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Corporate Innovation: Do Diverse Boards Help?

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Abstract

We find that corporate innovation is positively related to board diversity as measured by a multidimensional index. The benefit of board diversity is more pronounced for firms with more complex operations, more experienced boards, and stronger external governance, suggesting that diverse boards have superior advising capacity. We find evidence to suggest that firms with diverse boards engage in more exploratory innovations and develop new technology in unfamiliar areas. As a result, they create a larger number of both most-cited and uncited patents. Finally, of the six different aspects of board diversity, professional diversity matters the most for corporate innovation.

I. Introduction

The composition of the board of directors has become a high-profile corporate governance issue, attracting substantial interest from shareholders, governments, and the media. Proponents of board diversity argue that it improves firm performance by enhancing monitoring and advising effectiveness. However, the push for diverse boards could be driven by social justifications rather than firm performance. Moreover, the effects of board diversity on firm performance have received limited research attention, with mixed evidence.[1] In this article, we focus

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[1]The empirical research disproportionately focuses on demographic diversity (e.g., Carter, D'Souza, Simkins, and Simpson (2010), Garcia-Meca, Garcia-Sanchez, and Martinez-Ferrero (2015), Upadhyay and Zeng (2014)), particularly gender diversity (e.g., Adams and Ferreira (2009),

on the potential impact of board diversity on innovation, a key indicator of firm performance.

Innovation can be a catalyst for growth and success of today's corporations (Porter (1992), Hall, Jaffe, and Trajtenberg (2005)). The board could play a vital role in shaping corporate innovation strategies. Charged with advising and monitoring managers, the board not only oversees a firm's performance but also actively contributes to strategic decisions. The resource-based view suggests that corporate innovation might benefit from the strategic resources brought by directors with different socioeconomic backgrounds. A diverse group of directors brings a variety of talents, expertise, and perspectives, which helps the firm and executives identify opportunities, generate ideas, and overcome blind spots.

According to a *Wall Street Journal* article, "diversity leads to more innovation, more outside-the-box thinking and better governance; when directors are too alike… they look at problems and solutions the same way" (Manzoni, Strebel, and Barsoux (2010)). Watson, Kumar, and Michaelsen (1993) and Wiersema and Bantel (1992) show that more diverse groups produce a greater range of perspectives and solutions to problems. Giannetti, Liao, and Yu (2015) find that directors with foreign experience bring brain gains to firms in emerging markets by transmitting knowledge and good management practices. Therefore, board diversity can be a competitive advantage for innovative firms. Nonetheless, pursuing board diversity is not without costs. Differences among directors can create communication and coordination problems in the boardroom, protracting the decision-making process. In short, diversity affects the workings of corporate boards.[2] The cost–benefit tradeoff of board diversity indicates that its impact on corporate innovation is ultimately an empirical issue, which we address in this article.

To measure board diversity, we construct a multidimensional index based on six aspects of director characteristics: education, demographic attributes, cultural attitudes, managerial traits, professional backgrounds, and board experience. Using a large panel of U.S. public firms, we find a positive relation between board diversity and corporate innovation. Specifically, firms with a diverse board create a greater number of patents, and these patents receive significantly more citations. Besides patent and citation counts, we compare the innovation search strategies undertaken by firms with different board compositions. We find evidence to suggest that firms with diverse boards engage in more exploratory innovations,

Adams and Funk (2012)). Ferreira (2010) reviews the literature on board gender diversity and the role of women in the boardroom. Anderson, Reeb, Upadhyay, and Zhao (2011) and Chen and Zhang (2014) are two exceptions, who use a broader definition of diversity.

[2]Research on group diversity originates in the field of social psychology (see Levine and Moreland (1994) for a survey on group processes). When group members with different backgrounds work together, the effects can be combined in an additive fashion (e.g., Tuckman (1964)), combined in an assembly fashion (e.g., Rosenberg, Erlick, and Berkowitz (1955)), or dependent on the nature of the task (e.g., Steiner (1972)). In the management literature, Hambrick and Mason (1984) propose their upper echelon theory based on theories in social psychology (e.g., group dynamics) and strategic management (e.g., resource-based view), which has sparked intense research interest in top management team diversity. More recent empirical papers in management include Nielsen and Huse (2010) who find the proportion of female directors on the board is positively related to strategic control for a sample of 201 Norwegian firms, and Triana, Miller, and Trzebiatowski (2014) who find the relation between board gender diversity and corporate strategic change could be positive or negative depending on firm performance and the power of female directors.

developing new technology in unfamiliar areas. The pursuit of innovation in unknown areas can be risky since it increases the chances of both breakthroughs and failures. We find this to be true when analyzing the distribution of patent citations. As a board becomes more diverse, the probability distribution of patent quality flattens, ending up with long tails. That is, compared to firms with homogeneous boards, firms with diverse boards generate a larger number of both most-cited and uncited patents. However, there is no significant difference in the middle of the distributions. In other words, board diversity has little impact on incremental innovations. These findings suggest that a diverse board fosters a culture of innovation and creativity, which encourages thinking outside the box and venturing into novel technologies.

