

Human capital and innovation: mixing apples and oranges on the board of high-tech firms

Human capital
and innovation

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Abstract

Purpose – The purpose of this paper is to provide insights into the implications of board human capital heterogeneity for company innovation by focusing on the educational and the functional background of directors. Moreover, it examines the moderating effect of the CEO expertise-overlap within the innovation domain on the relationship between board human capital heterogeneity and firm innovation.

Design/methodology/approach – The hypotheses are tested through a set of ordinary least squares regressions on a unique dataset of 149 Italian high-tech companies observed between 2012 and 2015.

Findings – Findings show that the educational and the functional background heterogeneity of directors increase both the innovation input and output. However, results highlight that these relationships are negatively moderated by the CEO expertise-overlap within the innovation domain.

Practical implications – The paper emphasizes the importance of appointing directors with different and specific educational and functional backgrounds to foster the company innovation.

Originality/value – The paper fills a gap in the literature as it has devoted limited attention to the performance implications of board human capital heterogeneity in the high-tech industry where knowledge and skills are the primary sources of value. Moreover, the paper integrates the research on the CEO-board interface by shedding light on how the CEO expertise within the innovation domain affects the contribution of heterogeneous boards to company innovation.

Keywords Innovation, Board heterogeneity, Board human capital, CEO expertise, High-tech context

Paper type Research paper

1. Introduction

Over the last decades, board diversity has received increasing attention from both scholars and practitioners, especially in terms of demographic facets such as race, gender and age. Indeed, it is worth noting that, prompted by the Green Papers of the European Commission (e.g. 2010, 2011), many countries have adopted several legislative initiatives in order to improve the diversity of board members (e.g. Norway, Italy, France, Belgium, UK, Portugal).

However, only recently, the human capital facets of board heterogeneity have become a key issue of debate (Walker, 2009; Torchia *et al.*, 2015). In this regard, academics and practitioners have highlighted that balancing knowledge, skills and expertise of board directors matters for their ability to fulfill the governing roles (Hillman and Dalziel, 2003; Berezinets *et al.*, 2016; Ciaravella, 2017). On the one hand, literature suggests that board human capital heterogeneity can improve the team decision-making as it stimulates the



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debate among directors and enhances the board problem-solving (Cannella *et al.*, 2008; Cho and Hambrick, 2006). On the other hand, scholars posit that the diversity can enhance the company creativity and innovation as it is able to broaden the board perspectives and offer new insights (McNamara *et al.*, 2002; Brodbeck *et al.*, 2007).

While there are many reasons to believe that these circumstances can positively affect company performance, the implications of board human capital heterogeneity are still at issue and many gaps need to be addressed (Harrison and Klein, 2007; Wang *et al.*, 2015).

First of all, the empirical evidence on the effects of board human capital diversity on company outcomes is inconclusive with regard to the sign of the relationship. Indeed, some studies highlight that board heterogeneity positively influences the strategic decision-making (Brodbeck *et al.*, 2007) and improves firm outcomes (Carter *et al.*, 2003; Hutzschenreuter and Horstkotte, 2013; Kim and Lim, 2010; Wincent *et al.*, 2010, 2014). Differently, other research documents that board human capital diversity limits the firm results (Wellalage and Locke, 2013; Goodstein *et al.*, 1994) as it increases the level of conflict, reduces the information sharing (Bunderson and Sutcliffe, 2002; Forbes and Milliken, 1999) and hampers the decision-making process effectiveness (Li and Hambrick, 2005; Goodstein *et al.*, 1994).

Second, scholars have mainly examined one single dimension of board heterogeneity (Hutzschenreuter and Horstkotte, 2013), while investigating different facets of director human capital (Midavaine *et al.*, 2016) could be more helpful to disentangle the implications of the related sources (i.e. school and university education vs working experience) (Kim and Rasheed, 2014).

Third, most studies have focused on financial outcomes (Antonelli *et al.*, 2013; Wellalage and Locke, 2013) and less attention has been devoted to the influence of board human capital heterogeneity on corporate innovation (Midavaine *et al.*, 2016; Van Knippenberg *et al.*, 2011; Kim and Kim, 2015). In this regard, it is worth noting that the board human capital diversity is especially able to prompt more complex and innovative decisions as it provides directors with the pool of knowledge essential for creative breakthroughs (Cyert and March, 1963; Gradstein and Justman, 2000; Finkelstein and Hambrick, 1996). Moreover, previous research has only explored the effects of board human capital diversity on innovation driver (i.e. R&D investments) (Midavaine *et al.*, 2016), while exploring the related implications on different facets of the innovation process could advance the existing literature.

Finally, empirical studies have not explored whether the relationship between heterogeneous boards and company innovation can be affected by the CEO characteristics (Kim and Kim, 2015), despite literature has suggested that the CEO expertise might influence and guide the board decision-making (Heyden *et al.*, 2017). Therefore, understanding under what conditions the CEO expertise influences the relationship between board human capital diversity and company innovation could further broaden current literature.

Addressing these research gaps can be helpful in high competitive settings as scholars suggest that heterogeneous teams are more able to cope with novel issues where knowledge and skills represent the primary sources of firm value and competitive advantage (Sáenz *et al.*, 2009). Indeed, in these contexts, the background diversity of directors provides the board with specialized skills useful to address the challenging tasks of company innovation. In addition, in companies that require high flexibility, such as high-tech firms, the opportunity to rely on heterogeneous knowledge and skills improves not only the board versatility but also the related awareness of the key role played by the development of new business ideas (Pitcher and Smith, 2001; Latimer, 1998).

Moving from these premises, the paper aims to fill the above-mentioned gaps by exploring the implications of board and CEO human capital for the innovation process in the high-tech context. More specifically, it addresses two research questions:

- RQ1.* What is the effect of board human capital heterogeneity, in terms of educational and functional background, on innovation in high-tech companies?

RQ2. Does the CEO expertise-overlap within the innovation domain (i.e. expertise in R&D function) affect the relationship between board human capital heterogeneity and innovation in high-tech companies?

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To this aim, the paper examines a sample of 149 Italian high-tech firms over four years (2012–2015) by investigating the company innovation in terms of both input (i.e. proxied by R&D investments) and output (proxied by value of patents) measures.

Findings support the idea that the educational and the functional background heterogeneity of directors increase both the innovation input and output, and this relationship is influenced by the CEO expertise-overlap within the innovation domain.

Taking together, these results offer contributions to scholars and practitioners. As for the former, the paper extends the research field in many ways. First of all, differently from previous studies that have explored only one facet of board human capital heterogeneity, the paper examines both the educational and functional background dimensions and disentangles the related effects on company innovation (Kim and Lim, 2010; Buyl *et al.*, 2011; Midavaine *et al.*, 2016). In addition, the paper advances prior empirical research that has not provided conclusive evidence on the reported sign of the relationship between board human capital heterogeneity and company innovation, by supporting the conclusions of the cognitive approach proponents (Cannella *et al.*, 2008; Hambrick *et al.*, 1996). Furthermore, unlike previous literature exploring the effect of board human capital diversity on only one dimension of innovation process (e.g. R&D investments as innovation driver) (Midavaine *et al.*, 2016), the paper relies on both innovation input (R&D investments) and output (value of patents) measures. Moreover, it integrates the research on the CEO-board interface (Walters *et al.*, 2007) by illustrating how the CEO expertise within the innovation domain affects the influence of heterogeneous boards on company innovation. Finally, the study fills a gap in the literature as it focuses on underexplored contexts. Indeed, it not only explores the condition under which, in growing and high competitive settings, the board human capital heterogeneity can address complex and novel issues but it also sheds light on the phenomenon under scrutiny in the Italian context.

At the same time, the paper provides additional relevant insights for both managers and policy makers. In particular, by highlighting that firm innovation is positively affected by the board human capital heterogeneity, it suggests that the board nomination committee should assure enough diversity in terms of educational and functional background when appointing directors. In addition, the research points out the importance of ensuring the consistency between CEO and board characteristics as the human capital of the former interacts with the latter and affects its decision-making process. Finally, the study takes over from the European Commission (i.e. Directive 2014/95/EU) and reawakens the attention of policy makers toward the importance of stimulating the appointment of directors with different educational and functional backgrounds by revising the corporate governance code and guidelines.

The remainder of the paper is structured as follows. Section 2 provides an overview of the theoretical background. Section 3 develops the hypotheses. Section 4 presents the methodology. Section 5 illustrates the research findings. Section 6 discusses and concludes.

2. Theoretical background

The implications of board human capital heterogeneity for company innovation can be explained through multiple theoretical lenses. A strong contribution to the interpretation of this phenomenon has been provided by the arguments of the human capital theory (Becker, 1962; Schultz, 1961), the upper echelon theory (Hambrick and Mason, 1984) and the behavioral theory of the firm (Cyert and March, 1963).

The concept of human capital stems from the 1960s when the economists Schultz (1961) and Becker (1962) formalized the so called “human capital theory” in response to the strong difficulties of the economic growth accounting studies to explain the boost of the USA

economy through the traditional factors of production (Krueger, 1968). In this sense, Schultz (1961) and Becker (1962) interpreted the economic gap in the light of the human capital (Weisbrod, 1966), defined as the expertise, experience, knowledge and skills that individuals own thanks to their education and job experience. The base principle of the human capital theory is that, in an organization, the human capital is valuable similarly to all the other resources employed in the production process. In this sense, if these resources are empowered through investments and are effectively used, the results are profitable not only for individuals but also for organizations and the overall society (Becker, 1962; Schultz, 1961). As a result, the human capital is considered as a crucial determinant of organizational outcomes.

