When Do Firms Benefit from Overconfident CEOs? The Role of Board Expertise and Power for Technological Breakthrough Innovation

Priscilla S. Kraft
Entrepreneurship & Innovation Group
WHU – Otto Beisheim School of Management
Burgplatz 2, 56179 Vallendar, Germany
e-mail: priscilla.kraft@whu.edu
Phone: +49 261 6509 245

Teresa A. Dickler
Sustainability Management / Strategy Group
Philipps University Marburg / IE Business School
Am Plan 1, 35037 Marburg, Germany
Mail: Teresa.Dickler@wiwi.uni-marburg.de
Phone: +49 (0)6421 28 23734

Michael C. Withers
Department of Management
Mays Business School
Texas A&M University
College Station TX 77843-4221
e-mail: mwithers@mays.tamu.edu
Phone: 979 845 3734

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ABSTRACT

While prior upper echelon research has shown that overconfident CEOs are beneficial for firm innovation, less is known about how firms can harness their benefits for breakthrough innovations. To extend this stream of research, we identify crucial board characteristics that enable firms to benefit from overconfident CEOs in the context of promoting breakthrough innovations. Using longitudinal data of U.S. high-tech firms, our results emphasize that overconfident CEOs guided by boards with expertise *and* power strongly outperform fellow CEOs who are monitored by boards lacking either or both of these characteristics. By theorizing and empirically demonstrating how powerful expert boards are important for firms to profit from their CEO's overconfidence, our study provides important contributions to the CEO overconfidence, corporate board, and breakthrough innovation literatures.

Keywords: CEO overconfidence, breakthrough innovation, board expertise, board power, corporate governance

1. INTRODUCTION

Confidence is an important determinant of how CEOs direct their firms and shape strategy (Finkelstein, Hambrick, & Cannella, 2009; Heavey, Simsek, Fox, & Hersel, 2022). However, when this confidence becomes inflated, in the form of overconfidence, it can be a double-edged sword. As such, recent research has focused on how CEO overconfidence – or, the "overestimation of one's actual ability, performance, level of control, or chance for success" (Moore & Healy, 2008, p. 502) – affects strategic decision making and firm outcomes (e.g., Chen, Crossland, & Luo, 2015; Schumacher, Keck, & Tang, 2020; Smith, Hill, Wallace, Recendes, & Judge, 2018; Tang, Mack, & Chen, 2018). This research suggests that overconfident CEOs tend to perceive novel business opportunities more favorably and engage more in risky large-scale projects due to overconfidence in their abilities (Malmendier & Tate, 2005; Pavićević & Keil, 2021; Van Zant & Moore, 2013). While this may result in strategic failures, such as value-destroying mergers and acquisitions (M&As) (Malmendier & Tate, 2008), unsuccessful pioneering products (Simon & Houghton, 2003), and inaccurate management forecasts (Chen et al., 2015), prior research finds that overconfident CEOs can also be beneficial for firms because of their increased propensity to engage in innovation (Galasso & Simcoe, 2011; Hirshleifer, Low, & Teoh, 2012; Tang, Li, & Yang, 2015a)[1].

While prior research documents that overconfident CEOs are associated with innovation in general, less is known about the influence of these CEOs on breakthrough innovations – or innovations that are the basis for new technological paradigms, enable firms to shape the competitive landscape, and achieve long-term success (Ahuja & Lampert, 2001; Hall, Jaffe, & Trajtenberg, 2005; Phene, Fladmoe-Lindquist, & Marsh, 2006). Thus, a key question remains: How are firms able to harness the benefits of overconfident CEOs to promote breakthrough innovations?

[1] Although Tang et al. (2015a) focus on CEO hubris in their study, we include them here as this construct is closely related to CEO overconfidence (see also Chen et al., 2015; Heavey et al., 2022). More information about the different constructs is provided on p. 6.

To answer this question, we theorize that the board of directors is an essential mechanism. Specifically, we draw from the literature on corporate boards which suggests that directors' expertise is critical for boards to effectively contribute to strategic decision making in firms (Hambrick, Misangyi, & Park, 2015; Haynes & Hillman, 2010; Hillman & Dalziel, 2003; McDonald, Westphal, & Graebner, 2008). Building on these insights, we argue that boards possessing expertise with breakthrough innovations – gained through their diverse experiences at firms that previously conducted breakthrough innovations – are better able to contribute to and guide the strategic decision making of overconfident CEOs, thus increasing the likelihood of creating breakthrough innovations. In particular, due to their broad range of experiences, such boards have greater exposure to heterogeneous, relevant knowledge that enables them to better understand and cope with novel, ill-structured, and complex challenges (Genin, Ma, Bhagwat, & Bernile, in press; Golden & Zajac, 2001; Haynes & Hillman, 2010) and hence, to contribute to the CEO's breakthrough innovation endeavors. However, prior research indicates that overconfident CEOs tend to be heavily convinced of their opinions and exclude others from their decision making (Chen et al., 2015). We thus further theorize that firms benefit most from overconfident CEOs with regards to breakthrough innovation when boards not only possess the expertise to advise but also the power to influence the CEO's decision making (Finkelstein et al., 2009; Pearce & Zahra, 1991).

We examine these hypotheses in a sample of U.S. publicly listed firms within the *S&P 1500* that operate in high-tech industries as prior research has shown that breakthrough innovations are especially important in these dynamic environments (Phene et al., 2006). We find empirical support for our predictions as the relationship between CEO overconfidence and breakthrough innovations is strongest in firms with high board expertise and power, resulting in a 128 percent increase in breakthrough innovations relative to the sample mean. Interestingly, firms with overconfident CEOs guided by powerful boards lacking expertise achieve less breakthrough innovations as compared to firms in which both expertise and power is low.

Our study contributes to current research in the following ways. First, we extend prior research on CEO overconfidence and innovation (Galasso & Simcoe, 2011; Hirshleifer et al., 2012) by integrating insights from the literature on corporate boards to identify crucial board characteristics that enable firms to harness the benefits of such CEOs in the context of breakthrough innovations. More broadly, we thereby shift the focus from studying how CEO overconfidence affects innovation outcomes towards studying ways to effectively manage such an influential CEO personality through relevant governance mechanisms. While prior research has shown that overconfident CEOs are inclined to promote innovation in general (e.g., Galasso & Simcoe, 2011), we theorize and empirically demonstrate that the presence of powerful, expert boards is a crucial condition to achieve breakthrough innovations. In doing so, our work also answers calls in the literature on CEO overconfidence to examine governance mechanisms that help firms benefit from the risky endeavors pursued by overconfident CEOs (Simon & Houghton, 2003; Smith et al., 2018).

Second, this study contributes to the growing stream of governance research examining the interplay between board expertise and power (Golden & Zajac, 2001; Hambrick et al., 2015; Haynes & Hillman, 2010). This literature generally shows that boards possessing both expertise and power have the greatest influence on firm outcomes (Golden & Zajac, 2001). Building on this literature, within the context of breakthrough innovations, we theorize and find that boards require both expertise and power in order to provide the greatest benefit from CEO overconfidence. However, by examining the interaction between CEO overconfidence, board expertise, and power, we also consider those instances in which boards lack either expertise, power, or both. Specifically, we find the lack of expertise to be particularly harmful when boards are powerful, which, interestingly, represents the most detrimental condition for the CEO overconfidence-breakthrough innovation relation. In doing so, we advance research on board expertise and power by underscoring the fact that lacking either or both may have detrimental effects on firm outcomes.

Finally, our study contributes to the stream of research which aims to identify the determinants of breakthrough innovation (Phene et al., 2006; Randle & Pisano, 2021; Srivastava & Gnyawali, 2011) by suggesting that overconfident CEOs may be an important driver – if they are complemented by boards that have both expertise and power. While CEO characteristics are recognized as important factors leading to breakthrough innovations (Eggers & Kaplan, 2009), our research suggest that this is only part of the theoretical story. In particular, given their importance to develop or sustain a competitive advantage, both CEOs and board of directors may focus their efforts on exploring such novel opportunities (Genin et al., in press; Tuggle, Schnatterly, & Johnson, 2010). It is the interplay between these two that may determine whether breakthrough innovations occur. As such, our work adds to the broader understanding of the role of strategic leadership at the executive and board levels that cultivate and produce breakthrough innovations.

2. THEORETICAL BACKGROUND AND HYPOTHESES

2.1 CEO overconfidence

Upper echelon theory posits that individual differences influence how executives perceive and interpret situations and thus affect their strategic decision-making processes (Hambrick, 2007; Hambrick & Mason, 1984). As Hambrick (2007, p. 334) states, "if we want to understand why organizations do the things they do, or why they perform the way they do, we must consider the biases and dispositions of their most powerful actors—their top executives." Building on this view, researchers have increasingly focused on CEO overconfidence (e.g., Chen et al., 2015; Heavey et al., 2022; Pavićević & Keil, 2021; Smith et al., 2018).

Overconfidence differs from related constructs, such as hubris and narcissism. While hubris refers to overconfidence with excessive pride (Hayward & Hambrick, 1997), prior research has often used overconfidence and hubris synonymously and applied similar measures to assess them (e.g., Chen et al., 2015; Hill, Kern, & White, 2012; Smith et al., 2018). Specifically, the recent review by Heavey et al. (2022, p. 1431) criticizes that the literature is characterized by an "unclear

distinction" between these constructs and that hubris is "a nebulous construct" and "all too often used to describe the behavioral manifestations of confidence as distinct from a particular level of confidence" (Heavey et al., 2022, p. 1442). The authors conclude that "hubris can be best characterized as the outward manifestations of excessive confidence levels" (Heavey et al., 2022, p. 1142). We focus on overconfidence because our theorizing does not require the "pride" aspect of hubris (Hayward & Hambrick, 1997) and it seems to be the more precise construct (Heavey et al., 2022).

Overconfidence differs from narcissism, a personality trait that refers to an individual's inflated view of one's self that requires constant validation from others (Chatterjee & Hambrick, 2007). While both narcissistic and overconfident CEOs have a preference for risk-taking (Gerstner, König, Enders, & Hambrick, 2013), they differ in that narcissistic CEOs require constant attention and praise to reinforce their self-view whereas overconfident CEOs do not (Tang et al., 2018). Moreover, overconfidence differs from dispositional optimism, which refers to the generalized tendency to expect positive outcomes even when such expectations are not rationally justified (Hmieleski & Baron, 2009). Whereas overconfidence refers to an individual's overestimation of his or her own abilities, optimism refers to an individual's general expectation that future events will turn out well without regard to his or her own abilities (Hmieleski & Baron, 2009).

While the extent and nature of overconfidence varies considerably among individuals (Klayman, Soll, González-Vallejo, & Barlas, 1999), executives are particularly likely to exhibit overconfidence (Chen et al., 2015; Heavey et al., 2022). Furthermore, research suggests that overconfidence is a cognitive disposition that is largely stable over time (Chen et al., 2015; Hirshleifer et al., 2012; Schumacher et al., 2020). For instance, overconfident founders are more likely to start new ventures after experiencing failures suggesting that overconfidence persists among individuals despite negative experiences (Hayward, Forster, Sarasvathy, & Fredrickson, 2010). This cognitive disposition is distinct from "situation-specific confidence", a construct that refers to CEOs' confidence with regards to a specific situation, e.g., acquisition-related confidence (Gamache et al., 2019).

Prior research has shown that CEO overconfidence often results in negative consequences for firms, such as investment distortions (Malmendier & Tate, 2005), value-destroying M&As (Malmendier & Tate, 2008), socially irresponsible activities (Tang, Qian, Chen, & Shen, 2015b), higher acquisition premiums (Hayward & Hambrick, 1997; Pavićević & Keil, 2021), and management forecasts errors (Chen et al., 2015). However, recent research in this field suggests that overconfident CEOs may also provide benefits for firms, such as an increased propensity to innovate (Galasso & Simcoe, 2011; Hirshleifer et al., 2012; Tang et al., 2015a). The focus has thus shifted towards considering both the positive and negative consequences of CEO overconfidence (Heavey et al., 2022; Smith et al., 2018).