Although board diversity and innovation are positively correlated, their relation might not always be linear, given the cost–benefit tradeoff of board diversity. Piecewise regressions reveal that the relation between board diversity and innovations becomes insignificant when board diversity reaches very high levels, implying that the benefits of board diversity are offset by its costs. Therefore, policy makers and shareholders should exercise caution in designing the composition of a board. Diversity can be too much of a good thing.

The balance between the benefits and costs of board diversity can also vary across firms, depending on firms' internal and external characteristics. Specifically, we find the positive relation between board diversity and corporate innovation is more pronounced for firms subject to stronger external governance, such as institutional monitoring, external takeover threat, and market competitive pressure. The two main functions of a board are monitoring and advising managers. Strong external governance disciplines managers, rendering board monitoring less imperative. Therefore, the result that corporate innovation benefits more from board diversity when external governance is stronger suggests that the benefits are mainly due to the advising function of diverse boards. Additional cross-sectional tests show the superior advisory capacity of diverse boards is especially beneficial for firms with complex operations, operating in highly innovative industries, and with more experienced directors.

Finally, we assess which aspects of board diversity contribute to corporate innovation. Of the six diversity subindexes, we find professional diversity is the most important for innovation output. Overall, these results indicate that board diversity fosters corporate innovation. The results withstand a battery of robustness checks, including the instrumental variable (IV) approach, alternative measures of innovation, and controlling for firm and chief executive officer (CEO) fixed effects and several CEO characteristics related to innovation.

This article is related to several strands of the literature. First, our findings shed light on the debate over the benefits of board diversity. Despite the often-stated belief that board diversity creates shareholder value, supporting evidence based on a comprehensive data set is still in short supply. A notable exception is a study by Anderson et al. (2011), who find a positive impact of board diversity on firm value. What is left unanswered, however, is the process by which board diversity creates value. By constructing one of the most comprehensive data sets on board diversity, we are able to uncover a mechanism by which board diversity affects shareholder value: by enhancing corporate innovation. After assessing six different aspects of board diversity, we find that professional diversity matters the most for corporate innovation.[3]

Second, and more broadly, our article is related to the recent literature that emphasizes the dual roles of boards as monitors and advisors of management. Empirical research focuses disproportionately on the monitoring role rather than the advising role of the board. The main source of director heterogeneity that most economists consider is whether directors are independent from managers. However, various dimensions of board diversity clearly become important when directors are viewed as resource providers. Our findings suggest that directors perform multiple functions and that innovation particularly benefits from the beneficial advisory capacity of diverse boards.

Third, our article contributes to the growing literature on the determinants of corporate innovation, especially those focusing on the importance of managerial and director traits.[4] Using different measures of CEO overconfidence, Galasso and Simcoe (2011) and Hirshleifer, Low, and Teoh (2012) find that overconfident CEOs are better innovators. Islam and Zein (2018) show that CEOs' hands-on innovation experience enhances both the quality and quantities of their firms' innovation. Sunder, Sunder, and Zhang (2017) report that CEOs with pilot licenses are successful in corporate innovation. Faleye, Kovacs, and Venkateswaran (2014) find that better-connected CEOs invest more in R&D and their firms file more and higher-quality patents. Custodio, Ferreira, and Matos (2019) show that CEOs with general managerial ability spur innovation because they acquire knowledge beyond the firm's current technological domain and are less sensitive to the risk of termination. Baranchuk, Kieschnick, and Moussawi (2014) find that managers are motivated to pursue innovation through "innovation-friendly" incentive schemes with more deferred compensation, longer vesting periods for unexercised options, and some protection from takeover threats. Our evidence indicates that board diversity in general, and directors' professional diversity in particular, represents an important determinant of firm innovative activities.

Two recent papers are the most relevant to our article. Balsmeier, Fleming, and Manso (2017) report that board independence increases both patent and

[3]There is a growing literature in management that examines the relation between board diversity and corporate innovation. For example, Torchia, Calabro, and Huse (2011) find that at least three female directors are needed for gender diversity to enhance firm innovation for a sample of 317 Norwegian firms. Galia and Zenou (2012) examine the relation between board diversity and four types of innovation: product, process, organization, and marketing using survey data of 176 French firms in 2008. They find gender diversity is positively (negatively) related to marketing (product) innovation, while age diversity is positively (negatively) related to product (organization) innovation. Midavaine, Dolfsma, and Aalbers (2016) find that tenure (gender and education) diversity of directors is negatively (positively) correlated to the research and development (R&D) of 25 large U.S. companies.