Building on these assumptions, the human capital theory has been extensively applied in strategic management, human resources management, entrepreneurship and corporate governance studies. In this last field, literature has developed the concept of human capital as part of the wider notion of Board capital (Hillman *et al.*, 2002). According to Hillman and Dalziel (2003), Board capital is the sum of human and social capital of directors, and represents the best proxy to appreciate the board ability to provide resources to the firm by performing all its roles. This concept allows to overcome the weakness of choosing one theoretical approach over another (Nicholson and Kiel, 2004), as well as the limited ability of typical board composition measures (e.g. board independence, board size, presence of committee, CEO duality, etc.) to predict its effectiveness (Dalton *et al.*, 1998). In this sense, the board capital is the precondition to make the board able to effectively engage all governance tasks (i.e. monitoring, strategic and service role) and to improve firm outcomes (Haynes and Hillman, 2010).

Different arguments are provided by the proponents of the “upper echelon theory” (Hambrick and Mason, 1984) as it postulates that processes and characteristics of corporate elites (i.e. top management team (TMT) and board of directors) (Hambrick, 2007; Mueller and Barker, 1997) play a pivotal role in shaping organizational outcomes (i.e. strategic choices and performance levels). In particular, literature in this tradition assumes that values, cognitive bases and perceptions of corporate elite affect the process of strategic choice and influence the company outcomes (Zarutskie, 2010; Carpenter *et al.*, 2004). Thereby, upper echelon theorists highlight that the corporate performance can be predicted by the demographic attributes of the elite members such as age, gender, experience, tenure, educational and functional background (Hambrick and Mason, 1984; Wiersema and Bantel, 1992; Hambrick *et al.*, 1996; Knight *et al.*, 1999; Bantel and Jackson, 1989; Datta and Rajagopalan, 1998). As suggested by the upper echelon literature, the cognitive structures of TMT and board members depend on the above-mentioned demographic characteristics and affect how they collect, filter, interpret and use information in their decision-making activity (Finkelstein and Hambrick, 1996; Dutton and Jackson, 1987; Hambrick *et al.*, 1993). Therefore, corporate elites’ demographics are often used as proxies for the cognitive attributes of managers/directors and are considered as able to predict not only their strategic preferences (Carpenter *et al.*, 2004; Hambrick and Mason, 1984) but also their competencies (Hodgkinson and Sparrow, 2002). Following the upper echelon approach, the combination of different demographic attributes of top managers and directors influences the company strategic decision-making processes/implementation (Knight *et al.*, 1999; Johnson *et al.*, 1993) and affects organizational outcomes (Chakravarthy and White, 2002; Wally and Baum, 1994; Bantel and Jackson, 1989).

Aside the interpretation of the human capital and the upper echelon theories, a relevant contribution to understand the decision-making process of board is offered by the “behavioural theory of the firm” (Simon, 1955; Cyert and March, 1963). This framework provides an important input to the theory of the firm by bringing into focus the multiple goals in managerial decision-making. Indeed, it interprets firms as coalitions of groups of participants (i.e. shareholders, employees, managers, suppliers and customers) with largely conflicting interests and goals. In this sense, the fundamental objective of a firm is searching for solutions that are mutually acceptable to all different internal groups. Thereby, the theory

focuses on the process by which companies make their economic choices. Following this interpretation, the decision-making process is given to top managers who, in turn, examine and decide upon firm projects on the bases of the information and expectations formed within the organization. Thereby, under this theoretical approach, the more comprehensive the information available and evaluated during the decision-making process is, the better the group's decision will be (Cyert and March, 1963).

Based on these premises, we rely on the arguments of the human capital theory (Becker, 1962; Schultz, 1961), the upper echelon theory (Hambrick and Mason, 1984) and the behavioral theory of firm (Cyert and March, 1963) to develop our hypotheses on the implications of board human capital heterogeneity for company innovation.

3. Hypotheses development

The research on board human capital emphasizes the relevance of knowledge and skills of board members for the fulfillment of their governing tasks. More specifically, literature claims that expertise, experience, knowledge and skills of directors are able to drive the effective execution of all governing roles with positive implications for corporate outcomes (Hillman and Dalziel, 2003; Berezinets *et al.*, 2016).

In this regard, while some studies enlighten the importance of improving board human capital (Hillman and Dalziel, 2003), other research suggests to combine its different attributes to foster heterogeneity (Wincent *et al.*, 2014). Broadly defined, heterogeneity/diversity is the degree to which team members differ from one another (Jackson *et al.*, 2003). In this sense, scholars identify the board human capital heterogeneity as the variety in the members' expertise, knowledge and skills (Harrison and Klein, 2007; Hillman and Dalziel, 2003) and explore its drawbacks and benefits for companies (Jackson *et al.*, 2003).

A first strand of studies in this tradition highlights that board human capital heterogeneity brings positive outcomes to the firm as it provides several advantages to board decision-making. Indeed, research posits that the director's cognitive heterogeneity in terms of background improves company outcomes as it limits narrow-mindedness, stimulates the debate and fosters the board problem-solving attitude (Cannella *et al.*, 2008; Cho and Hambrick, 2006). The rationale is that the director's diversity enhances the range of skills, experiences and the breadth of knowledge available for the decision-making activity (Finkelstein and Hambrick, 1996; Jackson *et al.*, 2003), leading to wider range of solutions and alternatives to properly drive company choices (Gradstein and Justman, 2000; Soutaris, 2002; Cho and Hambrick, 2006). From a different standpoint, board human capital heterogeneity improves the pool of information available, fostering the decision comprehensiveness and the evaluation of company options and opportunities (McNamara *et al.*, 2002; Brodbeck *et al.*, 2007). Indeed, the diversity of directors individual cognitive schema (i.e. organizational tenure, functional experience, educational background) drives the attention of decision makers toward key issues and filters the useful information to address critical problems (Ocasio, 1997). Moreover, the board background heterogeneity leads to the group's information-based diversity and boosts its ability to select, collect and process relevant information, enhancing the exchange of key viewpoints (Midavaine *et al.*, 2016). Thereby, board members with different backgrounds can bring diverse perspectives, specialties and expertise to discussions, improving the board's ability to positively influence company outcomes (Cannella *et al.*, 2008; Cho and Hambrick, 2006).

While there are many reasons to assert that board human capital heterogeneity increases the aggregate level of resources at the group's disposal, this attribute plays as a "double-edged sword." Indeed, a second strand of literature suggests that board human capital heterogeneity can hamper board decision-making and limit its effectiveness as diversity is associated with higher levels of conflict, communication problems, narrow information sharing and integration (Bunderson and Sutcliffe, 2002; Forbes and Milliken,

1999). In this regard, the presence of too many areas of expertise curtails the information flow among directors hindering their consensus and cohesion (Li and Hambrick, 2005; Jackson *et al.*, 2003). As a result, the divergence of perspectives and backgrounds can create disorganization and miscommunication to the detriment of board task effectiveness (Walsh *et al.*, 1988).

The empirical evidence supports these conclusions by providing mixed results on the implications of board human capital heterogeneity. Some studies find a positive relationship between educational diversity (Kim and Lim, 2010), expertise heterogeneity (Wincent *et al.*, 2010, 2014) and company outcomes. Differently, other research documents that board human capital diversity limits firm results (Wellalage and Locke, 2013; Goodstein *et al.*, 1994).

However, following a contingency perspective, we believe that both the board task and the company setting might influence the above-mentioned relationships (Joshi and Roh, 2009; Zona *et al.*, 2013). Indeed, concerning the board task, literature suggests that the contribution of board human capital heterogeneity is especially valuable for innovation processes (Midavaine *et al.*, 2016). Moreover, looking at the type of setting, academics claim that the diversity of competencies of board members is more relevant in industries characterized by low level of heterogeneity such as the high-tech context (Cumming *et al.*, 2015). Furthermore scholars posit that, while homogenous directors are more appropriate to handle routine problems in mature and low competitive markets (e.g. manufacturing), heterogeneous teams better address novel issues in growing and high competitive settings (e.g. high-tech) (House *et al.*, 1971). Finally, aside the above-mentioned factors, we deem that the relationship between board human capital diversity and firm outcomes can be also affected by the CEO-board interface. Indeed, some studies document that the CEO characteristics in terms of power, career and demographic features influence the link between the board human capital and the firm strategic change (Haynes and Hillman, 2010; Ling *et al.*, 2008; Heyden *et al.*, 2017; Cummings and Knott, 2018), as well as the relationship between the TMT decision-making process and the organizational performance (Peterson *et al.*, 2003; Kisfalvi and Pitcher, 2003).

Moving from these premises, the following sub-paragraphs develop our hypotheses by drawing on the literature examining the implications for company innovation of board human capital heterogeneity in terms of educational and functional background, as well as on the role played by the CEO-board interface.

3.1 Board educational background heterogeneity and innovation

Literature suggests that the educational background provides individuals with different values, beliefs, attitudes, perspectives, knowledge and information-processing behaviors, which in turn are critical for their decision-making process (Jackson *et al.*, 2003).