2.2 CEO overconfidence and breakthrough innovation

Breakthrough innovations represent a subset of innovations which replace existing technologies and thus build the basis for new technological paradigms (Ahuja & Lampert, 2001; Anderson & Tushman, 1990; Randle & Pisano, 2021). They allow firms to shape and create new markets leading to competitive advantage (Phene et al., 2006) and, in turn, long-term performance benefits (Hall et al., 2005). However, while innovation is by nature an uncertain endeavor, the creation of breakthrough innovations requires a departure from existing practices and knowledge to explore novel solutions (Benner & Tushman, 2003; Byun, Oh, & Xia, 2021). The literature thus consistently demonstrates that pursuing breakthrough innovations poses several challenges as they are typically associated with high costs and long-term resource commitments, delayed and uncertain returns, a large amount of risk and uncertainty, as well as high failure rates (Damanpour, 1996; Hill & Rothaermel, 2003; Simon & Houghton, 2003; Singh & Fleming, 2010). Given that decisions on R&D budgets and the prioritization of innovative projects typically fall within the purview of top executives (Custódio, Ferreira, & Matos, 2019), studies have focused on how executives influence a firm's breakthrough innovation (Cho & Kim, 2017) or entry into radical new technological markets (Eggers & Kaplan, 2009).

Prior research on CEO overconfidence provides evidence that these CEOs perceive opportunities and risks associated more favorably, resulting in increased R&D investments (Galasso & Simcoe, 2011; Hirshleifer et al., 2012) and innovation outcomes, including number of patents and forward citations (Galasso & Simcoe, 2011; Hirshleifer et al., 2012; Tang et al., 2015a). Moving beyond innovation in general, Simon and Houghton (2003) find that overconfident top managers tend to introduce risky, pioneering products which they find to be less successful than their incremental counterparts. While Simon and Houghton (2003) focus on pioneering versus incremental product introductions, for example, based on how products differed from competitive offerings or what distribution channels the manager planned to use, and others focused on innovation in general (Galasso & Simcoe, 2011; Hirshleifer et al., 2012; Tang et al., 2015a), the focus of our study is on breakthrough innovations. They refer to the most valuable types of innovations (i.e., reflected in the top one percent of the most cited patents) as they form the basis for new technological paradigms and enable firms to shape the competitive landscape (Ahuja & Lampert, 2001; Phene et al., 2006). This small proportion of innovations is particularly important for the long-term performance of firms (Hall et al., 2005).

Building on prior research suggesting that overconfident CEOs are more inclined to engage in innovative behaviors in general, we propose that they may also foster breakthrough innovations for similar reasons. First, overconfident CEOs tend to overestimate their problem-solving abilities (Camerer & Lovallo, 1999) and the potential chances of success associated with risky initiatives (Hirshleifer et al., 2012). This misperception makes them more likely to engage in innovative endeavors (e.g., Tang et al., 2015a) and may particularly spur initiatives to break away from existing knowledge and paradigms increasing the likelihood of pursuing breakthrough innovations (Benner & Tushman, 2003). Second, overconfident CEOs prefer difficult and challenging tasks as they tend to believe that they are in control and particularly good at conquering such tasks (Griffin & Tversky, 1992; Tang et al., 2015a). This tendency may lead them to prefer departing from existing and proven practices, which is critical for breakthrough

innovations. Third, overconfident CEOs are inclined to make decisions quickly, as they tend to overestimate the value of their own knowledge and feel less need to consider and discuss additional information (Chen et al., 2015). As a result, they are less likely to be discouraged by potential risks associated with pursuing novel initiatives (e.g., technological feasibility) and, therefore, tend to evaluate them more favorably which increases their inclination to pursue new opportunities.

While several of these misperceptions may promote innovation in general and breakthrough innovations in particular, the downsides of these misperceptions also may be particularly detrimental for achieving breakthrough innovations for several reasons. First, the tendency to prefer and search for difficult tasks (Camerer & Lovallo, 1999) makes overconfident CEOs prone to pursue breakthrough innovation endeavors. However, pursuing such types of innovations requires more attention than innovation in general due to their risky and challenging nature (Fleming, 2001; Singh & Fleming, 2010), which can result in a cognitive overload and goal conflicts if the CEOs simultaneously perceive multiple potential opportunities (Engelen, Neumann, & Schwens, 2015).

Second, overconfident CEOs tend to overestimate their firms' resources (Malmendier & Tate, 2005; Schumacher et al., 2020) and make less comprehensive and more hasty resource commitments (Engelen et al., 2015; Pavićević & Keil, 2021; Simon & Houghton, 2003). This can lead to resource conflicts and poor resource allocation decisions (Malmendier & Tate, 2005; Van Zant & Moore, 2013) reducing the probability of creating breakthrough innovations, for which enormous long-term resource investments are typically more relevant than for innovation in general (Benner & Tushman, 2003).

Finally, overconfident CEOs tend to be heavily convinced of their opinions and thus are likely to ignore relevant information from others which do not support their views (Chen et al., 2015; Russo & Schoemaker, 1992). Ignoring such (potentially disconfirming) information undermines a CEO's ability to identify potential threats early on, make necessary adjustments,

and consider more appropriate courses of action (Navis & Ozbek, 2016), which can be particularly harmful for breakthrough innovation. In part, these innovation efforts are inherently more uncertain than innovation in general and thus require constant incorporation of newly available information (Simon & Shrader, 2012). Overconfident CEOs tend to ignore such information and instead rely on "unreliable cues" (Simon & Houghton, 2003), which limits a firm's ability to pursue more promising initiatives that may lead to breakthrough innovations.

In summary, prior research indicates that overconfident CEOs offer both benefits as well as detriments when it comes to breakthrough innovation. While overconfident CEOs spur innovation in general (Galasso & Simcoe, 2011; Hirshleifer et al., 2012; Tang et al., 2015a), in the context of breakthrough innovations, we propose that their higher inclination to innovate is canceled out by their misperceptions about potential challenges and threats. As such, rather than offering a hypothesis regarding the direct relationship between CEO overconfidence and breakthrough innovation, we propose that this relationship depends on the governance context in which the CEO operates. In the following, we develop theory about how the ability of the corporate board to provide useful advice to the CEO and, thus, to contribute to the complex and novel decision making associated with these risky endeavors, helps firms benefit from overconfident CEOs with regards to breakthrough innovation.

2.3 The moderating influence of corporate boards with expertise

A board's ability to monitor and provide advice serves as an important mechanism to influence risky and uncertain initiatives (Genin et al., in press; Hambrick et al., 2015; Haynes & Hillman, 2010; Kor, 2006), such as breakthrough innovation. Prior research emphasizes that board expertise—reflecting a directors' knowledge and understanding of a specific domain gained through their experiences—enhances the quality of board monitoring and advice provision (Carpenter & Westphal, 2001; Hillman & Dalziel, 2003; McDonald et al., 2008; Oehmichen, Schrapp, & Wolff, 2016). Expertise enables directors to better assess strategy-related issues. As Hambrick et al. (2015, p. 331) emphasize, "[a] director cannot begin to ask the right questions or

to interpret the answers in complex matters unless he or she has the ability to comprehend the issue at hand." For example, prior research finds that directors' acquisition experience is positively associated with subsequent acquisition performance (Kroll, Walters, & Wright, 2008; McDonald et al., 2008). In addition, general diversity in board experience stemming from board members' different educational and industry backgrounds has been show to promote radical innovation (Genin et al., in press).

Extending these findings, we propose that directors' expertise with breakthrough innovations, gained through their experiences at other firms that previously conducted these innovations, improve the board's ability to contribute to the decision making of overconfident CEOs and thus to increase a firm's breakthrough innovations. Specifically, their involvement as directors at other boards engaged in breakthrough innovations enables them to observe the strategic decision-making process around such decisions and their consequences firsthand (Beckman & Haunschild, 2002; Carpenter & Westphal, 2001). To be clear, the corporate board is typically not involved with operational matters, such as technological specificities of individual innovations. Rather, the board is involved in strategic decisions around breakthrough innovations, as it reviews and approves important strategic decisions, such as the allocation of enormous resource endowments including the evaluation of the firm's risk exposures (Haynes & Hillman, 2010; Kor, 2006), placing them in a position to critically influence breakthrough innovation.

Given that breakthrough innovations require departures from existing knowledge and practices (Benner & Tushman, 2003), boards with a broad range of experiences gained in multiple industries might be better able to cope with ill-defined, complex, or novel problem-solving situations (Golden & Zajac, 2001; Haynes & Hillman, 2010). Conversely, boards with homogenous knowledge and experiences possess limited ability to depart from industry norms as they tend to consider a smaller array of potential solutions (i.e., those favored by the overrepresented industry, see Haynes & Hillman, 2010). This notion is also supported when firms announce the appointment of directors with specialized expertise. For example, when Intel

Corp.—a company whose "strategic intent is to lead in key technology inflections that are fundamentally changing computing and communications" (Intel Corp., 2017)—announced two new director appointments, Intel Chairman Andy Bryant stated:

> "We are very pleased to welcome two new, independent directors with the depth of leadership experience at innovative, global companies that both Mr. [Omar] Ishrak and Mr. [Gregory] Smith bring. […] We look forward to their valuable contributions as Intel continues to transform itself for growth in emerging, adjacent market segments" (Intel Corp., 2017).

The press release went on to note that Dr. Ishrak "has extensive experience identifying and developing emerging technologies" that derived from his positions in the medical technology industry (e.g., GE Healthcare). Similarly, Mr. Smith was suggested to bring expertise from identifying and investing "in start-ups that are developing emerging technologies and businesses in markets such as cybersecurity, AI and machine learning, and autonomous systems among others" within the aerospace industry (Boeing HorizonX) (Intel Corp., 2017).[2]

Therefore, we propose that boards possessing heterogeneous expertise with breakthrough innovations[3] influence the relationship between overconfident CEOs and breakthrough innovation in a number of ways. First, due to their exposure to a wide variety of breakthrough innovation experiences in multiple industries, directors are better able to consider a more diverse set of options outside of firm-level norms (Golden & Zajac, 2001; Haynes & Hillman, 2010). Boards with this expertise are thus better able to understand and support initiatives of overconfident CEOs to break away from existing knowledge and practices with their innovation endeavors. These board members have been exposed to breakthrough innovations at other firms in a variety of contexts providing them with the ability to envision potential opportunities associated with such endeavors. In particular, boards with breakthrough innovation expertise recognize the uncertainty around breakthrough innovation success and the required tolerance of

[2] Table A1 in the Appendix presents two exemplary firms from our sample that have successfully produced breakthrough innovations, along with a list of their board members who possess breakthrough innovation experience and where they gained their experiences from.

[3] For brevity, we use the term "board expertise" in the remainder of the manuscript to refer to boards possessing heterogenous expertise with breakthrough innovations unless otherwise stated.

potential (costly) mistakes (Byun et al., 2021), the lack of comprehensive information, and long-term, resource-intensive investments needed (Anderson & Tushman, 1990; Hill & Rothaermel, 2003). Instead, boards without such expertise might fear the risks associated with these innovations, such as uncertain outcomes and unfavorable stock market reactions in the short term due to enormous innovation investments (Cohen, Diether, & Malloy, 2013). Thus, they are less likely to support breakthrough innovation endeavors pursued by overconfident CEOs and instead encourage them to focus on less risky initiatives to maximize short-term financial outcomes (Balsmeier, Fleming, & Manso, 2017).

