directors' knowledge of cost requirements and payoff patterns of sector R&D projects helps them to alleviate the managerial risk aversion and myopia and prompt executives to make innovation investments (Kothari *et al.*, 2002; Manso, 2011). The ability of industry expert directors to properly identify sector opportunities, trends, and competitive threats (Bailey and Helfat, 2003; Kor, 2003) also addresses the board strategic advice towards promising R&D options (Carter and Lorsch, 2003; Guldiken and Darendeli, 2016). Perhaps more interestingly, our findings highlight that, after board industry expertise goes beyond a certain threshold, it can limit the board effectiveness in terms of monitoring and strategic advising roles with negative implications for innovation input. Indeed, results chime with the idea that too much of industry expertise can make directors firmly dependent on the sector rules, hampering their aptitude to detect innovation opportunities (Faleye *et al.*, 2018). Moreover, excessive industry expert directors exacerbate the similarity between top managers and board, which in turn enhances the related interpersonal attraction and produces biases in board monitoring over executives (Westphal and Zajac, 1995). At the same time, too much sector experts on the board can involve board background homogeneity, thus hampering the board decision comprehensiveness and the proper evaluation of innovation projects due to the information overload (Finkelstein and Hambrick, 1996; Gradstein and Justman, 2000; Brodbeck *et al.*, 2007; Midavaine *et al.*, 2016). Additionally, it can limit the exchange of viewpoints and board problem-solving attitude, distracting executives from innovation issues (Ocasio, 1997; Cannella *et al.*, 2008).

Shifting the attention to the role of CEO, the tests of both H2 and H3 highlight that the CEO education is able to influence the above mentioned relationship, supporting our predictions. Overall this result is in line with previous studies suggesting that CEO education, both in terms of level and area, influences the board ability to monitor and strategically advise top managers (Thampas and Boon-itt, 2018; Sarto *et al.*, 2020). Indeed, the CEO background plays a key role in terms of receptivity to innovation activities/initiatives and drives the innovation choices of top management team (Lin *et al.*, 2011; Chen, 2013).

With regard to H2, findings document that the presence of a CEO with advanced educational level moderates the inverted U-shaped relationship between board industry expertise and innovation input. In detail, the results highlight that the effect of board industry expertise becomes less pronounced in the presence of a highly educated CEO. This evidence supports the conclusion that the high level of education improves the CEO-board cognitive conflicts (Arena *et al.*, 2015) because it increases the CEO prestige (Haynes *et al.*, 2019). Indeed, having a high academic degree hinders the quality of board strategic decision-making (Arena *et al.*, 2015) because better educated CEOs tend to impose their ideas and rise relationship conflicts with directors (Simons and Peterson, 2000; Petrovic, 2008), thus hampering the board monitoring and resource provision roles.

Turning to H3, in line with our expectation, our analyses document that the presence of a CEO with a technology educational background acts as a moderator of the curvilinear relationship between board industry expertise and innovation input. Specifically, results highlight that the effect of board industry expertise on innovation input becomes sharper when the CEO is technologically trained. This result underscores that, CEOs characterized by degrees and training in scientific and technical fields present a higher open mindedness and risk taking propensity, thus encouraging innovation investments (Tyler and Steensma, 1998; Barker and Mueller, 2002). As such, technology literate CEOs can provide top managers with supportive information, skills and specific knowledge for the identification and selection of innovation projects (Barker and Mueller, 2002; Dass *et al.*, 2014; Faleye *et al.*, 2018). In doing so, CEOs with a technology training can stimulate the top managers' innovation awareness and therefore improve the managerial openness towards board monitoring and advising in connection to innovation investments (Sarto *et al.*, 2020; Qiu and Yu, 2021).