Some scholars enlighten that the educational area of decision-makers matters for the firm's strategic orientation and preferences, and therefore for its innovation. Indeed, studies in this tradition document that top managers with marketing, engineering or scientific educational background are more inclined to pursue innovation strategy through R&D spending (Thomas *et al.*, 1991; Datta and Guthrie, 1994; Tyler and Steensma, 1998). From a different perspective, other research highlights that individuals with higher formal education are more likely to elaborate creative solutions for their organization (Soutaris, 2002). Following these arguments, some studies report that the level of education of TMT positively influences firm innovation and R&D expenditures (Dalziel *et al.*, 2011; Wincent *et al.*, 2010).

However, academics suggest that what matters for strategic innovation is not the type and the level of director education but its heterogeneity (Wincent *et al.*, 2014). In this regard,

following the behavioral theory of the firm, the board human capital heterogeneity might impact on company innovation through a number of mechanisms. First of all, directors with diverse cognitive backgrounds provide the board with a greater pool of knowledge and information-processing behaviors, increasing the breadth of the group cognitive perspectives. As a result, the educational diversity improves the creative breakthrough of directors and supports them in processing more comprehensive information, leading to more complex and innovative decisions (Cyert and March, 1963; Gradstein and Justman, 2000; Finkelstein and Hambrick, 1996). From a different standpoint, the heterogeneous educational background of board members involves cognitive conflicting processes that produce alternative solutions and innovative ideas improving the firm commitment to innovation (Amason, 1996; Hillman *et al.*, 2002). Finally, the diversity of the educational area limits the board risk aversion that, in turn, fosters the use of innovative problem-solving approaches in decision-making (Van Knippenberg and Schippers, 2007).

Despite these conclusions, other studies highlight that diversity may not be beneficial at all. In this regard, opponents of board heterogeneity claim that the educational background diversity can produce conflicts, disorganization and miscommunication issues limiting the directors' cohesion (Bunderson and Sutcliffe, 2002; Forbes and Milliken, 1999). Indeed, research in this tradition reports that educationally heterogeneous top managers are characterized by cognitive conflicts that prevent the directors' consensus and curb the swiftness of their decisions (Hambrick *et al.*, 1996).

However, in challenging contexts such as the high-tech setting, the negative implication of background heterogeneity can be undone by the related peculiarities. Indeed, literature suggests that, in high-tech companies, innovation is critical for the firm competitiveness (Sáenz *et al.*, 2009), and the educational background heterogeneity can result in scientific and specialized skills useful to solve complex tasks (Pitcher and Smith, 2001; Latimer, 1998). Since innovation activities require high level of flexibility, the cognitive behavior diversity of directors can play a pivotal role by making the board more flexible and cognizant to new business ideas and hampering the firm strategic inertia also in terms of innovation strategy. Building on these assumptions, we predict that, in the high-tech context, the board educational diversity can improve the firm innovation.

Thus, we formulate the following hypothesis:

- H1.* In the high-tech context, the board educational background heterogeneity positively affects firm innovation.

3.2 Board functional background heterogeneity and innovation

Literature suggests that board heterogeneity can also appear in the presence of directors with various functional backgrounds (Kim and Rasheed, 2014; Tuggle *et al.*, 2010). Scholars posit that board members tend to select strategies and corporate options consistent with their own functional background (Waller *et al.*, 1995) as it plays a key role in shaping the cognitive bases to approach corporate issues and allocate firm resources (Michel and Hambrick, 1992). This phenomenon is confirmed by the tendency of managers with throughput functional backgrounds (e.g. operation and accounting) to primarily attend to corporate operational efficiency, unlike those with dominant output functional backgrounds (e.g. marketing and sales) that are more prone to investments aiming to take market opportunities (Hambrick, 1981).

Looking at the implications of board functional background heterogeneity, some studies contend that the functional diversity negatively influences corporate innovation (Kor, 2006) and emphasize the supportive role played by the background similarity of directors for technological innovation (Ahuja, 2000; Sampson, 2007). In line with these conclusions, following a cognitive approach, literature highlights that diverse boards are more

challenging to reach consensus as they are characterized by strong cognitive conflicts that arise communication problems and improve the difficulties in making innovation decisions (Forbes and Milliken, 1999; Hafsi and Turgut, 2013; Tarus and Aime, 2014). Furthermore, differences in functional background may lead to social categorization and team conflict. Indeed, the expertise diversity of directors tends to result in differential organizational goals and increases the competition among top executives belonging to different departments, especially when corporate funds are scarce. In this vein, two directors with different background (e.g. accounting vs engineering) may disagree about resource allocation across the two functions because each perceives the other as a member of the “out-group” (Tasheva and Hillman, 2018; Branch, 1974; Jehn *et al.*, 1999).

Notwithstanding these arguments it is reasonable to assume that, in settings that require intensive innovation investment policies and present low level of heterogeneity (e.g. high-tech), the functional background diversity is especially beneficial (Wincent *et al.*, 2010, 2014; Heyden *et al.*, 2018; Kim and Kim, 2015; Cumming *et al.*, 2015; Nuscheler *et al.*, 2019). Scholars argue that, for complex matters like innovation, the interaction among directors with heterogeneous expertise results in high-innovative board decisions (Hambrick *et al.*, 1996) for many reasons. First of all, the functional background diversity of directors enriches the boardroom cross-functional discussions (Bantel and Jackson, 1989) as it combines different perspectives (Amason, 1996; Van der Vegt and Janssen, 2003) that provide a broader set of interpretations of current issues (Hambrick *et al.*, 1996; Forbes and Milliken, 1999). In addition, more diversified boards in terms of functional expertise improve the firm’s innovation capacity as this kind of heterogeneity boosts the information available to identify innovative initiatives and enhances the willingness of high-tech firms to innovate (Cannella *et al.*, 2008; Joshi and Roh, 2009; Mahadeo *et al.*, 2012). Moreover, the presence of members belonging to different functions increases not only the communication level among directors but also outside the board (Ancona and Caldwell, 1992). The information sharing among the board and the line/staff managers is especially relevant for high-tech companies where all the managerial efforts aim to innovate by requiring the involvement of all the organizational members. Building on these assumptions, we predict that in the high-tech context, the board functional diversity can improve the firm innovation.

Thus, we formulate the following hypothesis:

- H2. In the high-tech context, the board functional background heterogeneity positively affects firm innovation.

3.3 *The moderating role of the CEO expertise-overlap*

Literature suggests that the decision-making process of corporate teams can be influenced and guided by the leader’s behavior. In this sense, CEOs can play an important role in shaping the strategic orientation and the activity of heterogeneous boards (Hambrick, 1995).

Scholars in the upper echelon tradition highlight that the CEO strongly affects the firm strategic choices (Hambrick and Mason, 1984) and is of utmost importance in reconciling the conflicting views of managers, while giving voice to those who provide fresh perspectives to firm decisions (Hambrick, 1995; Simsek *et al.*, 2005; Jaw and Lin, 2009). In this regard, literature on team processes claims that the managerial teams’ effectiveness depends on the leader’s interactions and features as he/she perceives the strategic options consistently with his/her own personal characteristics and past experiences (Zaccaro and Klimoski, 2002; Hambrick and Mason, 1984).

Turning the attention to company innovation, research suggests that the team diversity *per se* does not affect the firm innovation but rather the CEO attitude to make the debate on innovation as systematic (Kisfalvi and Pitcher, 2003). Based on these premises, some studies highlight that effective CEOs play a unique and pivotal role in driving the board innovation

processes (Arendt *et al.*, 2005; Jaw and Lin, 2009; Tharnpas and Boon-itt, 2018) as they give voice to fresh perspectives and foster the exchange of innovative ideas among team members (Simsek *et al.*, 2005). On the contrary, if CEOs disapprove the board efforts, the innovation process tends to be hindered as they drive the innovation decisions and the resulting policies/operations (Westphal and Fredrickson, 2001).

It is worth noting that the ability under scrutiny can depend on the expertise that the CEO brings to the company (Hamori and Koyuncu, 2013). Indeed, the scholarly debate emphasizes that the career path and the professional experience in specific business functions influence the way CEOs interpret information and drive the company decision-making (Datta and Guthrie, 1994; Tyler and Steensma, 1998; Roach and Sauermann, 2010).

Based on these premises, there are many reasons to assume that the consistency between the CEO expertise and the innovation domain (i.e. CEO's expertise-overlap) might improve the team processes and the related choices. Indeed, studies report that CEOs with career experience within the domain of technology influence innovation in many ways. On the one hand, they tend to not be vulnerable to efficiency concerns (Finkelstein and Hambrick, 1996; Hambrick and Mason, 1984; Thomas *et al.*, 1991) and therefore to support R&D spending (Barker III and Mueller, 2002) consistently with the focus of their career experience/background. On the other hand, their expertise impacts on the related innovation planning skills and openness to change, enabling or limiting the identification of utmost technological alliance opportunities (Tyler and Steensma, 1998; Ahn *et al.*, 2017). Building on these assumptions we might expect that, in the high-tech context, the presence of a CEO with an expertise in the innovation domain could interface with board innovation decisions, thus positively moderating the effect of its heterogeneity on company innovation.

Therefore, we formulate the following hypothesis:

- H3.* In the high-tech context, the CEO expertise-overlap within the innovation domain positively moderates the relationship between board human capital (educational and functional background) heterogeneity and firm innovation.

Figure 1 summarizes the predicted hypotheses.

4. Methodology

4.1 Sample and data collection

To empirically test our hypotheses, we rely on a sample of 149 Italian high-tech firms observed between 2012 and 2015.