Second, boards possessing expertise can help contribute to a more comprehensive decision making (Carpenter & Westphal, 2001; Haynes & Hillman, 2010), which can aid overconfident CEOs in achieving breakthrough innovations. Because they are exposed to a wider range of experiences and knowledge associated with breakthrough innovations, such boards are better able to ask questions and review resource allocation decisions (Hambrick et al., 2015; Meng & Tian, 2020; Tuggle et al., 2010) enabling them to debate and challenge the opinions of overconfident CEOs. These informed discussions between the board and CEO may help to prioritize opportunities and focus on pursuing the most promising ones, thereby helping the CEO to avoid goal and resource conflicts. Boards with expertise are thus better able to reduce the tendencies of overconfident CEOs to underestimate required resources (Malmendier & Tate, 2005; Schumacher et al., 2020). In comparison to boards lacking expertise, boards having the ability to advise contribute to more comprehensive resource allocation decisions which increase the likelihood of overconfident CEOs creating breakthrough innovations.

Third, boards possessing a broader set of experiences with the creation of breakthrough innovation are better able to advise overconfident CEOs about potential threats that may emerge during the development of these risky projects. Prior research finds that overconfident CEOs tend to ignore new information that do not support their judgements (Chen et al., 2015) and proceed with risk-taking initiatives, resulting in failure more frequently (Simon & Houghton, 2003).

Boards with expertise are better equipped to rectify these potential misperceptions by drawing the CEO's attention to new challenges and threats. Due to their diverse experiences with breakthrough innovations, such boards are better able to help overconfident CEOs to find a wider array of strategic solutions (Genin et al., in press; Golden & Zajac, 2001; Haynes & Hillman, 2010), which increases a firm's breakthrough innovations.

In developing our arguments for the moderating effect of board expertise on the CEO overconfidence-breakthrough innovation relationship, it is important to note that our theorizing pertains to CEOs who are overconfident. For CEOs who lack overconfidence, we assume that other board characteristics and governance mechanisms may be necessary to stimulate breakthrough innovation since these CEOs are generally less inclined to innovate (Galasso & Simcoe, 2011). Their lower inclination towards innovation may result in identifying fewer opportunities and evaluating associated risks less favorably. Hence, CEOs lacking overconfidence might need more inducements, such as incentive structures that offer tolerance for failures and learning (e.g., long-term compensation plans, job security, etc.), to encourage their engagement in breakthrough innovation endeavors in the first place (Manso, 2011; Tian & Wang, 2014). Conversely, overconfident CEOs inherently possess the inclination to innovate but benefit from the proposed board characteristics to help guide their decision making.

In summary, boards with diverse expertise relating to breakthrough innovations play a critical role in both supporting the inclinations of overconfident CEOs towards pursuing breakthrough innovations and correcting potential misperceptions held by these CEOs. Building on these arguments, we propose that firms are more likely to reap the benefits of having overconfident CEOs if their boards possess the relevant expertise to effectively guide them:

Hypothesis (H1). *Board expertise moderates the relationship between CEO overconfidence and breakthrough innovation, such that the relationship is more positive for boards with more heterogeneous breakthrough innovation expertise.*

2.4 The moderating influence of corporate boards with expertise *and* power

Given that overconfident CEOs tend to be heavily convinced of their opinions and ignore or even counter feedback from others (Chen et al., 2015), they may also disregard advice from boards with expertise. Thus, the conditions under which board advice is actually considered by overconfident CEOs are important to examine. Related to this, corporate governance research finds that a board is more likely to influence firm strategy when it is powerful relative to the CEO (Golden & Zajac, 2001; Zajac & Westphal, 1996b). Specifically, board relative power is the ability of boards to influence and constrain the decision making of CEOs by blocking or even sanctioning their actions (Finkelstein et al., 2009; Pearce & Zahra, 1991).

Drawing on insights from the governance literature, we argue that the relationship between overconfident CEOs and breakthrough innovation is most positive when boards have both expertise and power due to the following reasons. First, while boards with expertise possess the ability to support the overconfident CEOs' inclination to pursue breakthrough initiatives, we further propose that overconfident CEOs are most likely to consider the advice from boards with expertise if they are confronted with powerful boards. Specifically, we theorized that for overconfident CEOs pursuing breakthrough innovations, the advice of expert boards is critical to help prioritize opportunities and improve resource allocation decisions. If overconfident CEOs face powerful boards that are in a strong position to demand justifications and explanations for risky and resource intensive initiatives (Finkelstein et al., 2009), they are more likely to heed the advice of their board members in regarding resource allocation decisions. In other words, if overconfident CEOs fail to convince expert board members of their investment proposals envisioned to lead to desired breakthrough innovations, and neglect to incorporate their useful advice into their decisions, powerful boards are able to block CEOs' decisions and thus, to constrain their discretion to engage in risk-taking initiatives (Finkelstein et al., 2009; Pearce & Zahra, 1991). Consequently, boards possessing both expertise and power relative to the CEO are

able to significantly guide resource allocation decisions (Haynes & Hillman, 2010) increasing the likelihood of producing breakthrough innovations.

Second, powerful boards with expertise are in a strong position to draw the overconfident CEO's attention to potential threats associated with pursing breakthrough innovations. Given that overconfident CEOs tend to be strongly convinced of their opinions and are likely to disregard disconfirming feedback (Chen et al., 2015), board power is necessary to ensure that overconfident CEOs truly consider the potential problems and alternative paths highlighted by their expert board members. Thus, when confronted with powerful boards able to leverage their expertise, overconfident CEOs are less likely to ignore threats and unsuccessful developments enabling them to make necessary adjustments early on, thereby increasing the probability of creating breakthrough innovations.

To deepen our theorizing about the moderating role of having both board expertise and power for the CEO overconfidence-breakthrough innovation relationship, we contrast different scenarios in which boards are lacking either or both of these characteristics in the following. We start by considering expert boards lacking power to propose that overconfident CEOs are less likely to consider the advice of such boards in their decision making. While these boards have the knowledge and experience to assist the initiatives of overconfident CEOs to pursue breakthrough innovations, they lack the power to rectify any misperceptions, for instance, through requesting formal justifications for resource budgets or suggesting corrective actions. Given that overconfident CEOs tend to ignore such valuable advice from board members who are lacking power, board expertise does not automatically translate into improved decision making of the CEO. As a consequence, overconfident CEOs governed by expert boards without power are less likely to achieve breakthrough innovations as compared to a governance context in which expert boards also possess the power to influence the CEO.

While expert boards without power are less effective when guiding overconfident CEOs in their strategic decision making associated with breakthrough innovations as compared to boards

possessing both, powerful boards without expertise might even have detrimental effects. This is because they are less likely to envision the opportunities and rather fear the threats and short-term financial consequences associated with pursuing risky innovations (Balsmeier et al., 2017) and are also in a strong position to suppress potentially promising endeavors initiated by overconfident CEOs. Given that powerful boards are able to sanction the CEOs (Finkelstein et al., 2009), overconfident CEOs might conform to the board's preferences and pursue less risky initiatives (Manso, 2011). Moreover, powerful boards without expertise might not only constrain such initiatives overall, but also provide limited or even misleading advice to the overconfident CEO. In contrast to a governance context in which the board possesses not only power but also expertise, overconfident CEOs are therefore less likely to achieve breakthrough innovation if they are confronted with powerful boards lacking expertise.

Finally, while boards without expertise or power lack the knowledge and experiences to provide valuable advice necessary to support breakthrough innovation initiative, they are also limited in their ability to constrain or block such endeavors. Therefore, such boards can neither constrain overconfident CEOs inclined to innovate, nor contribute to a more comprehensive decision making through rectifying their misperceptions. Compared to a governance context in which boards possess both expertise and power, overconfident CEOs are therefore less likely to achieve breakthrough innovation if boards lack both of these characteristics. Overall, these arguments suggest that the relationship between overconfident CEOs and breakthrough innovation is most positive when boards have both expertise and power. Building on these arguments, we propose:

Hypothesis (H2). *There is a three-way interactive relationship between CEO overconfidence, board expertise, and board power on breakthrough innovation. The effect of CEO overconfidence on breakthrough innovation is most positive at high levels of both heterogeneous board expertise with breakthrough innovation and board power.*

3. METHODS

3.1 Sample and data

Prior research has shown that breakthrough innovations are crucial in technology-intensive industries due to their dynamic nature (Phene et al., 2006; Srivastava & Gnyawali, 2011) and that the CEOs' decision making about innovation is particularly important in these industries (Eggers & Kaplan, 2009; Tang et al., 2015a). We thus tested our hypotheses in a sample of U.S. publicly listed firms from the *S&P 1500* index that operate in high-tech industries. In line with prior research (Tang et al., 2015a), we included firms that operate in the following three-digit SIC industries: drugs (283), computers and office equipment (357), communication equipment (366), electronic components and accessories (367), telephone communications (481), and computer and data processing services (737). In addition, we included aerospace and aircraft (372, 376) as well as medical and electronical instruments (382, 384) as they have been defined as high-tech sectors by the Organization for Economic Co-operation and Development (OECD (2011).

First, we identified CEOs of firms listed in the ExecuComp database and then merged data from various sources. We included financial and accounting information for these technology-intensive firms from the Compustat database and board data from BoardEx and Institutional Shareholder Services (ISS). Data for institutional ownership were retrieved from Thompson Reuters Institutional Holdings. In the next step, we matched patent data from the National Bureau of Economic Research (NBER) to construct our dependent variable *breakthrough innovation*. Given that NBER data are available until 2006, our sample covers the time period from 1995 until 2006. Following related studies (Atanassov, 2015; Hirshleifer et al., 2012), we include all firms in the sample which operate in the same (three-digit SIC) industries as the firms that are listed in the NBER database and assigned zero patents to those firms which have no patents. Our sample is thus not restricted to firms that have patents which helps to

alleviate sample selection concerns (Atanassov, 2015).[4] After deleting firms with missing data, the final sample consists of 1,612 firm-year observations stemming from 331 firms between 1995 and 2006.

3.2 Variables

3.2.1 Dependent variable

To capture a firm's ability to generate breakthrough innovation, we measured the number of a firm's breakthrough innovations in relation to the firm's overall innovation output. In line with prior research, we use the number of forward citations a patent receives to detect top cited patents, i.e., breakthrough innovations (Ahuja & Lampert, 2001; Cho & Kim, 2017; Phene et al., 2006; Srivastava & Gnyawali, 2011). Previous findings have shown that forward citations are highly associated with the technological importance of the patent (Trajtenberg, 1990) and market value (Hall et al., 2005). Given that forward citations vary across technological classes and are influenced by the duration after a patent is granted, we followed the recommendation provided by Hall, Jaffe, and Trajtenberg (2001) and divided the number of a patent's forward citations by the mean value of forward citations based on all patents in the same application year and technological subcategory. This fixed-effects approach allows to remove year effects and thus the potential issue of truncation (Srivastava & Gnyawali, 2011). In line with prior studies, we classified the top one percent of cited patents as breakthrough innovations (e.g., Ahuja & Lampert, 2001; Phene et al., 2006).[5] We then divided the number of top cited patents by the total number of patents of a firm in a given year to capture the firm's increase in the number of breakthrough innovations in relation to the overall patenting activities. Breakthrough innovation is measured at *t+1*, while the predictor and control variables were measured at *t* to account for a time lag between CEO decisions and innovation.

[4] As a robustness check, we reran our models based on a sample with no missing patent values (only firms with patents included in the NBER database) and find robust results.
[5] In a series of post-hoc robustness checks, we conducted our analyses using the top two, three, and five percent of cited patents (e.g., Phene et al., 2006; Srivastava & Gnyawali, 2011) and the results remain robust.