6. Concluding remarks

Grounding on multiple theoretical frameworks, our empirical research offers wide-ranging contributions to theory and practice. From a scholarly standpoint, the paper contributes to the debate on both innovation management and board capital. Starting with the former, the article specifically advances the literature on the governance antecedents of firm innovation input. While there is a large amount of evidence on the board structure and composition effects on innovation investments (Yoo and Sung, 2015; Kor, 2006; Guldiken and Darendeli, 2016; Han *et al.*, 2015; Terjesen *et al.*, 2016; Helmer *et al.*, 2017; Ain *et al.*, 2021), far less is known on the implications of a specific dimension of board human capital, that is the director's expertise in the focal firm industry. Our paper fills this gap in the literature and advances the understanding of the link between board sector expertise and R&D by documenting the presence of an inverted U-shaped relationship. Indeed, while prior studies have only tested the presence of a positive and linear effect (Chen, 2014; Dass *et al.*, 2014; Faleye *et al.*, 2018; Valenti and Horner, 2020b), our paper provides evidence that the directors' experience in the industry is beneficial for innovation investments, but too much of such kind of expertise can limit this outcome. At the same time, the paper represents also an advancement of the studies on board industry expertise and innovation input from a theoretical standpoint. Indeed, previous research has examined the implications of directors' industry expertise on one single board role (monitoring or advising) and has alternatively used the two related theoretical lenses (agency or resource dependence approach). Differently, our paper interprets the relationship under scrutiny as the outcome of the fulfillment of both roles in the light of both theories.

A second related theoretical contribution of our study is provided to the literature on board capital. First of all, our article integrates prior empirical evidence on the performance implications of board industry expertise that is still scarce for what concerns the innovation side of firm performance. At the same time, by interpreting the innovation effect in the light of

both board monitoring and resources provision roles, it supports board capital proponents suggesting that the board of directors could effectively and simultaneously fulfill the monitoring and resource provision tasks and this ability depends on the related human and social capital (Hillman and Dalziel, 2003). Furthermore, by offering insights into the moderating effect of the CEO educational level and technology background on the above-mentioned curvilinear relationship, our study fills a gap in the literature and integrates the research on the interplay between CEO and board. Indeed, it supports the expectation that the CEO human capital moderates the link between board characteristics and company outcomes (Kisfalvi and Pitcher, 2003). Finally, the paper helps to bridge a literature gap on Italian companies. In such context, academics have devoted scant attention not only to the implications of board industry expertise, but also on the board human capital effects in terms of firm innovation. In doing so, our study provides knowledge that might be applied to other European developed settings due to the presence of notable similarities in terms of innovation and board human capital (Clarysse *et al.*, 2007; Mazzoleni and Giacosa, 2017; Ramella, 2017).

Some managerial implications can be also inferred from our article. Indeed, in line with the conclusions of the European confederation of directors' association, it emphasizes to managers the importance to strengthen the board human capital when their companies aim to innovate. Indeed, research highlights that board industry expertise is a meaningful driver of board task effectiveness and can affect company innovation. Therefore, our article encourages board nomination committees to take into due account not only the typical board composition elements (e.g. independence, gender diversity) but also the directors' expertise, when designing the board in their firms. In particular, our results do not advise to limit the level of directors' industry expertise because its increasing up to a certain threshold boosts innovation input. However, they suggest to refine the board structure when too much directors with sector expertise are appointed so as to leverage all potential benefits of their human capital. Moreover, as the CEO interplays with board expertise and moderates the curvilinear relationship previously described, our study recommends to top managers the importance to take into due consideration how the CEO education can influence such effect. In doing so, our paper has relevant implications also for the industry under scrutiny and their related managers. Indeed, high-tech managers can take advantage from our study by effectively designing their board so as to improve the level of innovation investments that are especially crucial for their competitive advantage and which in turn increase firm performance.

While drawing these conclusions, we acknowledge that our results come with some potential caveats that provide insights for new lines of enquiry. A first research flaw is the focus of our study as it only tests the effect of board industry expertise and CEO education in absolute terms and not in a comparative manner. Despite such approach is in line with our research question, future empirical studies could further explore the CEO experience and education in relation to other board members. Indeed, they could use comparative indicators of CEO vs Board in order to catch the power distribution among them. An additional limitation concerns the choice to focus on the educational level and technology background of CEO that are some specifications of the related human capital. Therefore, further empirical research should assess how other types of CEO human capital, such as functional and firm expertise, can shape the relationship between directors' industry expertise and innovation input. Moreover, further studies are needed to observe the internal board dynamics to shed light on the reasons behind the relationship between board industry expertise and innovation. Despite we can speculate about the board industry ability to affect R&D investments, additional qualitative research examining how board, top managers and CEO interact could advance our understating of board industry expertise-innovation inputs coupling. Finally, a last research flaw is related to the choice to focus on a specific sector. Although high-tech companies represent a suitable context to examine the effects of board

human capital on innovation input, our results could not apply to other settings as literature suggest that diverse kinds of companies might differently benefit from board industry expertise (Faleye *et al.*, 2018). Given this premise, future research efforts could broaden the sample to other contexts in the aim to explore how sector specific features impact on the relationship between industry experienced directors and innovation input.

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