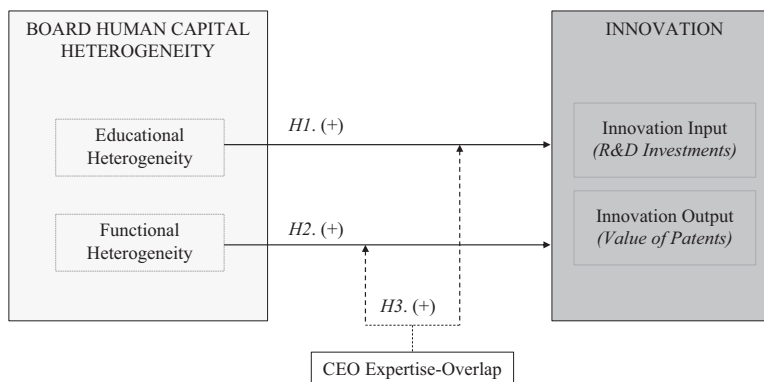


Figure 1.
Summary of
hypotheses

Our sample selection procedure started with all the Italian firms with more than 50 employees at the end of the fiscal year 2012 (i.e. 11,019). Following prior literature, we use this threshold in order to identify medium and large-sized firms (Hendry *et al.*, 2010). This choice relies on the circumstance that, this kind of companies presents the capabilities and the economies of scope needed to absorb the costs of innovation. Moreover, they are characterized by a stronger funding availability than smaller peers to be allocated toward innovative investments (Damanpour, 2010). In addition, such firms are more likely to hire professional and skilled employees in diverse disciplines, and therefore tend to appoint more heterogeneous directors to manage their complex activities (Alpkan *et al.*, 2010).

Then, we selected companies (i.e. 349) belonging to the industries classified by the literature as high-tech (i.e. information technology, electrical and electronic equipment, telecommunications) (Gharbi *et al.*, 2014). We decided to focus on the high-tech companies as they represent the ideal setting to investigate the effects of board human capital. Indeed, according to prior studies knowledge and skills are the primary sources of their value and competitive advantage (Sáenz *et al.*, 2009).

Finally, we excluded firms with missing financial (i.e. 89) and governance (i.e. 111) data for the whole observation period 2012–2015. Thereby, the selection procedure led to a final sample of 149 firms, corresponding to 596 observations (see Table I). To assess whether the final sample was representative of the initial one, we ran the χ^2 goodness of fit test by dividing the sample in three categories (i.e. information technology, electrical and electronic equipment, telecommunications) according to the industry. Findings show that our sample is representative of the initial one based on industry ($\chi^2 = 2.59$; $p=0.274$).

For these companies, we collected data on innovation and board human capital heterogeneity in terms of educational and functional background.

We gathered information from the AIDA database (Bureau Van Dijk). However, to improve the accuracy of our dataset, and due to the lack of information on the educational and functional background, we also hand-collected data reported in the CVs of the directors appointed to the selected firms. More specifically, we took the board composition of our sample from the AIDA database. Then, we completed an exhaustive search by manually working through the companies' websites, the annual reports, the corporate governance reports and a professional networking website (i.e. LinkedIn).

The following sub-paragraphs and Table II offer a detailed explanation of each variable in our dataset.

4.2 Dependent variables

We tested the firm innovation based on both innovation input (R&D) and output (Patents) as dependent variables:

- R&D is the amount of research and development investments (million euro) as disclosed in the financial statement of the companies in our sample. We chose this

Table I.
Sample selection

Steps	Frequency
Italian firms with number of employees>50 at fiscal year 2012	11,019
	–10,670
High-tech firms	349
(missing financial data for the whole observation window 2012–2015)	–89
	260
(missing governance data for the whole observation window 2012–2015)	–111
Final sample	149
Number of observations (Final sample × Number of years (2012–2015))	596

Table II.
Description of
variables

Variables	Definition	Source
<i>R&D</i>	Research and development investments (million euro)	AIDA database
<i>PATENTS</i>	Value of Patents (million euro)	AIDA database
<i>EDU_HET</i>	Heterogeneity of board education measured through the Blau's index board educational background (3 groups: law and economy; engineering, mathematics and informatics; others)	Hand collected
<i>FUNC_HET</i>	Heterogeneity of board functional background measured through the Blau's index board functional expertise (5 groups: R&D; commercial; finance; human resources; others)	Hand collected
<i>CEO_R&D_EXP</i>	Dummy variable assuming value "1" if CEO is expert in R&D, "0" otherwise	Hand collected
<i>BD_SIZE</i>	Number of directors appointed to the board	AIDA database
<i>INDEP</i>	Number of independent directors divided by the total number of directors on the board	Hand collected
<i>INTERLOCK</i>	Number of interlocked directors on the board	Hand collected
<i>F_SIZE</i>	Number of firm employees	AIDA database
<i>F_AGE</i>	Number of years since the firm founding year	AIDA database
<i>F_LEVERAGE</i>	Total debt divided by total assets (million euro)	AIDA database
<i>F_SALES</i>	Total firm sales (million euro)	AIDA database

variable to proxy for the innovation input as literature suggests that R&D investments represent the driver of innovation processes (Baraldi *et al.*, 2014) and are essential to support companies in accumulating technological capabilities to develop innovation (Chen and Hsu, 2009; Midavaine *et al.*, 2016; Zona *et al.*, 2013).

- *PATENTS* is the value of patents (million euro) disclosed in the financial statement of the companies in our sample. We chose this measure as it is considered as the most common one for the innovation output (Baraldi *et al.*, 2014) and provides an objective information on the innovation and technological changes of companies (Hall *et al.*, 2005; Kim and Kim, 2015)

4.3 Independent variables

Our explanatory variables included the board human capital heterogeneity and the CEO expertise:

- *EDU_HET* catches the heterogeneity of board educational background. Following prior studies, we computed this variable through the Blau's (1977) index of board educational background as it is the most commonly accepted measure of heterogeneity/variety (Harrison and Klein, 2007). The construct under scrutiny is an index of observation dispersion over specific categories and is equal to $1 - \sum_{i=1}^N \rho_i$ (i stands for the educational background category, ρ is the proportion of individuals in each category, n is the number of categories). To compute the index, we applied the following categorization to the type of educational background of directors: law and economy; engineering, mathematics and informatics; others (Kor, 2006; Clarysse *et al.*, 2007). The index ranges from "0" (absolute educational homogeneity) to "1" (absolute educational heterogeneity).
- *FUNC_HET* catches the board functional background heterogeneity. It was computed through the Blau's index (1977) of board functional background (Harrison and Klein, 2007). More specifically, the construct is equal to $1 - \sum_{i=1}^N \rho_i$ where i stands for the functional background category. To compute the index, we applied the following categorization to the of type of functional background of

directors: R&D, commercial, finance, human resources, others (Kor, 2006; Clarysse *et al.*, 2007). The index ranges from “0” (absolute functional homogeneity) to “1” (absolute functional heterogeneity).

- *CEO_R&D_EXP* proxies for the CEO expertise-overlap within the innovation domain. The circumstance under scrutiny occurs when the CEO expertise covers innovation activities. Following prior literature, we categorized the CEOs according to their previous professional experience in the R&D function, as it is a department devoted to technology and innovation activities (Ahn *et al.*, 2017; Barker III and Mueller, 2002). It is a dummy variable that takes value “1” when the CEO is expert in R&D and “0” otherwise.

4.4 Control variables

In line with prior literature, we included several control variables reflecting the characteristics of both companies and boards (Midavaine *et al.*, 2016). In particular, we controlled for the following variables:

- *BD_SIZE* proxies for the board size and is equal to the number of directors appointed to the board (Han *et al.*, 2015).
- *INDEP* is equal to the number of independent directors divided by the total number of directors on the board (Chen and Hsu, 2009).
- *INTERLOCK* is equal to the number of interlocked directors appointed to the board (Han *et al.*, 2015).
- *F_SIZE* proxies for the firm size and is measured as the total number of company employees (Zona *et al.*, 2013).
- *F_AGE* proxies for the firm age and is computed as the number of years since the firm founding year (Zona *et al.*, 2013).
- *F_LEVERAGE* proxies for the firm leverage and is computed by the total debt divided by total assets (million euro) as disclosed in the financial statement of each company.
- *F_SALES* is equal to the value of firm sales (million euro) as disclosed in the income statement of each company.

4.5 Data analyses

To test our hypotheses, we used pooled ordinary least squares (OLS) regression analyses, reporting the robust standard errors for each regression coefficient and using two proxies for innovation. We chose the pooled OLS regression after checking whether the random or fixed effect regressions were more appropriate compared to the pooled OLS regression by running the Breusch-Pagan Lagrange multiplier test (Mertens *et al.*, 2017). The results of the test show that the pooled OLS regression is a valid estimation strategy and therefore the panel data solution is not preferable.