3.2.2 Independent and moderator variables

CEO overconfidence

Following prior studies (e.g., Campbell, Gallmeyer, Johnson, Rutherford, & Stanley, 2011; Chen et al., 2015; Galasso & Simcoe, 2011; Hirshleifer et al., 2012), we used an option-based measure of CEO overconfidence to test our predictions. This stock option-based measure by Malmendier and Tate (2005) classifies CEOs who persistently postpone exercising in-the-money stock options as overconfident with respect to evaluating firm prospects. The underlying assumption is that risk-averse CEOs should exercise their stock options when the stock price has reached a rational benchmark (and the option is "in the money") to minimize their shareholdings and to avoid an overexposure to the firms' idiosyncratic risks (Malmendier & Tate, 2005).[6]

We used ExecuComp data to compute the average stock option moneyness of the CEO's portfolio as follows (Campbell et al., 2011; Hirshleifer et al., 2012). First, we calculated the average realizable value per option as the total realizable value of the exercisable options divided by the number of exercisable options held by the CEO. Then, we computed the average exercise price of the options as the fiscal year-end stock price minus the average realizable value per option. To assess the average moneyness of the options, we divided the average realizable value per option by the estimated average exercise price. Following prior research (Hirshleifer et al., 2012; Malmendier & Tate, 2005), we created an indicator variable for overconfidence taking on a value of "1" for CEOs who do not exercise their exercisable options although they are at least 67% in the money (i.e., the stock price was larger than the exercise price by more than 67%) and "0" otherwise.[7] We required CEOs to exhibit this option-holding behavior at least twice during

[6] This stock option-based measure of overconfidence has been validated by Kaplan, Sorensen, and Zakolyukina (2020) using a proprietary set of detailed personality assessments of candidates for top management positions who subsequently became the CEO of a public company. Specifically, the authors show that the stock option-based measure is significantly related to several specific characteristics that prior literature in psychology has found to be related to overconfidence.
[7] In supplemental analyses, we used a 100% in the money threshold as an alternative (e.g., Chen et al., 2015; Gamache et al., 2019) and our results remained robust.

the sample period and treated CEOs that were identified as overconfident so for the rest of the sample period (Chen et al., 2015; Hirshleifer et al., 2012).

Board expertise with breakthrough innovations

It is well documented that board members acquire knowledge and experience through their interconnections with other firms (Beckman & Haunschild, 2002; Carpenter & Westphal, 2001; Kroll et al., 2008; Zajac & Westphal, 1996a). To capture the directors' expertise with breakthrough innovations we utilize their board appointments at other firms that have successfully produced breakthrough innovations during the period when the focal director served on their boards. Specifically, we ensured that the director was appointed to the other firms' boards at least one year prior to the development of their breakthrough innovations and remained on the board for the subsequent year. Our analysis of director interlocks includes firms from multiple industries, categorized based on three-digit SIC codes, that had breakthrough innovations over a five-year period from *t-4* to *t* (Kroll et al., 2008).[8] To measure the heterogeneity of these inter-organizational linkages, we employed the Blau (1977) heterogeneity index (Haynes & Hillman, 2010; Zhu & Shen, 2016). The index is calculated as $1-\sum p_i^2$, where p_i represents the proportion of interlocks within the *i*th three-digit SIC code category. It is important to note that multiple interlocks within the same three-digit SIC industry are aggregated to ensure that the Blau index is computed based on ten distinct industry categories. This approach is more conservative than simply considering the number of firms a focal firm has interlocks with since it avoids artificially inflating the diversity of experiences by counting interlocks within the same industry. Consequently, higher values of the index indicate that the board possesses a more diverse set of experiences and knowledge related to breakthrough innovations, thereby reflecting a higher level of *board expertise*.

[8] We were careful to examine different specifications of this variable using a time frame of four years (Oehmichen et al., 2016) as well as two-digit and four-digit SIC codes to define industries and to capture industry board interlocks. The results remained robust.

Board power

Board power may stem from multiple sources, including structural or ownership power (e.g., Finkelstein et al., 2009; Zajac & Westphal, 1996a). To assess the power of the board relative to the CEO, we adopted a well-established approach in prior research by constructing a board power index comprising four widely recognized indicators (Finkelstein et al., 2009; Westphal & Zajac, 1995; Zajac & Westphal, 1996a, 1996b): *board independence* (measured as the ratio of outside directors to the total number of directors), *CEO non-duality* (measured as a binary variable which was coded as one if the CEO did not serve as the chairman of the board and zero otherwise), *relative CEO-board tenure* (measured as the average board tenure of the directors divided by the CEO's tenure) and *relative CEO-board ownership* (measured as the ratio of outside directors' to CEO stock ownership). We used the sum of the standard scores of these variables to create the index of *board power*.

Control variables

At the firm-level, we accounted for the influence of the firm's *prior breakthrough innovation*, which is measured as the mean of breakthrough innovation created by the firm in the five years prior to the firm's entry into the sample (Phene et al., 2006)[9]. We controlled for firm performance which was captured as the firm's return on assets (*ROA*) and market-to-book value (*MTB*). We controlled for *firm size* (logarithm of the number of employees), firm age (in years), and *R&D intensity* (ratio of current assets to current liabilities). To control for resource availability or slack, we included *unabsorbed slack* (ratio of current assets to current liabilities) and the *debt-to-equity* ratio. To control for the influence of institutional investors, we included *institutional ownership* (measured as the percentage of blockholders owning at least five percent of a firm's stock). At the board-level, we controlled for *board size* (number of directors) and the proportion of *new directors appointed under the CEO* (i.e., during the CEO's tenure). At the CEO-level, we control

[9] Our results remain robust if we exclude this control variable from the analyses.

for *CEO age* (in years), *CEO compensation*, and *CEO gender*. Finally, we included year and industry dummy variables to control for potential influences of time and industry.

3.3 Analysis

Given that our dependent variable *breakthrough innovation* is a ratio defined to lie strictly between 0 and 1, we applied fractional regression for panel data with a probit link function and robust standard errors (clustered at the firm level) using the generalized linear models command (i.e., -glm-) with a binary distribution for the dependent variable, a probit link function, and robust standard errors as recommended by Papke and Wooldridge (1996) in Stata 16 (Stata command: "xtgee y x1 x2 ... xk family(bin) link(probit) corr(exchangeable) vce(robust)"). When imposing a functional form for the conditional mean of the fractional outcome: $E(y|X) = G(X \beta)$ where X is a vector of regressors and β contains the corresponding parameters, the nonlinear function G(.) ensures that predictions lie inside the natural bounds of our fractional outcome [0, 1] (Papke & Wooldridge, 1996). This has the benefit of (a) circumventing transformations such as log-odds and log transformations, which are problematic when the dependent variable includes zero values, or (b) applying tobit models appropriate only for censored data, whereas fractional outcomes are certainly not censored but instead defined only over the interval [0, 1] (Villadsen & Wulff, 2021; Wulff, 2019b). As a robustness check, we ran additional regression models using different estimators which we describe in the supplemental analysis section.

In addition, variables were standardized prior to the creation of the interaction terms to reduce the potential problem of multicollinearity (Aiken & West, 2001). All independent variables and control variables are lagged by one year to account for a time lag between CEO decisions and our dependent variable.

4. RESULTS

4.1 Main results

Table 1 presents descriptive statistics and correlations. Prior to the main analysis, we checked the variance inflation factor (VIF) values, which ranged from 1.06 to 3.89, and together with an

examination of the pairwise correlations in Table 1 suggests that multicollinearity is not a concern in this study.

INSERT TABLE 1 AND 2 HERE

The fractional regression results of CEO overconfidence on breakthrough innovation are presented in Table 2. Our baseline results are shown in Model 1 which includes only control variables and in Model 2 which adds the direct effect of CEO overconfidence on breakthrough innovation. The results show no meaningful direct effect of CEO overconfidence on breakthrough innovation (Model 2 in Table 2: $\beta = 0.110$, $p = 0.257$). To test our predictions, we then included the two-way interaction term of CEO overconfidence and board expertise on breakthrough innovation in Model 3 and added the three-way interaction term of CEO overconfidence, board expertise, and board power on breakthrough innovation in Model 5 (Model 4 presents the two-way interaction of CEO overconfidence and board power).

Hypothesis 1 proposed that the relationship between overconfident CEOs and breakthrough innovation is more positive for firms with boards that possess more heterogeneous expertise with breakthrough innovation. Given our sample, the results in Model 3 show that board expertise positively moderates the relationship between CEO overconfidence and breakthrough innovation with a coefficient of $\beta = 0.208$ and a *p-value* of 0.027. Figure 1 illustrates the interaction effect. While the two slopes are meaningfully different from each other ($p = 0.023$), aiding the interpretation of our results, the point estimate of 0.13 (low expertise, high overconfidence) is meaningfully different ($p = 0.003$) from 0.18 (high expertise, high overconfidence).

To provide a more nuanced interpretation of the results, we examined the marginal effects (Busenbark, Graffin, Campbell, & Lee, 2022a; Villadsen & Wulff, 2021; Wulff, 2015, 2019b). Specifically, the estimated average marginal effect implies that holding other variables at their observed values, a one standard deviation increase in board expertise (0.29 in the Blau index of heterogeneity) is associated with a 0.021 ($p = 0.023$) increase in the influence of overconfident

CEOs on the proportion of breakthrough innovations. Given that the sample mean of breakthrough innovation is 0.039 (i.e., on average 3.9 out of 100 patents are breakthrough innovations), this translates into a 54 percent (0.021/0.039) increase in the proportion of breakthrough innovations for overconfident CEOs governed by corporate boards with high expertise. Thus, firms with overconfident CEOs and expert boards on average achieve 6.0 breakthrough innovations instead of the mean 3.9 breakthrough innovations per 100 patents granted. Together, this supports Hypothesis 1.

INSERT FIGURE 1 HERE

Hypothesis 2 proposed a three-way interactive relationship between CEO overconfidence, board expertise, and board power, such that the relationship between CEO overconfidence and breakthrough innovation is most positive when both board expertise and power are high. In line with this prediction, we find a positive three-way interaction of CEO overconfidence, board expertise, and board power on breakthrough innovation (Model 5 in Table 2: $\beta = 0.350$, $p = 0.000$). In addition, we used split samples for board power (above and below its median value) and tested two-way interactions between CEO overconfidence and board expertise in the two resulting subsamples. The results show that for our sample firms the interaction between CEO overconfidence and board expertise is only meaningfully different from zero ($\beta = 0.452$, $p = 0.000$) in the subsample of firms having high board power. In contrast, the relationship is not meaningfully different from zero ($\beta = -0.153$, $p = 0.263$) in the subsample of low board power firms. To better interpret this complex relationship, we plotted the interaction in Figure 2 using a cut-off of one standard deviation above and below the mean for the main predictor variables (Aiken & West, 2001; Dawson, 2014).

INSERT FIGURE 2 HERE

As shown in Figure 2, the relationship between CEO overconfidence and breakthrough innovation is most positive when both the expertise and the power of boards are high (slope 1). In

line with recent studies that examine three-way interactions (Burgers & Covin, 2016; Zona, Gomez-Mejia, & Withers, 2018), we followed the recommendation by Dawson and Richter (2006) and conducted slope difference tests to further analyze the interaction and tested values one standard deviation above and below the mean (Dawson, 2014; Dawson & Richter, 2006). The slope difference test shows that line 1 and 2 are meaningfully different from each other (p = 0.000), indicating that the relationship between CEO overconfidence and breakthrough innovation is stronger when boards possess both high expertise and high power (slope 1) as compared to boards that have high expertise but only low power (slope 2). Moreover, we find that line 1 and 3 are meaningfully different from each other (p = 0.000), indicating that the relationship between CEO overconfidence and breakthrough innovation is stronger when boards possess both high expertise and high power (slope 1) as compared to boards which have high power but only low expertise (slope 3). Finally, the slope difference test shows that line 1 and 4 are meaningfully different from each other (p = 0.028), indicating that the relationship between CEO overconfidence and breakthrough innovation is stronger when boards possess both high expertise and high board power (slope1) as compared to boards which have low expertise and low power (slope 4).

Further aiding the interpretation of our results, the point estimates for high CEO overconfidence in the different contexts—for example, when both board expertise and power are high as compared to boards with high power but low expertise—are meaningfully different from each (p-value = 0.000 for slope 1 vs. 2; p-value = 0.001 for slope 1 vs. 3; p-value = 0.007 for slope 1 vs. 4). Estimated average marginal effects of overconfidence on breakthrough innovation over values of board power and board expertise imply a 0.044 increase (p = 0.000) in the influence of overconfident CEOs on the proportion of breakthrough innovations when both expertise and power are one standard deviation above the mean. This translates into a 128 percent (0.044/0.039) increase in the influence of overconfident CEOs on the proportion of breakthrough innovations if they are governed by corporate boards with high expertise and power, resulting in

8.3 breakthrough innovations per 100 patents. In contrast, further evaluating the marginal effects of other contexts, such as boards having high power, but low levels of expertise illuminates a 0.029 (74 percent) meaningful *decrease* ($p = 0.034$) in the effect of overconfident CEOs on the proportion of breakthrough innovations, resulting in only 1.0 breakthrough innovations per 100 patents. In sum, overconfident CEOs achieve roughly eight times more breakthrough innovations per 100 patents if they are governed by the most conducive boards, those having high levels of expertise and power, compared to the most detrimental boards having high power over CEOs but lacking the expertise to effectively guide them. Together, this yields support for Hypothesis 2.

Another interesting finding worth highlighting is that the relationship between CEO overconfidence and breakthrough innovation is meaningfully weaker (slope difference test: $p = 0.053$) when boards have high power but low expertise (slope 3) as compared to boards with low expertise and power (slope 4). While powerful boards that have low expertise are detrimental for overconfident CEOs achieving breakthrough innovations, boards that have low levels of both expertise and power have no meaningful impact on the CEO overconfidence-breakthrough innovation relationship. This finding indicates that powerful boards with low expertise are the most detrimental combination for overconfident CEOs pursuing breakthrough innovations. All other scenarios are not meaningfully different from each other.

4.2 Supplemental analysis

4.2.1 Additional estimators

To scrutinize the robustness of our results, we reran our models using generalized estimating equations (GEE) in Stata 16 with a probit link function and a binomial distribution as well as robust standard errors (clustered at the firm level) (Stata command: "xtgee y x1 x2 ... xk family(bin) link(probit) corr(exchangeable) vce(robust)"). The similarity of those results with our main analysis lends further support to our findings. Moreover, we reran our models using a tobit function in Stata 16 with a lower-censoring limit of 0 and an upper-censoring limit of 1 because of the

bounded nature of our dependent variable (Stata command: "xttobit y x1 x2… ll(0) ul(1)"). The results were consistent with our main findings and are presented in Appendix B1 and B2.

4.2.2 Alternative overconfidence measure

Following related research, we conducted supplemental analyses using a media-based measure which builds on the premise that media portrayals reflect the CEOs' underlying characteristics. In line with prior research (e.g., Chen et al., 2015; Hirshleifer et al., 2012; Malmendier & Tate, 2008), we searched for news articles that mentioned the CEOs of our sample firms in major publications, including *The Wall Street Journal, The New York Times, Business Week, The Economist,* and *The Financial Times.* For each CEO and each year, we counted the number of articles that referred to the CEO in confident terms (e.g., "confident", "confidence", "optimism", or "optimistic") as well as the number of articles that referred to the CEO as non-confident (e.g., "cautious", "conservative", "practical", "frugal", "steady", "not confident", or "not optimistic") (Malmendier & Tate, 2008). We retrieved all articles in the period from entering office up to the prior year and counted these terms only if they appeared within 10 words before or after the CEO's name was mentioned (Chen et al., 2015). In line with prior studies (Chen et al., 2015; Tang et al., 2018), we followed Hribar and Yang (2016) and operationalized the CEO overconfidence measure as the difference between the number of articles depicting the CEO as confident and non-confident, divided by the total number of articles for each CEO in each year. Thus, CEO overconfidence is a continuous variable ranging from -1 to 1 with higher values indicating higher overconfidence. CEOs without media coverage are assigned a zero and therefore incorporated in the middle of the overconfidence distribution (Chen et al., 2015).

We find that the media-based measure of CEO overconfidence is correlated at r = 0.09 with our original option-based measure, which although relatively low, is in line with prior research (Chen et al., 2015; Hirshleifer et al., 2012; Schumacher et al., 2020). As indicated in Appendix C1, when employing the media-based measure of CEO overconfidence, the results remain robust.

4.2.2 Endogeneity

Prior research suggests that overconfidence is a cognitive disposition that is largely stable over time (Chen et al., 2015; Hirshleifer et al., 2012; Schumacher et al., 2020), and thus less likely to suffer from endogeneity issues related to reverse causality. However, to alleviate potential concerns that our estimates of the main effect could be biased due to an omitted variable, we followed recent studies (Busenbark, Lange, & Certo, 2017; Busenbark, Yoon, Gamache, & Withers, 2022b; Westphal & Zhu, 2019) and examined the impact threshold of a confounding variable (ITCV) (Frank, 2000) using the "konfound" command in Stata to analyze the potential for an omitted variable to invalidate the results. Note that the effect of CEO overconfidence on breakthrough innovation is not meaningfully different from zero in our sample (Model 2 in Table 2), but the ITCV test can still be applied to examine the probability that an omitted variable is masking a potential significant effect. The results show that to obtain a significant effect, which is at *p-value* = 0.05 in the conventional application of the "konfound" command, 677 (42%) of the cases with a null effect would have to be replaced at the threshold of inference (i.e., $p = 0.05$). In addition, the results show that a confounding variable would have to be correlated with both breakthrough innovation and CEO overconfidence at r = 0.141 to overturn the results. The highest correlation of our predictors with breakthrough innovation is r = 0.130 (board expertise) and r = -0.12 for CEO overconfidence (board power). For a confounding variable to have an impact on the inference, however, it should be noted that it would need to be correlated with both, the dependent and the independent variable (Frank, 2000). Following Busenbark et al. (2021b), we further looked at the impact threshold which is 0.020 in our model and compared that to the partialed out impact threshold values of all our covariates. This shows that the highest partial correlation in our sample is r = 0.007 which is roughly three times lower than the ITCV value. Given that there are no covariates that exhibit correlations stronger than the impact threshold would require, this provides some evidence that the likelihood for an omitted variable to invalidate our results is quite low (Busenbark et al., 2021b).

In addition, recent research suggests that endogeneity bias is less likely to influence interaction terms, which are the focus of this study (Bun & Harrison, 2019; Busenbark et al., 2022b). However, we still aim to address the remaining endogeneity concerns using a novel instrumental variable approach. The potential drawback with a traditional instrumental variable approach is that several exogenous and strong instrumental variables are needed, given the need to account for potential endogeneity in the direct effects, secondary-order interactions, and the three-way interaction. As such, we turned to recent advances in identifying instrumental variables when "external" instruments are not available and applied the Lewbel (2012) estimator that has recently been used in strategic management research (e.g., Campbell, Busenbark, Graffin, & Boivie, 2021; O'Sullivan, Zolotoy, & Fan, 2021). This technique enables the identification of a causal effect by generating instrumental variables via leveraging heteroskedastic errors and has been applied to consider multiple endogenous moderators (Chen, 2020). We do so using the user-generated Stata command "ivreg2h" (Baum & Lewbel, 2019). For our model, we were able to generate a set of strong and exogenous heteroskedasticity-based instruments (Kleibergen-Paap rk LM statistic of 169.055 with $p = 0.000$; Hansen J statistic of 37.703 with $p = 0.347$) for the potentially endogenous variables based on six covariates (i.e., ROA, unabsorbed slack, debt-to-equity ratio, institutional ownership, new directors appointed under the CEO, and CEO age) out of the full set of control variables considered. However, because the Lewbel estimator does not take into consideration the bounded nature of our dependent variable, we implement the fractional regression analysis accounting for potential endogeneity using a conditional mixed process estimator (Wulff, 2019a; Wulff, 2019b) specified via the "cmp" command in Stata (Roodman, 2011). This method allows us to specify a set of simultaneous equations for each of the potential endogenous variables. We used the CMP estimator with the set of instrumental variables generated from the Lewbel estimator and the analysis supported our general findings regarding the two-way interaction between CEO overconfidence and board expertise ($\beta = 0.507$,

$p = 0.050$) as well as the three-way interaction between CEO overconfidence, board expertise, and board power on breakthrough innovation ($\beta = 0.602$, $p = 0.000$).

5. DISCUSSION

A growing stream of upper echelon research focuses on the influence of CEO overconfidence on strategic decision making and firm outcomes (e.g., Heavey et al., 2022; Smith et al., 2018). While prior studies have shown that overconfident CEOs are prone to engage in innovation in general (Galasso & Simcoe, 2011; Hirshleifer et al., 2012), less is known about their influence on breakthrough innovations. To advance this literature, our study theorizes about and empirically examines how corporate boards may enable firms to benefit from overconfident CEOs in the context of breakthrough innovations. From this perspective, we offer several new insights into the complex interplay of board and CEO characteristics for firm outcomes.

5.1 Theoretical contributions

Our study contributes to the existing literature in the following ways. First, we extend prior research on CEO overconfidence and innovation (e.g., Galasso & Simcoe, 2011) by theorizing that for overconfident CEOs to foster breakthrough innovations, the presence of a corporate board that possesses both expertise and power is an important governance condition. Building on prior research showing that overconfident CEOs spur innovation in general (e.g., Galasso & Simcoe, 2011; Hirshleifer et al., 2012), we suggest that they also have a higher inclination to engage in breakthrough innovation which is, however, offset by the repercussions of their misperceptions, such as poor resource allocation decisions. In support of our arguments, we find that overconfident CEOs have no meaningful effect on breakthrough innovation per se, but demonstrate that firms can benefit from overconfident CEOs' inclination to innovate if they are equipped with expert boards that have the power to leverage their expertise in breakthrough innovation endeavors. Our study thus supports the view that board members can be strategic partners with CEOs (Boivie, Withers, Graffin, & Corley, 2021) and suggests that future research

should consider both board expertise and power relative to the CEO when examining mechanisms effective to guide strong CEO personalities in innovation endeavors.

Second, our study offers important insights to the governance literature examining the interplay between board expertise and power (e.g., Golden & Zajac, 2001; Hambrick et al., 2015; Haynes & Hillman, 2010; Kroll et al., 2008) by demonstrating that, in the context of breakthrough innovation, firms benefit most from overconfident CEOs if they are governed by boards possessing both, expertise and power. Another interesting insight our study provides is that boards lacking expertise but possessing power relative to the CEO represent the most detrimental condition for overconfident CEOs producing breakthrough innovations. Prior research emphasizes that board members' expertise is crucial for their ability to guide strategic decisions in firms and implied in this work that the lack of expertise is problematic for board effectiveness (e.g., Genin et al., in press; Hambrick et al., 2015; Haynes & Hillman, 2010; Hillman & Dalziel, 2003; Schnatterly, Calvano, Berns, & Deng, 2021). However, empirical research on the consequences of boards that *lack* expertise is surprisingly rare. Feldman and Montgomery (2015) represent an exception as they show that directors with significant ownership but lacking top-level management experience are negatively associated with firm value. We complement their work by finding that boards with less expertise but having power relative to the CEO are likely to attenuate the relationship between overconfident CEOs breakthrough innovations.

One potential explanation for this negative finding regarding powerful boards with less expertise is that these boards may be limited in their ability to contribute to fruitful boardroom interactions with an overconfident CEO as those conversations relate to innovation initiatives. For example, these boards might fear the risks associated with such resource-intensive innovations, such as failures and negative stock market reactions (Balsmeier et al., 2017; Cohen et al., 2013). This may result in conflicts between the CEO and the powerful board, ultimately restraining overconfident CEOs in their pursuit of breakthrough innovations. Moreover, it is important to

note that in our sample, boards that have low levels of both expertise and power have no meaningful impact on the CEO overconfidence-breakthrough innovation relationship. Together this finding suggests that future research should continue to examine the interplay between board power and expertise especially regarding lower levels of expertise to increase our understanding of effective boards in governing CEOs and their influence on firm outcomes.