On the basis of these premises, to test *H1* we estimated the following models:

$$\begin{aligned} R\&D_i = & \beta_0 + \beta_1 \times EDU_HET_i + \beta_2 \times B_SIZE_i + \beta_3 \times INDEP_i \\ & + \beta_4 \times INTERLOCK_i + \beta_5 \times F_SIZE_i + \beta_6 \times F_AGE_i \\ & + \beta_7 \times F_LEVERAGE_i + \beta_8 \times F_SALES_i + \beta_9 \times year_i + \beta_{10} \times firm_i + \epsilon_i, \end{aligned}$$

$$\begin{aligned}
 PATENTS_i = & \beta_0 + \beta_1 \times EDU_HET_i + \beta_2 \times B_SIZE_i + \beta_3 \times INDEP_i \\
 & + \beta_4 \times INTERLOCK_i + \beta_5 \times F_SIZE_i + \beta_6 \times F_AGE_i \\
 & + \beta_7 \times F_LEVERAGE_i + \beta_8 \times F_SALES_i + \beta_9 \times year_i + \beta_{10} \times firm_i + \epsilon_i.
 \end{aligned}$$

Differently, to test [H2](#) we estimated the following models:

$$\begin{aligned}
 R\&D_i = & \beta_0 + \beta_1 \times FUNC_HET_i + \beta_2 \times B_SIZE_i + \beta_3 \times INDEP_i \\
 & + \beta_4 \times INTERLOCK_i + \beta_5 \times F_SIZE_i + \beta_6 \times F_AGE_i \\
 & + \beta_7 \times F_LEVERAGE_i + \beta_8 \times F_SALES_i + \beta_9 \times year_i + \beta_{10} \times firm_i + \epsilon_i, \\
 PATENTS_i = & \beta_0 + \beta_1 \times FUNC_HET_i + \beta_2 \times B_SIZE_i + \beta_3 \times INDEP_i \\
 & + \beta_4 \times INTERLOCK_i + \beta_5 \times F_SIZE_i + \beta_6 \times F_AGE_i \\
 & + \beta_7 \times F_LEVERAGE_i + \beta_8 \times F_SALES_i + \beta_9 \times year_i + \beta_{10} \times firm_i + \epsilon_i.
 \end{aligned}$$

Finally, to test [H3](#) we estimated the following models:

$$\begin{aligned}
 R\&D_i = & \beta_0 + \beta_1 \times EDU_HET + \beta_2 \times FUNC_HET_i + \beta_3 \times CEO_R\&D_EXP_i \\
 & + \beta_4 \times (EDU_HET \times CEO_R\&D_EXP)_i \\
 & + \beta_5 \times (FUNC_HET \times CEO_R\&D_EXP)_i \\
 & + \beta_6 \times B_SIZE_i + \beta_7 \times INDEP_i + \beta_8 \times INTERLOCK_i \\
 & + \beta_9 \times F_SIZE_i + \beta_{10} \times F_AGE_i + \beta_{11} \times F_LEVERAGE_i \\
 & + \beta_{12} \times F_SALES_i + \beta_{13} \times year_i + \beta_{14} \times firm_i + \epsilon_i, \\
 PATENTS_i = & \beta_0 + \beta_1 \times EDU_HET + \beta_2 \times FUNC_HET_i + \beta_3 \times CEO_R\&D_EXP_i \\
 & + \beta_4 \times (EDU_HET \times CEO_R\&D_EXP)_i \\
 & + \beta_5 \times (FUNC_HET \times CEO_R\&D_EXP)_i \\
 & + \beta_6 \times B_SIZE_i + \beta_7 \times INDEP_i + \beta_8 \times INTERLOCK_i + \beta_9 \times F_SIZE_i \\
 & + \beta_{10} \times F_AGE_i + \beta_{11} \times F_LEVERAGE_i + \beta_{12} \times F_SALES_i \\
 & + \beta_{13} \times year_i + \beta_{14} \times firm_i + \epsilon_i.
 \end{aligned}$$

5. Findings

[Table III](#) reports the descriptive statistics of our variables. It illustrates that, in the sample under investigation, R&D investments are on average 0.119ml, while the mean value of patents is 0.186ml. Concerning the board human capital heterogeneity, the descriptives highlight that the board is more likely to be diverse in terms of educational (0.595) than functional background (0.343). Furthermore, our results show that the majority of sample firms are ruled by CEOs expert in R&D (0.551).

[Table IV](#) reports the Pearson bivariate correlations to check for potential multicollinearity. As a rule of thumb, a problem of multicollinearity exists if the pairwise correlation coefficients between two regressors are normally in excess of 0.8 ([Gujarati, 2004](#)). As shown in the matrix, the coefficients for each explanatory variable in the regression models range from -0.210 to 0.717 . The values are below the threshold and

Table III.
Descriptives

Variables	<i>n</i>	Min.	Mean	Median	Max.	SD
<i>R&D</i>	596	0	0.119	0.000	3.588	0.415
<i>PATENTS</i>	596	0	0.186	0.000	10.510	0.776
<i>EDU_HET</i>	596	0	0.343	0.408	1.000	0.244
<i>FUNC_HET</i>	596	0	0.595	0.640	0.790	0.163
<i>CEO_R&D_EXP</i>	596	0	0.551	1	1	0.498
<i>BD_SIZE</i>	596	1	11.800	8	20	10.641
<i>INDEP</i>	596	0	0.039	0.000	0.600	0.094
<i>INTERLOCK</i>	596	1	3.369	3	16	2.740
<i>F_SIZE</i>	596	50	424.034	190.000	6,612.000	869.514
<i>F_AGE</i>	596	3	21.879	21	65	10.715
<i>F_LEVERAGE</i>	596	0	0.738	0.050	10.130	1.389
<i>F_SALES</i>	596	0.16	76.250	32.433	1,298.776	150.901

suggest that there are not serious correlation problems among our variables. These results are also supported by the test of the variance inflation factor (VIF) for all models. Indeed, taking into consideration that there is a serious multicollinearity concern if the VIF is higher than 10 (Wincent *et al.*, 2014), it is important to note that the VIF of our variables are lower than 3.

Table IV also shows other important findings that need to be mentioned. In particular, the correlation matrix enlightens a positive and statistically significant relationship between firm size and board size. Indeed, according to previous research, larger firms are more complex and need larger boards in order to increase the monitoring and specialization skills of their members (Boone *et al.*, 2007). Moreover, findings highlight a positive correlation between the proportion of independent directors and the value of patents. This circumstance emphasizes the role played by independent directors as guardians for innovation. Indeed, literature suggests that non-executive directors stress the importance for managers to develop and maintain innovative capabilities (Kor, 2006). Finally, it is worth noting that there is a lack of correlation between our proxies for innovation (i.e. R&D and patents). As suggested by previous studies, this finding is in line with the national level of our analysis (Baraldi *et al.*, 2014; Shapiro, 2001) and can be justified taking into consideration that Italy is characterized by a low propensity to patent due to the weak level of protection of property rights (Levy-Carciente, 2017).

Turning the attention to the hypotheses assessment, Table V illustrates the results of the pooled OLS regressions testing the relationship between board human capital (educational and functional) heterogeneity and the innovation input as proxied by R&D investments.

Specifically, Models (1) and (2) examine the effect of board educational background heterogeneity on R&D investments (*H1*), respectively without and with year and firm dummy control variables. Similarly, Models (3) and (4) investigate the effect of functional background heterogeneity on the innovation input variable (*H2*) by including the same control variables of Models (1) and (2). Finally, Model (5) assesses the effect of both board educational and functional background heterogeneity, while Model (6) tests the interaction effect of the two measures of board human capital diversity.

All models are statistically significant and provide evidence on the relationships between our independent variables and R&D investments.

The analyses of Models (1) and (2) show that the coefficient of educational background heterogeneity (*EDU_HET*) is positive and statistically significant (Model 1: $\beta=0.199$; $p<0.05$; Model 2: $\beta=0.193$; $p<0.05$). Therefore, we can assert that *H1* is supported as a board with higher diversity in terms of educational background is more likely to invest in innovation.

<i>n</i>	Variables	1	2	3	4	5	6	7	8	9	10	11	12
1	<i>R&D</i>	1											
2	<i>PATENTS</i>	-0.058	1										
3	<i>EDU_HET</i>	0.075*	0.124***	1									
4	<i>FUNC_HET</i>	0.046	0.139***	0.329***	1								
5	<i>CEO_R&D_EXP</i>	0.080*	-0.006	-0.110***	-0.074*	1							
6	<i>BD_SIZE</i>	-0.065	0.139***	0.265***	0.394***	-0.009	1						
7	<i>INDEP</i>	0.057	0.224***	0.175***	0.161***	0.084**	0.196***	1					
8	<i>INTERLOCK</i>	0.000	-0.035	-0.056	-0.022	-0.038	0.051	-0.036	1				
9	<i>F_SIZE</i>	-0.010	0.115***	0.145***	0.136***	-0.033	0.356***	0.093**	-0.039	1			
10	<i>F_AGE</i>	0.035	-0.031	-0.015	0.013	-0.032	-0.002	0.058	-0.205***	-0.025	1		
11	<i>F_LEVERAGE</i>	0.177***	-0.083**	-0.177***	-0.145***	-0.029	-0.210***	-0.050	-0.136***	-0.086**	-0.072*	1	
12	<i>F_SALES</i>	-0.055	0.338***	0.101**	0.152***	-0.116***	0.366***	0.177***	-0.041	0.717***	0.020	-0.141***	1

Notes: * $p < 0.1$; ** $p < 0.05$; *** $p < 0.01$

Table IV.
Correlation matrix

Table V.
OLS regression models
testing *H1* and *H2*
(dependent
variable: R&D)

Variables	Model 1	Model 2	Model 3	Model 4	Model 5	Model 6
<i>EDU_HET</i>	0.199** (0.085)	0.193** (0.084)	0.239*** (0.068)	0.314*** (0.083)	0.154* (0.081)	-0.124 (0.102)
<i>FUNC_HET</i>					0.253*** (0.077)	0.110 (0.105)
<i>EDU × FUNC_HET</i>						0.516** (0.240)
<i>BD_SIZE</i>	-0.003** (0.001)	-0.003** (0.001)	-0.003** (0.001)	-0.004*** (0.001)	-0.04*** (0.001)	-0.005*** (0.001)
<i>INDEP</i>	0.284 (0.242)	0.208 (0.249)	0.318 (0.248)	0.210 (0.257)	0.170 (0.254)	0.164 (0.251)
<i>INTERLOCK</i>	0.008 (0.005)	0.008 (0.005)	0.007 (0.005)	0.008 (0.005)	0.009* (0.005)	0.010* (0.005)
<i>F_SIZE</i>	0.000* (0.000)	0.000 (0.000)	0.000** (0.000)	0.000* (0.000)	0.000 (0.000)	0.000* (0.000)
<i>F_AGE</i>	0.002 (0.002)	0.001 (0.002)	0.002 (0.002)	0.000 (0.002)	0.001 (0.002)	0.001 (0.002)
<i>F_LEVERAGE</i>	0.058*** (0.015)	0.052*** (0.014)	0.055*** (0.015)	0.048*** (0.014)	0.052*** (0.015)	0.053*** (0.015)
<i>F_SALES</i>	-0.000** (0.000)	-0.000*** (0.000)	-0.000*** (0.000)	-0.000*** (0.000)	-0.000*** (0.000)	-0.000*** (0.000)
<i>CONSTANT</i>	-0.047 (0.062)	0.069 (0.080)	-0.108 (0.070)	-0.007 (0.075)	-0.035 (0.083)	0.032 (0.085)
<i>YEAR DUMMY</i>		Yes	Yes	Yes	Yes	Yes
<i>FIRM DUMMY</i>		Yes	Yes	Yes	Yes	Yes
Observations	596	596	596	596	596	596
<i>F</i>	4.49***	3.35***	4.62***	3.05***	2.86***	2.67***
<i>R</i> ²	0.056	0.069	0.051	0.069	0.076	0.080

Notes: Standard errors are provided in parentheses. * $p < 0.1$; ** $p < 0.05$; *** $p < 0.01$

Similar findings are reported for board functional background heterogeneity. Indeed, the analyses of Models (3) and (4) show that the coefficient of board functional background heterogeneity (*FUNC_HET*) is positive and statistically significant (Model 3: $\beta=0.239$; $p<0.01$; Model 4: $\beta=0.314$; $p<0.01$). This result supports *H2* predicting that the board functional background heterogeneity positively influences the board commitment to innovation as measured by R&D investments.

The positive effects of board educational and functional background heterogeneity are still statistically significant even when the regression incorporates both the diversity variables (Model 5). Moreover, when we add the interaction term in the Model (6) (*EDU* $\times$ *FUNC_HET*), the related predictive power increases (see the R^2) and the coefficient of the interaction term is positive and statistically significant (Model 6: $\beta=0.516$; $p<0.05$). This result suggests that the coexistence of both educational and functional background heterogeneity increases the innovation input.

As previously stated, we also test the presence of a relationship between board human capital heterogeneity and the innovation output. Indeed, Table VI illustrates the same models of Table V by employing the value of patents (*PATENTS*) as alternative dependent variable.

Consistent with the results in Table V, all models included in Table VI are statistically significant and support the predictions of a positive relationship between our independent variables and the value of patents.

More specifically, Models (1) and (2) provide support for *H1* as the coefficients of board educational background heterogeneity (*EDU_HET*) are positive and statistically significant (Model 1: $\beta=0.253$; $p<0.05$; Model 2: $\beta=0.249$; $p<0.05$). Similarly, the analyses of Models (3) and (4) support *H2* as the coefficients of board functional background heterogeneity (*FUNC_HET*) are positive and statistically significant (Model 3: $\beta=0.362$; $p<0.01$; Model 4: $\beta=0.397$; $p<0.01$). Finally, the findings provided by Models (5) and (6) in Table V are confirmed in Table VI. Indeed, the analysis shows that, if the model includes both the educational and functional background heterogeneity, the related coefficients are positive and statistically significant at the 5 percent level (Model 5). Moreover, when the regression incorporates the interaction term (*EDU* $\times$ *FUNC_HET*), the coefficient of this variable is positive and statistically significant (Model 6: $\beta=0.677$; $p<0.1$). Thereby, findings support the conclusion that the coexistence of both measures of board human capital heterogeneity increases the board commitment to innovation as measured by the value of patents.

Shifting the attention to the moderation effect of the CEO expertise-overlap within the innovation domain on the relationship between board human capital heterogeneity and firm innovation, Tables VII and VIII report the results of the pooled OLS regression analyses testing *H3*, respectively with R&D investments and value of patents as proxies for innovation.

In particular, Table VII shows that the main effect of CEO expertise in R&D (*CEO_R&D_EXP*) on innovation input is positive and statistically significant (Model 1: $\beta=0.190$, $p<0.01$). As for the interaction between this variable and the educational background heterogeneity, the model highlights that, consistently with the correlations (see Table IV), the coefficient is negative and also statistically significant (Model 1: $\beta=-0.250$, $p<0.1$). This result suggests that the CEO expertise-overlap within the innovation domain negatively moderates the main relationship between board educational background heterogeneity and innovation, thus rejecting *H3*. However, it is worth noting that the construct of the interaction term could be biased by the characteristics of our sample and its sign and statistical significance could depend on the negative correlation between *CEO_R&D_EXP* and *EDU_HET*. Therefore, in order to assess the effective presence of the expected moderation of CEO expertise in R&D on the relationship between the educational background heterogeneity and our measure of innovation input, we have performed additional robustness tests (see Appendix). In particular, we have run the regression Model (1) of Table VII by employing an alternative measure of firm outcome (i.e. ROI) as dependent variable. Results show that the interaction term is negative but

Table VI.
OLS regression models
testing *H1* and *H2*
(dependent variable:
patents)

Variables	Model 1	Model 2	Model 3	Model 4	Model 5	Model 6
<i>EDU_HET</i>	0.253*** (0.099)	0.249** (0.098)	0.362*** (0.125)	0.397*** (0.147)	0.199** (0.085)	-0.166 (0.147)
<i>FUNC_HET</i>					0.320** (0.125)	0.131 (0.102)
<i>EDU × FUNC_HET</i>						0.677* (0.354)
<i>BD_SIZE</i>	0.000 (0.004)	0.000* (0.004)	-0.001 (0.004)	-0.001 (0.004)	-0.001 (0.004)	-0.002 (0.005)
<i>INDEP</i>	1.232** (0.582)	1.195** (0.598)	1.267** (0.583)	1.199** (0.602)	1.148* (0.600)	1.139* (0.597)
<i>INTERLOCK</i>	-0.009* (0.005)	-0.008* (0.005)	-0.010** (0.005)	-0.009* (0.005)	-0.007 (0.005)	-0.006 (0.005)
<i>F_SIZE</i>	-0.000** (0.000)	-0.000** (0.000)	-0.000** (0.000)	-0.000** (0.000)	-0.000** (0.000)	-0.000** (0.000)
<i>F_AGE</i>	-0.005** (0.002)	-0.004** (0.002)	-0.005** (0.002)	-0.005** (0.002)	-0.005** (0.002)	-0.005** (0.002)
<i>F_LEVERAGE</i>	-0.013 (0.010)	-0.016 (0.012)	-0.017* (0.010)	-0.021 (0.013)	-0.016 (0.012)	-0.014 (0.012)
<i>F_SALES</i>	0.003*** (0.001)	0.002*** (0.000)	0.002*** (0.001)	0.002*** (0.001)	0.002*** (0.001)	0.002*** (0.001)
<i>CONSTANT</i>	0.100 (0.076)	0.219* (0.113)	-0.010 (0.090)	0.125 (0.100)	0.089 (0.104)	0.176* (0.096)
<i>YEAR DUMMY</i>		Yes		Yes	Yes	Yes
<i>FIRM DUMMY</i>		Yes		Yes	Yes	Yes
Observations	596	596	596	596	596	596
<i>F</i>	8.57***	6.66***	8.55***	6.40***	6.22***	5.98***
<i>R</i> ²	0.184	0.189	0.183	0.189	0.192	0.194

Notes: Standard errors are provided in parentheses. * $p < 0.1$; ** $p < 0.05$; *** $p < 0.01$