Third, our findings contribute to the literature on breakthrough innovations (Phene et al., 2006; Randle & Pisano, 2021; Srivastava & Gnyawali, 2011) by identifying that overconfident CEOs in combination with appropriate governance mechanisms may be an important driver. In particular, our study emphasizes that it is the interplay between overconfident CEOs and the board's power as well as the expertise that determines whether breakthrough innovations occur.

Finally, a key insight from our study for practitioners is that one possibility to harness the benefits of overconfident CEOs is to focus on the composition of corporate boards. In line with evidence emphasizing the growing role of boards as governors of innovation projects (Genin et al., in press; Hill & Davis, 2017), our results confirm that boards can have an influence on breakthrough innovation and they do so by harnessing the CEO's characteristics. For director selection, our results suggest that (new) directors should bring in expertise with breakthrough innovation while having the necessary power over the CEO; and that firms need to be careful *not* to compose boards with directors that have power but lack expertise and thus the ability to contribute to strategic decision-making regarding breakthrough innovation. In addition, our study's insights help corporate boards in appreciating the influence of CEOs and their personalities on firm outcomes. This is particularly informative for board members striving for fruitful boardroom interactions and aiming to better understand the CEOs they work with.

5.2 Limitations and Future Research

This study has several limitations which provide avenues for future studies. First, our study theorizes about the ways in which boards guide CEOs in the context of breakthrough innovation. However, we do not observe boardroom interactions directly but rather use empirical proxies for

board characteristics (i.e., expertise and power) to examine our hypotheses. To gain deeper insights, we encourage future studies to examine boardroom interactions in a more direct way, for instance using qualitative research designs (e.g., Boivie et al., 2021), field studies (Westphal & Park, 2020), or observational data (Pugliese, Nicholson, & Bezemer, 2015). In addition, while our study investigates a specific innovation outcome (i.e., breakthrough innovations), future studies may look at other entrepreneurial and innovation outcomes. With this focus on other strategic outcomes, the main effect of CEO overconfidence as well as other contingencies in which this CEO characteristic can be beneficial for firms may be examined (e.g., Smith et al., 2018).

Second, our study builds on data from several databases which only cover the variables of interest in the U.S. We thus encourage future studies to extend our findings to other countries as different cultural and regulatory settings might influence the interaction between boards and CEOs (Crossland & Hambrick, 2011; North, 1990). For example, future research could examine whether our findings extend to other governance systems (e.g., the German two-tier board structure) or ownership patterns (e.g., dispersed vs. concentrated ownership) (e.g., Aguilera & Jackson, 2003; Tuschke & Sanders, 2003). Finally, although overconfidence has been defined as a cognitive disposition largely stable over time (Chen et al., 2015; Schumacher et al., 2020), therefore reducing endogeneity concerns, we were not able to completely rule out a potential endogeneity bias especially given the lack of instruments identified in the current literature. In an effort to overcome this challenge, we turned to recent advances in identifying instrumental variables via leveraging heteroskedastic errors when "external" instruments are not available (Lewbel, 2012; Baum & Lewbel, 2019; Campbell et al., 2021; O'Sullivan et al., 2021).

Beyond our study's limitations, our theorizing and findings offer several promising avenues for future research. In particular, our study suggests that research focusing on CEO personality characteristics may benefit from considering board factors that enhance their benefits. Building on our findings, future research may consider whether the board further enhances the value of CEO overconfidence with respect to other important organizational outcomes. For

example, do other types of board expertise, such as with acquisitions, internationalization, or corporate social responsibility help guide overconfident CEOs leading to other beneficial firm outcomes? Beyond overconfidence, the strategic decision making of CEOs with certain personality or cognitive characteristics, such as narcissistic tendencies (Chatterjee & Hambrick, 2007), prevention versus promotion focus (Gamache, Neville, Bundy, & Short, 2020), different ideologies (Chin, Hambrick, & Treviño, 2013), or cognitive schemas (Malhotra & Harrison, 2022), might benefit from different levels of board power and expertise.

Similarly, are there configurations of CEO personality dimensions and board characteristics that lead to better overall firm performance? Given recent methodological advances in studying CEO personalities (Harrison, Thurgood, Boivie, & Pfarrer, 2019), future research may be able to examine such interrelationships across a larger number of firms in contexts that differ from our sample. In addition, we invite follow-on research to scrutinize the potential costs for firms facing low levels of board expertise, which we have demonstrated to increase under the specific condition of powerful boards guiding overconfident CEOs in breakthrough innovation endeavors. Such costs, however, are likely to manifest across various contexts involving the interplay between CEOs, board characteristics, and strategic outcomes. For example, the costs associated with powerful boards with low expertise might be particularly high for firms involved in acquisition activities. This is due to the potential for overpayment in acquiring targets (Malmendier & Tate, 2008) which presents an even higher risk when compared to the cost-benefit tradeoffs associated with breakthrough innovations.

Our work also suggests that the interplay between CEOs and boards can be an important consideration for the impact of strategic leadership on corporate and strategic entrepreneurship (Ireland, Hitt, & Sirmon, 2003). In recognizing the critical role that board characteristics play in enhancing the relationship between CEO overconfidence and breakthrough innovation, our study suggests that future work may look to further explore the dynamic interplay between CEO and board characteristics to enhance strategically focused innovation activities.

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TABLE 1 Descriptive statistics

Variables	Mean	SD	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
1 Breakthrough innovation	0.04	0.15																		
2 CEO overconfidence	0.69	0.46	0.01																	
3 CEO age	53.70	8.39	0.02	0.06																
4 CEO change	0.08	0.27	0.03	-0.08	-0.05															
5 CEO compensation	6.27	18.97	0.03	0.01	-0.03	0.06														
6 CEO gender	0.02	0.14	-0.01	-0.01	-0.05	-0.01	0.01													
7 Board size	7.92	2.65	0.09	-0.07	0.16	0.10	0.10	0.02												
8 Board power	-0.08	0.51	0.09	-0.12	-0.26	0.12	0.02	0.08	0.16											
9 Board expertise	0.25	0.29	0.13	-0.03	0.02	0.01	0.16	0.01	0.34	0.18										
10 New directors under the CEO	0.36	0.28	0.01	0.10	0.09	-0.09	0.04	0.08	0.01	-0.07	0.16									
11 ROA	0.02	0.25	0.01	0.11	0.04	-0.01	0.05	-0.01	0.01	-0.07	0.06	-0.05								
12 MTB	2.89	4.11	0.02	0.09	-0.07	-0.02	0.07	0.02	-0.11	-0.10	-0.03	-0.03	0.07							
13 Firm size	1.55	1.21	0.12	-0.05	0.16	0.02	0.21	-0.04	0.54	0.05	0.46	0.14	0.14	-0.10						
14 Firm age	33.28	29.48	0.04	-0.06	0.21	0.06	0.05	-0.04	0.45	0.06	0.27	-0.00	0.10	-0.14	0.54					
15 R&D intensity	0.08	0.07	-0.01	-0.06	-0.10	0.03	-0.02	-0.00	-0.11	0.14	0.03	0.04	-0.29	0.03	-0.28	-0.16				
16 Unabsorbed slack	3.80	3.60	-0.02	0.09	-0.09	-0.04	-0.05	0.15	-0.25	-0.08	-0.24	-0.09	-0.02	0.11	-0.40	-0.22	0.05			
17 Debt-to-equity ratio	0.25	1.19	0.01	0.03	0.03	0.04	0.00	-0.05	0.12	0.00	-0.01	0.05	-0.19	-0.06	0.12	0.10	-0.11	-0.08		
18 Institutional ownership	0.17	0.13	-0.03	0.05	-0.06	-0.02	-0.09	0.00	-0.16	0.04	-0.13	-0.03	0.03	-0.12	-0.25	-0.13	0.01	0.08	0.03	
19 Prior breakthrough innovation	0.02	0.06	0.13	0.01	-0.06	-0.00	0.03	0.16	0.00	0.11	0.05	0.06	-0.05	0.06	-0.04	-0.08	0.03	0.03	0.01	0.04

Note: *N = 1,612*

TABLE 2 Fractional regression results of CEO overconfidence on breakthrough innovation

DV: Breakthrough innovation	(1)	(2)	(3)	(4)	(5)
ROA	-0.029	-0.034	-0.030	-0.032	-0.027
	(0.025) [0.240]	(0.025) [0.176]	(0.023) [0.196]	(0.025) [0.187]	(0.022) [0.235]
Firm size	0.245	0.247	0.251	0.249	0.268
	(0.067) [0.000]	(0.066) [0.000]	(0.066) [0.000]	(0.066) [0.000]	(0.066) [0.000]
MTB	0.083	0.084	0.082	0.082	0.086
	(0.032) [0.010]	(0.032) [0.009]	(0.033) [0.014]	(0.033) [0.013]	(0.034) [0.011]
Firm age	-0.100	-0.097	-0.093	-0.096	-0.095
	(0.058) [0.088]	(0.058) [0.096]	(0.056) [0.095]	(0.058) [0.099]	(0.055) [0.085]
R&D intensity	0.027	0.028	0.029	0.031	0.038
	(0.046) [0.553]	(0.047) [0.548]	(0.045) [0.517]	(0.046) [0.497]	(0.044) [0.390]
Unabsorbed slack	0.062	0.061	0.068	0.062	0.064
	(0.041) [0.127]	(0.040) [0.128]	(0.041) [0.102]	(0.040) [0.122]	(0.039) [0.100]
Debt-to-equity ratio	0.034	0.035	0.039	0.035	0.046
	(0.025) [0.173]	(0.026) [0.175]	(0.024) [0.108]	(0.025) [0.174]	(0.026) [0.074]
Institutional ownership	-0.002	-0.006	0.001	-0.003	0.015
	(0.054) [0.971]	(0.053) [0.916]	(0.053) [0.986]	(0.052) [0.955]	(0.053) [0.783]
Prior breakthrough innovation	0.157	0.157	0.156	0.160	0.150
	(0.044) [0.000]	(0.043) [0.000]	(0.044) [0.000]	(0.043) [0.000]	(0.042) [0.000]
Board size	0.057	0.060	0.058	0.057	0.056
	(0.060) [0.340]	(0.060) [0.316]	(0.059) [0.327]	(0.060) [0.337]	(0.059) [0.340]
Board expertise	0.113	0.109	-0.035	0.106	-0.003
	(0.051) [0.027]	(0.051) [0.032]	(0.081) [0.670]	(0.051) [0.037]	(0.080) [0.970]
Board power	0.074	0.078	0.067	0.030	0.008
	(0.052) [0.151]	(0.052) [0.134]	(0.050) [0.177]	(0.072) [0.675]	(0.067) [0.901]
New directors under the CEO	-0.048	-0.059	-0.070	-0.060	-0.051
	(0.050) [0.333]	(0.050) [0.240]	(0.050) [0.158]	(0.050) [0.232]	(0.050) [0.306]
CEO age	0.028	0.024	0.016	0.024	0.011
	(0.047) [0.552]	(0.047) [0.614]	(0.047) [0.732]	(0.047) [0.608]	(0.047) [0.823]
CEO change	0.032	0.036	0.032	0.035	0.028
	(0.041) [0.444]	(0.041) [0.376]	(0.041) [0.434]	(0.042) [0.396]	(0.041) [0.492]
CEO compensation	0.004	0.004	0.006	0.006	0.012
	(0.026) [0.884]	(0.026) [0.892]	(0.025) [0.803]	(0.026) [0.808]	(0.025) [0.633]
CEO gender	-0.029	-0.025	-0.021	-0.024	-0.024
	(0.058) [0.619]	(0.055) [0.644]	(0.055) [0.696]	(0.054) [0.652]	(0.056) [0.662]
CEO overconfidence		0.110	0.057	0.086	-0.022
		(0.097) [0.257]	(0.096) [0.552]	(0.096) [0.368]	(0.096) [0.818]
CEO overconfidence x board expertise			0.208		0.159
			(0.094) [0.027]		(0.097) [0.099]
CEO overconfidence x board power				0.086	0.029
				(0.088) [0.332]	(0.082) [0.722]
Board expertise x board power					-0.142
					(0.064) [0.026]
CEO overconfidence x board expertise x board power					0.350
					(0.084) [0.000]
Constant	-1.748	-1.807	-1.756	-1.786	-1.737
	(0.135) [0.000]	(0.144) [0.000]	(0.145) [0.000]	(0.142) [0.000]	(0.145) [0.000]
Year and Industry fixed effects	YES	YES	YES	YES	YES
Observations	1,612	1,612	1,612	1,612	1,612
Number of firms	331	331	331	331	331
Log-likelihood	-203.078	-202.797	-201.698	-202.593	-198.274

Note: Robust standard errors clustered at the firm-level are reported in parentheses and exact *p*-values are reported in square brackets.