Variables	Model 1 Full sample	Model 2 Firms with CEO expert in R&D	Model 3 Firms with CEO not expert in R&D	Model 4 Firms with CEO expert in R&D	Model 5 Firms with CEO not expert in R&D
<i>EDU_HET</i>	0.299*** (0.100)	0.061 (0.105)	0.367*** (0.113)		
<i>FUNC_HET</i>	0.306*** (0.110)			0.127*** (0.081)	0.520*** (0.185)
<i>CEO_R&D_EXP</i>	0.190*** (0.070)				
<i>EDU_HET</i> × <i>CEO_R&D_EXP</i>	−0.250* (0.140)				
<i>FUNC_HET</i> × <i>CEO_R&D_EXP</i>	−0.031 (0.109)				
<i>BD_SIZE</i>	−0.004*** (0.001)	0.000 (0.002)	−0.004** (0.002)	−0.001 (0.002)	−0.007** (0.003)
<i>INDEP</i>	0.135 (0.243)	0.539 (0.360)	−0.450*** (0.163)	0.503 (0.375)	−0.389** (0.158)
<i>INTERLOCK</i>	0.011** (0.005)	0.009 (0.005)	0.012 (0.008)	0.009* (0.005)	0.009 (0.008)
<i>F_SIZE</i>	0.000 (0.000)	0.000** (0.000)	−0.000 (0.000)	0.000*** (0.000)	0.000 (0.000)
<i>F_AGE</i>	0.002 (0.002)	0.000 (0.002)	0.003 (0.002)	0.001 (0.002)	0.002 (0.002)
<i>F_LEVERAGE</i>	0.054*** (0.014)	0.079*** (0.024)	0.038*** (0.016)	0.077*** (0.024)	0.033* (0.017)
<i>F_SALES</i>	−0.000** (0.000)	−0.000** (0.000)	0.000 (0.000)	−0.001** (0.000)	−0.000 (0.000)
<i>CONSTANT</i>	−0.188** (0.085)	0.088 (0.212)	−0.072 (0.062)	0.014 (0.111)	−0.150* (0.090)
<i>YEAR DUMMY</i>	Yes	Yes	Yes	Yes	Yes
<i>FIRM DUMMY</i>	Yes	Yes	Yes	Yes	Yes
Observations	596	324	272	324	272
<i>F</i>	2.66***	2.18**	1.24	2.13**	1.10
<i>R</i> ²	0.090	0.086	0.132	0.092	0.104

Notes: Standard errors are provided in parentheses. * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$

Table VII.
OLS regression models
testing *H3* (dependent
variable: R&D)

Variables	Model 1 Full sample	Model 2 Firms with CEO expert in R&D	Model 3 Firms with CEO not expert in R&D	Model 4 Firms with CEO expert in R&D	Model 5 Firms with CEO not expert in R&D
<i>EDU_HET</i>	0.220 (0.133)	0.297** (0.116)	0.224 (0.151)		
<i>FUNC_HET</i>	0.262 (0.236)			0.367** (0.146)	0.532 (0.325)
<i>CEO_R&D_EXP</i>	0.011 (0.144)				
<i>EDU_HET</i> × <i>CEO_R&D_EXP</i>	−0.012 (0.165)				
<i>FUNC_HET</i> × <i>CEO_R&D_EXP</i>	0.094 (0.249)				
<i>BD_SIZE</i>	−0.002 (0.005)	0.001 (0.005)	−0.003 (0.004)	0.001 (0.005)	−0.006 (0.005)
<i>INDEP</i>	1.105* (0.576)	0.948 (0.577)	1.731** (0.876)	0.968 (0.599)	1.757** (0.873)
<i>INTERLOCK</i>	−0.006 (0.005)	−0.020*** (0.006)	0.004 (0.006)	−0.020*** (0.006)	0.003 (0.006)
<i>F_SIZE</i>	−0.000*** (0.000)	−0.000 (0.000)	−0.000 (0.000)	−0.000 (0.000)	−0.000 (0.000)
<i>F_AGE</i>	−0.005* (0.002)	−0.005 (0.003)	−0.005* (0.002)	−0.005 (0.003)	−0.006** (0.002)
<i>F_LEVERAGE</i>	−0.014 (0.012)	−0.022 (0.019)	−0.012 (0.016)	−0.033 (0.020)	−0.013 (0.017)
<i>F_SALES</i>	0.003*** (0.001)	0.003 (0.002)	0.002** (0.001)	0.003 (0.002)	0.002** (0.001)
<i>CONSTANT</i>	0.074 (0.165)	0.233 (0.162)	0.216* (0.128)	0.156 (0.140)	0.048 (0.157)
<i>YEAR DUMMY</i>	Yes	Yes	Yes	Yes	Yes
<i>FIRM DUMMY</i>	Yes	Yes	Yes	Yes	Yes
Observations	596	324	272	324	272
<i>F</i>	4.95***	1.87**	11.22***	2.24***	11.68***
<i>R</i> ²	0.193	0.148	0.287	0.148	0.289

Notes: Standard errors are provided in parentheses. * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$

Table VIII.
OLS regression models
testing *H3* (dependent
variable: patents)

it is not statistically significant. This circumstance highlights that the interaction between the CEO expertise-overlap within the innovation domain and the board educational heterogeneity does not depend on the sample characteristics but it is only relevant for R&D.

Shifting the attention to the board functional background heterogeneity, our findings report that the CEO expertise in R&D does not moderate the relationship between *FUNC_HET* and *R&D*, thus not supporting *H3*.

To shed light into the implications of educational and functional background heterogeneity for innovation according to the presence of the CEO expertise-overlap within the innovation domain, we have also run our regression by splitting the sample according to the dummy variable *CEO_R&D_EXP* (Models 2–5). Our analyses show that the coefficient of board educational background heterogeneity is positive and statistically significant in the sub-sample characterized by inexperienced CEOs in R&D (Model 3: $\beta=0.367, p<0.01$) but not in the sub-sample with CEOs expert in R&D. Moreover, our findings highlight that the effect of functional background heterogeneity is positive and statistically significant in both sub-samples (Model 4: $\beta=0.127, p<0.01$; Model 5: $\beta=0.520, p<0.01$).

The same is not true for the findings of the regression analyses testing *H3* with the value of patents as proxy for innovation. Indeed, as shown in [Table VIII](#), the influence of CEO expertise in R&D (*CEO_R&D_EXP*) on innovation is positive but not statistically significant. Similar results are shown by the interaction terms as Model (1) highlights that the regression coefficients of the interaction terms (*EDU_HET*×*CEO_R&D_EXP* and *FUNC_HET*×*CEO_R&D_EXP*) are not statistically significant. However, turning the attention to the implications of educational and functional background heterogeneity on innovation in the sub-sample with a CEO expert in R&D (Models 2–5), [Table VIII](#) highlights that *H3* is supported. Indeed, it shows that the regression coefficients of board educational (Model 2: $\beta=0.297, p<0.05$) and functional (Model 4: $\beta=0.367, p<0.05$) background heterogeneity are positive and statistically significant. Consistently with this conclusion, the coefficients of both educational and functional background are not statistically significant for the models tested in the sub-sample with inexperienced CEOs.

6. Discussion and conclusions

The study explores how board human capital heterogeneity, in terms of educational and functional background, affects the board commitment to innovation in the high-tech context. To examine this relationship, the paper relies on a sample of 149 Italian high-tech firms observed between 2012 and 2015.

As shown in [Table IX](#), results confirm that the board heterogeneity in terms of educational background positively contributes to both innovation input (R&D investments) and output (value of patents). Indeed, according to our analysis, high-tech companies run by more heterogeneous boards in terms of education are more likely to invest in innovation. This finding suggests that directors with different educational backgrounds provide the board with diversity of knowledge and information-processing behaviors that increase the breadth of the group cognitive perspectives ([Gradstein and Justman, 2000](#)). This circumstance improves the creative breakthrough of directors and supports them in processing more comprehensive information, leading to more complex and innovative decisions ([Gradstein and Justman, 2000](#); [Finkelstein and Hambrick, 1996](#)). Shifting the attention to the implications of diversity for the organizational conflicts, our results highlight that the educational background heterogeneity of directors improves the board decision-making by involving conflicting but fruitful processes able to produce innovative ideas ([Hillman et al., 2002](#)). Moreover, from a different standpoint, our findings support the idea that the educational diversity hampers the risk aversion of directors and results in more innovative approaches to problem-solving and decision-making ([Van Knippenberg and Schippers, 2007](#)). All these

arguments especially apply to the high-tech context where board diversity is limited and innovation is a key resource for companies (Cumming *et al.*, 2015). On the one side, the educational background heterogeneity brings to the board scientific and specialized skills useful to solve the complex and challenging tasks of high-tech industry. On the other side, the diversity of knowledge and skills makes the board more flexible and cognizant to new business ideas since innovation requires that companies have a high level of flexibility (Pitcher and Smith, 2001; Latimer, 1998).

Moreover, consistent with our expectations, the research findings provide evidence on the presence of a positive relationship between the functional background heterogeneity and both innovation input and output (Wincent *et al.*, 2010, 2014; Sundaramurthy and Lewis, 2003). This circumstance can be interpreted in the light of the cognitive approach suggesting that, for complex matters like innovation, the interaction among directors with heterogeneous expertise results in high-innovative board decisions (Hambrick *et al.*, 1996). Indeed, the functional background heterogeneity of directors brings the board with representatives of various business functions that enrich the boardroom cross-functional discussions (Bantel and Jackson, 1989), providing a broader set of interpretations of current issues (Forbes and Milliken, 1999). In addition, our results emphasize that the presence of directors belonging to different functions boosts the company's innovation attitude as it increases the communication level among directors outside the board (Ancona and Caldwell, 1992) and improves the information useful to identify innovative initiatives (Joshi and Roh, 2009; Mahadeo *et al.*, 2012). This circumstance is especially true in the high-tech context (Joshi and Roh, 2009) as previous studies suggest that the competence diversity of board members could be more relevant in industries characterized by low level of diversity (Cumming *et al.*, 2015).