FIGURE 1 Interaction of CEO overconfidence and board expertise on breakthrough innovation

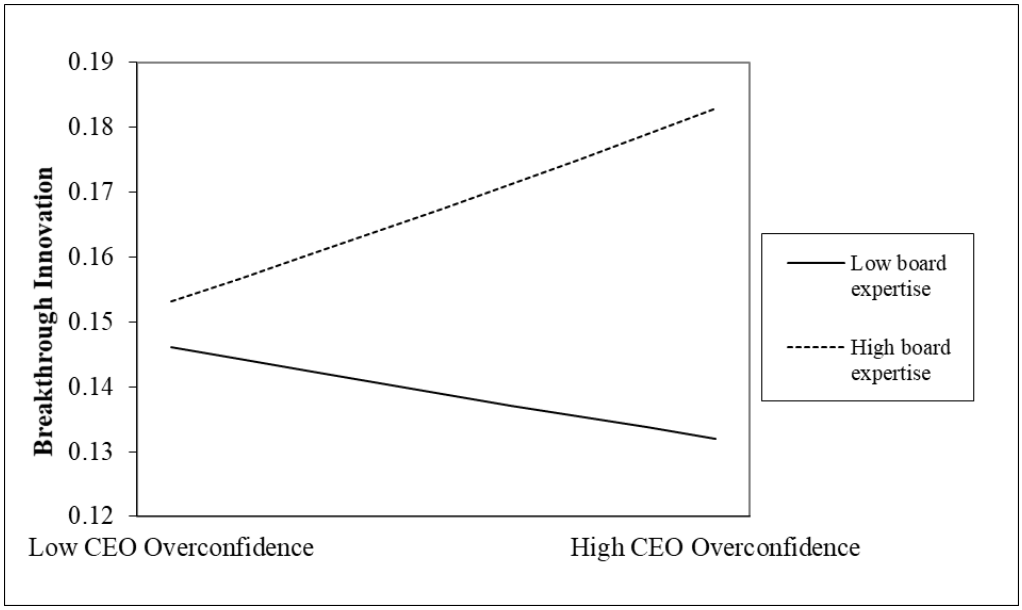
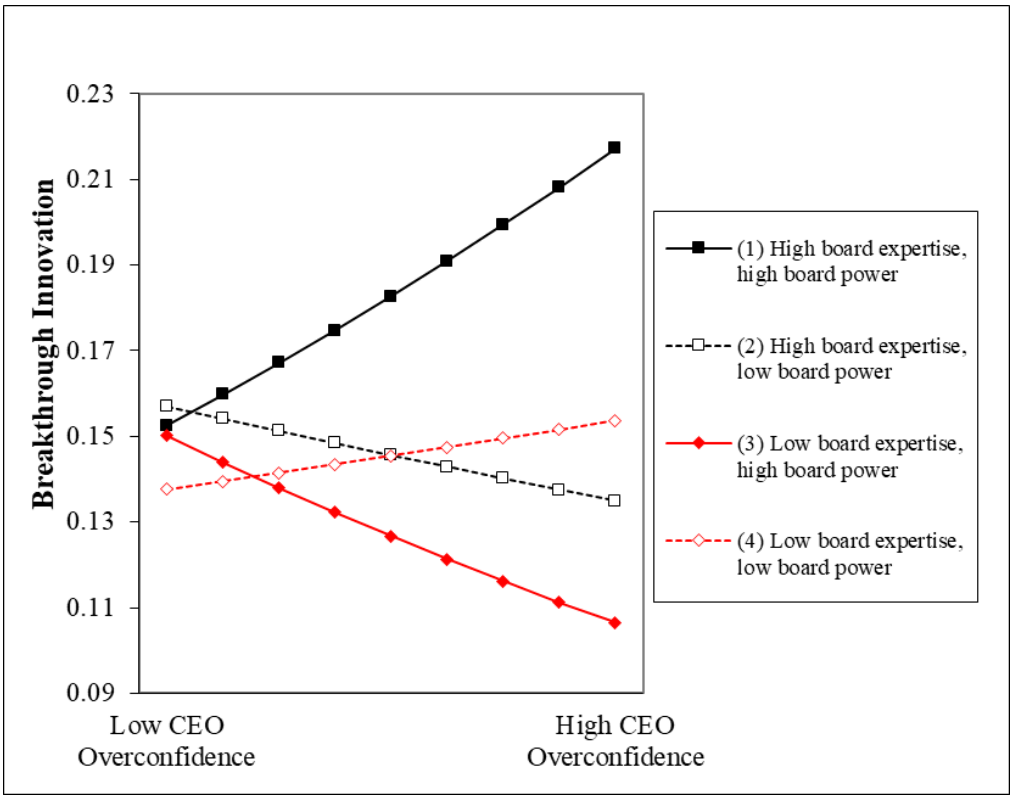


FIGURE 2 Three-way interaction of CEO overconfidence, board expertise, and board power on breakthrough innovation



APPENDIX A: Director biographies

Table A.1: Exemplary firms from our sample which have breakthrough innovations: Board members with breakthrough innovation expertise gained at other firms

Panel A: 3COM Board of Directors (2003)

Interlocked Companies	Name of director and biography
Cypress Semiconductor Corp.	*Eric Benhamou* Mr. Benhamou has been our Chairman of the Board since July 1994. Mr. Benhamou served as our Chief Executive Officer from September 1990 to January 2001 and President from April 1990 through August 1998. Mr. Benhamou is also Chairman of the Board of PalmOne, Inc., PalmSource, Inc. and Cypress Semiconductor Corporation, and a director of RealNetworks, Inc. Mr. Benhamou is also a member of the Computer Science and Technology Board and serves on the Executive Committee of Technet.
Apple Inc.	*Fred Anderson Jr* Mr. Anderson currently serves as our Lead Outside Director. Mr. Anderson has been Executive Vice President and Chief Financial Officer of Apple Computers, Inc., a manufacturer of personal computers, since March 1996. Prior to that, Mr. Anderson was the Chief Financial Officer of Automatic Data Processing, Inc. ("ADP") from 1992 to 1996. Prior to joining ADP, Mr. Anderson held several domestic and international executive positions, including President and Chief Operating Officer, at MAI Systems Corporation. Mr. Anderson is also a member of the Financial Accounting Standards Advisory Council.
Cypress Semiconductor Corp. / Ncr Corp.	*James Long* Mr. Long retired from his position as Executive Vice President of Nortel Networks, a global leader in telephony, data, wireless and wireline solutions for the Internet, on December 31, 1999, a position he held since 1994. Mr. Long also served as President of Enterprise Solutions of Nortel Networks from 1997 through 1999, President of Nortel World Trade, based in London and Hong Kong, from 1994 through 1997, and Senior Vice President of Nortel's Asia Pacific Division from 1992 to 1994. Mr. Long also is a director of Cypress Semiconductor Corporation.

Panel B: Texas Instruments Board of Directors (2004)

Interlocked Companies	Name of director and biography
Merck & Co Inc.	*Carrie Cox* Executive vice president and president of Global Pharmaceuticals at Schering-Plough Corporation since 2003. Executive vice president and president of Global Prescription Business at Pharmacia Corporation, 1997-2003.
United Technologies Corp.	*Christie Whitman* Director and president of The Whitman Strategy Group. Administrator of the Environmental Protection Agency, 2001-2003; Governor of New Jersey, 1994-2000; President of the New Jersey Board of Public Utilities, 1988-90. Director, S.C. Johnson & Son, Inc., and United Technologies Corp.

Caterpillar Inc.	*David Goode* Chairman of the board and chief executive officer of Norfolk Southern Corporation since 1992; president since 1991. Director, Caterpillar, Inc., Delta Air Lines, Inc. and Georgia-Pacific Corporation; member, The Business Council and The Business Roundtable.
Pfizer Inc.	*Ruth Simmons* President of Brown University since 2001. President of Smith College, 1995-2001; vice provost of Princeton University, 1992-95; provost of Spelman College, 1990-91. Director, Pfizer, Inc. and The Goldman Sachs Group, Inc.; fellow, American Academy of Arts and Sciences; member, Council on Foreign Relations.
First Data Corp.	*Pam Patsley* Senior executive vice president of First Data Corporation since 2000; president of its subsidiaries First Data International since 2002 and First Data Merchant Services, 2000-2002. President and chief executive officer of Paymentech, Inc., 1991-2000. Director, Molson Coors Brewing Company and Pegasus Solutions, Inc.; national trustee, Boys and Girls Clubs of America.
ConocoPhillips Company	*David Boren* President of the University of Oklahoma since 1994. U.S. Senator, 1979-94; Governor of Oklahoma, 1975-79. Director, AMR Corporation, ConocoPhillips and Torchmark Corporation; chairman, Oklahoma Foundation for Excellence.

APPENDIX B: Additional estimators

TABLE B.1 GEE regression results of CEO overconfidence on breakthrough innovation

DV: Breakthrough innovation	(1)	(2)	(3)	(4)	(5)
ROA	-0.029	-0.034	-0.030	-0.032	-0.027
	(0.024) [0.231]	(0.024) [0.168]	(0.022) [0.186]	(0.024) [0.178]	(0.022) [0.215]
Firm size	0.253	0.255	0.258	0.256	0.277
	(0.068) [0.000]	(0.067) [0.000]	(0.067) [0.000]	(0.067) [0.000]	(0.067) [0.000]
MTB	0.083	0.084	0.082	0.082	0.085
	(0.034) [0.014]	(0.034) [0.014]	(0.035) [0.020]	(0.035) [0.018]	(0.036) [0.019]
Firm age	-0.099	-0.097	-0.093	-0.095	-0.095
	(0.061) [0.104]	(0.061) [0.112]	(0.058) [0.107]	(0.061) [0.116]	(0.058) [0.100]
R&D intensity	0.027	0.028	0.029	0.031	0.037
	(0.046) [0.553]	(0.047) [0.548]	(0.045) [0.514]	(0.046) [0.496]	(0.044) [0.395]
Unabsorbed slack	0.063	0.061	0.068	0.063	0.064
	(0.042) [0.138]	(0.041) [0.138]	(0.043) [0.113]	(0.041) [0.132]	(0.040) [0.112]
Debt-to-equity ratio	0.034	0.035	0.039	0.035	0.045
	(0.024) [0.154]	(0.025) [0.158]	(0.023) [0.095]	(0.025) [0.159]	(0.025) [0.067]
Institutional ownership	-0.002	-0.006	0.001	-0.003	0.014
	(0.054) [0.964]	(0.053) [0.913]	(0.054) [0.986]	(0.053) [0.952]	(0.054) [0.801]
Prior breakthrough innovation	0.153	0.153	0.153	0.156	0.144
	(0.046) [0.001]	(0.044) [0.001]	(0.046) [0.001]	(0.043) [0.000]	(0.044) [0.001]
Board size	0.057	0.060	0.058	0.057	0.056
	(0.064) [0.369]	(0.063) [0.342]	(0.062) [0.350]	(0.063) [0.363]	(0.062) [0.365]
Board expertise	0.113	0.109	-0.035	0.106	-0.003
	(0.053) [0.033]	(0.053) [0.039]	(0.083) [0.676]	(0.052) [0.044]	(0.081) [0.970]
Board power	0.074	0.078	0.067	0.030	0.008
	(0.053) [0.167]	(0.054) [0.148]	(0.051) [0.190]	(0.075) [0.685]	(0.068) [0.903]
New directors under the CEO	-0.049	-0.059	-0.070	-0.060	-0.052
	(0.052) [0.350]	(0.052) [0.257]	(0.052) [0.173]	(0.052) [0.251]	(0.052) [0.320]
CEO age	0.028	0.024	0.016	0.024	0.010
	(0.048) [0.559]	(0.047) [0.620]	(0.047) [0.735]	(0.048) [0.615]	(0.048) [0.837]
CEO change	0.032	0.036	0.032	0.035	0.028
	(0.042) [0.450]	(0.042) [0.386]	(0.041) [0.441]	(0.043) [0.408]	(0.042) [0.499]
CEO compensation	0.004	0.004	0.006	0.006	0.012
	(0.025) [0.876]	(0.025) [0.887]	(0.025) [0.797]	(0.025) [0.800]	(0.024) [0.616]
CEO gender	-0.028	-0.025	-0.021	-0.024	-0.024
	(0.064) [0.659]	(0.061) [0.678]	(0.061) [0.726]	(0.059) [0.685]	(0.062) [0.700]
CEO overconfidence		0.110	0.057	0.086	-0.023
		(0.100) [0.269]	(0.098) [0.559]	(0.098) [0.379]	(0.097) [0.817]
CEO overconfidence x board expertise			0.208		0.158
			(0.096) [0.030]		(0.097) [0.103]
CEO overconfidence x board power				0.085	0.027
				(0.090) [0.347]	(0.082) [0.742]
Board expertise x board power					-0.142
					(0.063) [0.023]
CEO overconfidence x board expertise x board power					0.352
					(0.084) [0.000]
Constant	-1.735	-1.793	-1.742	-1.772	-1.724
	(0.133) [0.000]	(0.142) [0.000]	(0.143) [0.000]	(0.139) [0.000]	(0.144) [0.000]
Year and Industry fixed effects	YES	YES	YES	YES	YES
Observations	1,612	1,612	1,612	1,612	1,612
Number of firms	331	331	331	331	331
Wald chi-square	127.00 [0.000]	126.59 [0.000]	129.36 [0.000]	132.63 [0.000]	168.91 [0.000]

Note: Robust standard errors clustered at the firm-level are reported in parentheses and exact p-values in square brackets.

TABLE B.2 Tobit regression results of CEO overconfidence on breakthrough innovation

DV: Breakthrough innovation	(1)	(2)	(3)	(4)	(5)
ROA	-0.025	-0.026	-0.023	-0.025	-0.023
	(0.019) [0.188]	(0.019) [0.179]	(0.018) [0.206]	(0.019) [0.189]	(0.019) [0.234]
Firm size	0.219	0.219	0.200	0.219	0.221
	(0.035) [0.000]	(0.035) [0.000]	(0.027) [0.000]	(0.035) [0.000]	(0.035) [0.000]
MTB	0.057	0.057	0.063	0.056	0.054
	(0.017) [0.001]	(0.017) [0.001]	(0.017) [0.000]	(0.017) [0.001]	(0.017) [0.001]
Firm age	-0.051	-0.050	-0.038	-0.049	-0.049
	(0.027) [0.063]	(0.027) [0.067]	(0.020) [0.054]	(0.027) [0.075]	(0.027) [0.077]
R&D intensity	0.050	0.050	0.066	0.053	0.051
	(0.031) [0.110]	(0.031) [0.107]	(0.026) [0.012]	(0.031) [0.088]	(0.031) [0.096]
Unabsorbed slack	0.049	0.049	0.048	0.051	0.049
	(0.023) [0.035]	(0.023) [0.037]	(0.020) [0.016]	(0.023) [0.030]	(0.023) [0.037]
Debt-to-equity ratio	0.007	0.007	-0.002	0.005	0.006
	(0.026) [0.792]	(0.026) [0.804]	(0.026) [0.943]	(0.026) [0.839]	(0.026) [0.808]
Institutional ownership	-0.014	-0.014	0.001	-0.013	-0.010
	(0.021) [0.520]	(0.021) [0.514]	(0.018) [0.959]	(0.021) [0.538]	(0.021) [0.637]
Prior breakthrough innovation	0.060	0.060	0.081	0.061	0.056
	(0.017) [0.000]	(0.017) [0.000]	(0.014) [0.000]	(0.017) [0.000]	(0.017) [0.001]
Board size	0.025	0.025	0.015	0.024	0.027
	(0.024) [0.299]	(0.024) [0.295]	(0.020) [0.464]	(0.024) [0.316]	(0.023) [0.245]
Board expertise	0.065	0.065	0.024	0.063	0.017
	(0.022) [0.003]	(0.022) [0.004]	(0.030) [0.428]	(0.022) [0.005]	(0.033) [0.616]
Board power	0.027	0.028	0.038	-0.002	-0.001
	(0.020) [0.176]	(0.020) [0.169]	(0.018) [0.035]	(0.027) [0.938]	(0.027) [0.967]
New directors under the CEO	-0.006	-0.007	-0.007	-0.007	-0.004
	(0.020) [0.764]	(0.021) [0.722]	(0.018) [0.695]	(0.021) [0.732]	(0.021) [0.852]
CEO age	0.015	0.014	0.020	0.016	0.009
	(0.021) [0.477]	(0.022) [0.504]	(0.018) [0.266]	(0.021) [0.470]	(0.021) [0.665]
CEO change	0.016	0.016	0.016	0.016	0.014
	(0.016) [0.314]	(0.016) [0.295]	(0.016) [0.316]	(0.016) [0.295]	(0.016) [0.381]
CEO compensation	0.015	0.015	0.014	0.016	0.016
	(0.014) [0.291]	(0.014) [0.289]	(0.014) [0.324]	(0.014) [0.267]	(0.014) [0.257]
CEO gender	0.002	0.003	-0.007	0.003	0.005
	(0.022) [0.917]	(0.022) [0.904]	(0.017) [0.667]	(0.022) [0.909]	(0.022) [0.803]
CEO overconfidence		0.015	-0.003	0.005	-0.039
		(0.042) [0.725]	(0.037) [0.931]	(0.042) [0.914]	(0.044) [0.375]
CEO overconfidence x board expertise			0.074		0.070
			(0.034) [0.032]		(0.038) [0.067]
CEO overconfidence x board power				0.060	0.022
				(0.039) [0.124]	(0.037) [0.550]
Board expertise x board power					-0.033
					(0.026) [0.202]
CEO overconfidence x board expertise x board power					0.134
					(0.036) [0.000]
Constant	-0.602	-0.609	-0.568	-0.599	-0.574
	(0.075) [0.000]	(0.078) [0.000]	(0.070) [0.000]	(0.078) [0.000]	(0.078) [0.000]
Year and Industry fixed-effects	YES	YES	YES	YES	YES
Number of observations	1,612	1,612	1,612	1,612	1,612
Number of firms	331	331	331	331	331
Loglikelihood	-527.101	-527.039	-524.857	-524.910	-525.658

Note: Robust standard errors clustered at the firm-level are reported in parentheses and exact p-values in square brackets.

APPENDIX B: Alternative overconfidence measure

TABLE C.1 Fractional regression results of CEO overconfidence (media-based measure) on breakthrough innovation

DV: Breakthrough innovation	(1)	(2)	(3)	(4)	(5)
ROA	-0.029	-0.030	-0.028	-0.030	-0.029
	(0.025) [0.240]	(0.025) [0.231]	(0.025) [0.247]	(0.025) [0.222]	(0.025) [0.234]
Firm size	0.252	0.248	0.237	0.274	0.271
	(0.069) [0.000]	(0.070) [0.000]	(0.070) [0.001]	(0.071) [0.000]	(0.072) [0.000]
MTB	0.083	0.083	0.084	0.084	0.084
	(0.032) [0.010]	(0.032) [0.010]	(0.032) [0.009]	(0.033) [0.010]	(0.033) [0.012]
Firm age	-0.100	-0.098	-0.092	-0.101	-0.102
	(0.058) [0.088]	(0.059) [0.098]	(0.060) [0.128]	(0.059) [0.083]	(0.059) [0.085]
R&D intensity	0.027	0.025	0.028	0.035	0.042
	(0.046) [0.553]	(0.047) [0.588]	(0.047) [0.552]	(0.047) [0.455]	(0.046) [0.359]
Unabsorbed slack	0.062	0.062	0.055	0.065	0.060
	(0.041) [0.127]	(0.041) [0.126]	(0.041) [0.183]	(0.040) [0.108]	(0.040) [0.141]
Debt-to-equity ratio	0.034	0.035	0.037	0.033	0.034
	(0.025) [0.173]	(0.025) [0.163]	(0.025) [0.137]	(0.025) [0.180]	(0.025) [0.178]
Institutional ownership	-0.002	-0.000	-0.001	0.002	0.002
	(0.054) [0.971]	(0.053) [0.995]	(0.053) [0.985]	(0.053) [0.971]	(0.054) [0.966]
Prior breakthrough innovation	0.154	0.154	0.155	0.158	0.161
	(0.043) [0.000]	(0.043) [0.000]	(0.043) [0.000]	(0.043) [0.000]	(0.042) [0.000]
Board size	0.057	0.057	0.060	0.053	0.060
	(0.060) [0.340]	(0.060) [0.337]	(0.060) [0.314]	(0.059) [0.370]	(0.059) [0.309]
Board expertise	0.113	0.110	0.115	0.104	0.099
	(0.051) [0.027]	(0.051) [0.031]	(0.052) [0.028]	(0.051) [0.041]	(0.054) [0.068]
Board power	0.074	0.076	0.068	0.084	0.055
	(0.051) [0.151]	(0.053) [0.149]	(0.053) [0.195]	(0.053) [0.112]	(0.056) [0.325]
New directors under the CEO	-0.048	-0.050	-0.057	-0.054	-0.061
	(0.050) [0.333]	(0.048) [0.295]	(0.048) [0.233]	(0.048) [0.264]	(0.049) [0.210]
CEO age	0.028	0.027	0.028	0.030	0.030
	(0.047) [0.552]	(0.047) [0.562]	(0.048) [0.560]	(0.047) [0.528]	(0.048) [0.531]
CEO change	0.032	0.032	0.030	0.029	0.026
	(0.041) [0.444]	(0.041) [0.446]	(0.041) [0.474]	(0.042) [0.497]	(0.043) [0.539]
CEO compensation	0.004	0.004	0.005	0.007	0.008
	(0.026) [0.884]	(0.026) [0.866]	(0.026) [0.834]	(0.024) [0.774]	(0.024) [0.728]
CEO gender	-0.029	-0.029	-0.027	-0.025	-0.021
	(0.058) [0.619]	(0.057) [0.605]	(0.056) [0.634]	(0.059) [0.675]	(0.058) [0.714]
CEO overconfidence		0.022	-0.052	-0.012	-0.058
		(0.046) [0.636]	(0.035) [0.136]	(0.043) [0.772]	(0.033) [0.073]
CEO overconfidence x board expertise			0.082		0.043
			(0.046) [0.077]		(0.036) [0.237]
CEO overconfidence x board power				0.112	0.039
				(0.045) [0.013]	(0.032) [0.223]
Board expertise x board power					0.045
					(0.048) [0.347]
CEO overconfidence x board expertise x board power					0.080
					(0.030) [0.009]
Constant	-1.734	-1.731	-1.742	-1.744	-1.761
	(0.134) [0.000]	(0.134) [0.000]	(0.134) [0.000]	(0.135) [0.000]	(0.141) [0.000]
Year and Industry fixed-effects	YES	YES	YES	YES	YES
Number of observations	1,612	1,612	1,612	1,612	1,612
Number of firms	331	331	331	331	331
Log-likelihood	-203.078	-203.018	-202.303	-201.866	-200.619

Note: Robust standard errors clustered at the firm-level are reported in parentheses and exact p-values in square brackets.