At the same time, our evidence highlights that the presence of the CEO expertise-overlap within the innovation domain moderates the relationship between board human capital heterogeneity and firm innovation (Buyl *et al.*, 2011; Kim and Kim, 2015). Thereby, it supports the idea that the effectiveness of managerial teams depends on the demographic characteristics and professional experiences of their leader (Kisfalvi and Pitcher, 2003; Roach and Sauermann, 2010). Indeed, our study reports that the presence of a CEO expert in R&D negatively affects the relationship between educational background heterogeneity of directors and company innovation input (i.e. R&D investments). These findings suggests that, when CEOs are expert in R&D, they drive the firm innovation processes (Arendt *et al.*, 2005; Jaw and Lin, 2009) while the diversity of board members does not produce any effect. This result validates the assumption that CEOs with a professional experience consistent with innovation are more likely to address the challenges of innovation initiatives as their expertise-overlap positively influences the way they set priorities and prompts the achievement of innovation targets (Hambrick and Mason, 1984; da Mota Pedrosa *et al.*, 2013).

Hypotheses	Expected sign	Findings	
		R&D	Patents
H1. In the high-tech context, the board educational background heterogeneity positively affects firm innovation	+	Supported (+)	Supported (+)
H2. In the high-tech context, the board functional background heterogeneity positively affects firm innovation	+	Supported (+)	Supported (+)
H3. In the high-tech context, the CEO expertise-overlap within the innovation domain positively moderates the relationship between board human capital (educational and functional background) heterogeneity and firm innovation	+	Rejected (–)	Supported (+)

Table IX.
Summary of
hypothesized
relationships and
research findings

Therefore, they are less likely to be vulnerable to efficiency concerns and more likely to invest in R&D (Barker and Mueller, 2002; Finkelstein and Hambrick, 1996). Differently our results indicate that, when CEOs are inexperienced in R&D, the board decision-making process is influenced by its heterogeneity, thus supporting innovation opportunities (Hambrick and Mason, 1984). Taken together, these findings highlight that the CEO expertise and the board heterogeneity in the high-tech context act as substitutes for the input of innovation process (i.e. R&D investments) (Heyden *et al.*, 2018).

Different conclusions can be drawn when looking at the implications of human capital heterogeneity for innovation output (i.e. value of patents). Indeed, our results reveal that the CEO expertise-overlap within the innovation domain boosts the positive effects of both educational and functional heterogeneity of board members, thus improving company innovation. These findings confirm that the team diversity *per se* does not affect company innovation, unless the CEO features make the debate on innovation as systematic (Kisfalvi and Pitcher, 2003). Indeed, CEOs play a unique and pivotal role in driving the innovation processes (Jaw and Lin, 2009; Tharnpas and Boon-itt, 2018) by fostering the exchange of innovative ideas among team members (Simsek *et al.*, 2005). Therefore our analyses highlight that, in the high-tech context, the CEO expertise-overlap and the board heterogeneity act as complements for the output of innovation process (i.e. patents) (Midavaine *et al.*, 2016; Bravo and Reguera-Alvarado, 2017).

The results discussed above have potentially wide-ranging contributions for academics, managers and policy makers.

As for scholars, our paper broadens the literature on board diversity and board capital. First of all, it extends previous research that has explored only one facet of board human capital heterogeneity as our study disentangles the effects of two dimensions of board human capital diversity (i.e. educational and functional background) on company innovation (Kim and Lim, 2010; Buyl *et al.*, 2011; Midavaine *et al.*, 2016). Shifting the focus on the type of heterogeneity and documenting the positive effect of educational background diversity on company innovation, our paper integrates the literature on the topic as it has only explored the implications of the level of board educational heterogeneity without examining the effects of the related area (Midavaine *et al.*, 2016). Moreover, focusing on the other measure of board human capital heterogeneity, our study advances previous empirical research that has not provided conclusive evidence on the reported sign of the relationship between functional background diversity and firm innovation. Indeed, differently from the studies highlighting that expertise diversity increases the competition among top executives of different departments for the resources' allocation, and hampers the board commitment to innovation (Hambrick *et al.*, 1996; Kor, 2006), our paper provides evidence on the positive effect of functional background heterogeneity on innovation by supporting the cognitive approach arguments (Cannella *et al.*, 2008; Hambrick *et al.*, 1996). Furthermore, our research integrates the literature on the CEO-board interface by supporting the expectation that the CEO characteristics moderate the link between board/TMT features and firm outcomes (Kisfalvi and Pitcher, 2003). Specifically, unlike previous studies, our paper documents the implications of the CEO functional expertise within the innovation domain for the relationship between board human capital heterogeneity and innovation in the high-tech context. An additional contribution to the research on the implications of board heterogeneity for firm innovation relies on the empirical design of our study as it appreciates the dependent variable through two different measures. Indeed, differently from previous research (Midavaine *et al.*, 2016; Kim and Kim, 2015; Bianchi Martini *et al.*, 2012), it tests the effect of our main explanatory variables on both firm innovation input (R&D investments) and output (value of patents). Finally, our paper fills a gap in the literature as it focuses on underexplored contexts. Indeed, on the one side, it extends the research on the Italian setting where scholars have only investigated the connection between board human capital heterogeneity and financial performance (Antonelli

et al., 2013). On the other side, it integrates the literature on the high-tech context by supporting the prediction that, in growing and high competitive settings, the board human capital heterogeneity can be especially useful to cope with novel problems (House *et al.*, 1971).

From a managerial standpoint, our paper improves the awareness of directors on the positive implications of the related background for their decision-making effectiveness. More specifically, the study suggests that firm innovation is not limited to the R&D department but it is also affected by the board human capital heterogeneity. Thereby, our findings highlight that the board composition should be designed as a whole, without evaluating the background of each director separately from the others. In this vein, the board nomination committee should appoint directors by going beyond the typical talent pools and ensuring enough diversity in terms of educational and functional background so as to provide novel and fresh resources for firm innovation. The managerial implications of our study also stem from the findings related to the CEO-board interface. Indeed, by reporting that the human capital of CEOs interacts with the board and affects its decision-making, the paper suggests that companies should ensure the consistency between CEO and board characteristics.

At the same time, from a policy standpoint, our findings take over from the European Commission (i.e. Directive 2014/95/EU) and reawaken the attention of policy makers toward the importance of stimulating the appointment of directors with different educational and functional backgrounds to enhance the firms' innovative outcomes. In this sense, our paper suggests regulators to improve the corporate governance code and guidelines by also disciplining "soft" issues, such as the board human capital, rather than only the "hard" ones (e.g. CEO duality and directors' independence). This is especially true in a challenging context, such as the high-tech setting, where the intellectual capital is the primary source of competitive advantage (Sáenz *et al.*, 2009) and the background heterogeneity can be helpful in solving complex tasks (Pitcher and Smith, 2001; Latimer, 1998).

When drawing these conclusions, it is noteworthy to enlighten certain limitations that provide new insights and implications for future studies. A first limitation concerns the quantitative nature of our research. In this regard, literature highlights the need to focus on behavioural processes and dynamics inside and outside the boardroom (Forbes and Milliken, 1999). In this sense, future studies could combine primary survey data on board processes and in-depth interviews to offer new intriguing inquiries on the topic. Moreover, as exploring heterogeneity in boardroom is only one aspect of examining the implications of human capital at the "top floor," future research could assess how the TMT heterogeneity may be relevant for firm innovation propensity by looking at the complementarity and substitutive effects of board and TMT human capital heterogeneity. In addition, a considerable amount of research remains to be done in order to improve our understanding on the other side of the coin of board capital by exploring the contribution of board social capital heterogeneity to company outcomes. From a different standpoint, future research may explore the effects of alternative CEO expertise areas as we provide evidence on the implications of only one type of CEO functional expertise for the relationship between board human capital heterogeneity and innovation. Finally, despite we focus on an underexplored context such as the high-tech one, the research findings may not be generalizable to other industries. Therefore, following a contingency perspective, future studies could investigate how dissimilar settings (e.g. "diverse" vs "homogenous"; "mature" vs "growing"; "low" vs "high" competitive) may moderate the relationship between board human capital heterogeneity and company outcomes (Zona *et al.*, 2013).

Notwithstanding these caveats, our analysis breaks new ground in helping to quantify the impact of board human capital heterogeneity on company innovation and to specify the role played by the educational and the functional background as well as by the CEO human capital. While more work might be needed to look beyond the high-tech firms, our results can be applied to any international context as Italy is comparable to all the settings that lack of a regulation able to rule the board human capital heterogeneity.

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Table AI.
Additional OLS
regression dependent
variable: ROI

Variables	Model
<i>EDU_HET</i>	−0.666 (1.969)
<i>FUNC_HET</i>	−5.715 (3.561)
<i>CEO_R&D_EXP</i>	−0.218 (2.272)
<i>EDU_HET</i> × <i>CEO_R&D_EXP</i>	−0.063 (2.512)
<i>FUNC_HET</i> × <i>CEO_R&D_EXP</i>	1.461 (3.752)
<i>BD_SIZE</i>	0.007 (0.040)
<i>INDEP</i>	−1.616 (3.509)
<i>INTERLOCK</i>	0.068 (0.226)
<i>F_SIZE</i>	0.000*** (0.000)
<i>F_AGE</i>	−0.060** (0.032)
<i>F_LEVERAGE</i>	−0.122 (0.213)
<i>F_SALES</i>	−0.000 (0.003)
<i>ROI_{t−1}</i>	0.626*** (0.058)
<i>CONSTANT</i>	6.166*** (2.454)
<i>YEAR DUMMY</i>	Yes
<i>FIRM DUMMY</i>	Yes
Observations	596
<i>F</i>	13.17***
<i>R</i> ²	0.433
Notes: Standard errors are provided in parentheses. * <i>p</i> <0.1; ** <i>p</i> <0.05; *** <i>p</i> <0.01	

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