[4]The determinants of corporate innovation identified in the literature include market competition (Aghion, Bloom, Blundell, and Griffith (2005)), antitakeover provisions (e.g., Meulbroek, Litchell, Mulherin, and Netter (1990), Atanassov (2013), Chemmanur and Tian (2018)), financial analysts coverage (e.g., He and Tian (2013)), business group affiliation (Belenzon and Berkovitz (2010)), local banking competition (Cornaggia, Mao, Tian, and Wolfe (2015)), firm alliances (Schilling and Phelps (2007)), ownership structure (e.g., Aghion, Van Reenen, and Zingales (2013), Bernstein (2015)), organizational structure (e.g., Seru (2014)), and the backing of private equity (Lerner, Sorensen, and Strömberg (2011)) and venture capital (Chemmanur, Loutskina, and Tian (2014)). This is by no means a complete list of the literature on the determinants of corporate innovation. He and Tian (2018) providea comprehensive survey on the determinants of corporate innovation.

citation counts due to increased monitoring by independent directors. Chen, Leung, and Evans (2018) conclude that firms with more female directors obtain more patents and citations. Similarly, the authors attribute their findings to increased monitoring by female directors. While the two papers each focus on the level of a particular board characteristic and board monitoring, we examine the dispersion of a variety of board characteristics across directors (i.e., the second moment of the distribution of these characteristics). Importantly, after controlling for the level of board characteristics, we show that the diversity of board characteristics contributes to corporate innovation, which is mainly achieved through the superior advising capacity of diverse boards.

The remainder of this article is organized as follows: Section II describes the sample and variables. Section III presents the main empirical results and elaborates on the directors' advising role. Section IV discusses the innovation strategies. Section V conducts robustness checks, and Section VI concludes the article.

II. Sample and Variables

We extract board information and director biographies from MSCI GMI Ratings (formerly the Corporate Library), which covers more than 4,000 public firms in the United States. MSCI GMI Ratings provides annual information on board size and directors' age, gender, tenure, independence, executive positions, funder status, and external board seats. The database also provides a descriptive biography of each director, from which we extract the information on a director's nationality, education, professional experience, political connections, and military experience using SAS Text Miner.[5] Our board data are from 2001 to 2007, consisting of 179,399 directorships (director-firm-year observations) in 15,672 firm-years, for a total of 4,448 firms and 43,639 directors.[6]

We obtain patent and citation data from three sources: the National Bureau of Economic Research (NBER) patent citation database; the data set collected by Kogan, Papanikolaou, Seru, and Stoffman (2017); and a Google bulk download. We obtain accounting data from the Compustat Fundamental File, stock price data from the Center for Research in Security Prices (CRSP), and institutional ownership data from the Thomson Reuters Institutional Holdings (13F) Database. We follow Hirshleifer et al. (2012) by excluding the industries (at the

[5]SAS Text Miner is a software program that discovers and analyzes unstructured text information. We primarily use the Text parsing node, the Text filter node, and the Text topic and text clustering nodes to extract the relevant information. The Text topic and text clustering nodes differ from traditional keyword searches, since they are able to identify and cluster *relevant* words for the same topic. See SAS's website (http://www.sas.com/text-analytics/text-miner/index.html) and the SAS Text Miner manual for more information.

[6]MSCI GMI Ratings no longer provides the detailed biography of each director necessary to construct our diversity measures for more recent years. Our main results hold using an alternative board diversity index based on Institutional Shareholder Services' (ISS) Director Data for the sample period up to 2012. Compared to The Corporate Library, however, the ISS Director Data lacks key data such as directors' nationalities, educational backgrounds/degrees, political connections, military experience, and business-founding experience. Therefore, this alternative index consists of four subindexes with 10 components, compared with six subindexes with 20 components for the original index. The regression results of using this alternative diversity index are not tabulated to save space but are available from the authors upon request.

2-digit Standard Industrial Classification level) without patenting activities since 1976. After combining the data sets, our final sample consists of 10,850 firm-year observations from 2001 to 2007.

A. Measures of Board Diversity

We construct the composite board diversity index based on six subindexes: i) a demographic diversity index, ii) an educational diversity index, iii) a professional diversity index, iv) a director experience index, v) a managerial trait index, and vi) a cultural diversity index. These subindexes are based on 20 components: age, gender, nationality, education degree, education background, expertise, business funding experience, executive position, tenure, external board seats, independence, board size, political connection, military experience, generation of Depression babies, power distance, individualism, uncertainty avoidance, masculinity, and long-term orientation.[7]

We first calculate a firm's index components in a year using the formulas in the Supplementary Material. We then rank each firm component based on sample quintiles of all firms in the year. For example, the age component is measured by the coefficient of variation (CV) of all directors' ages across the board. Because a higher value of this component indicates a higher level of diversity, the firm would earn a rank of 5 on age diversity if the value of its age component fell in the fifth quintile of all firms in that year.

To construct a subindex, we first sum the rank numbers of its corresponding components and then scale the sum by 100.[8] Finally, the composite board diversity index is the sum of the six subindex scores. The Supplementary Material explains the construction of each subindex and the composite index in detail.

B. Measures of Innovation

We measure innovation output using patent-based metrics, which are better than input measures of innovation such as R&D (see He and Tian (2018) for the related discussions). We obtain information about all utility patents granted by the U.S. Patent and Trademark Office (USPTO) over the period of 1976–2006 from the NBER patent citation database. We supplement the patent and citation information from 2007 to 2010 with the Kogan et al. (2017) data set and from 2011 to 2015 using a Google bulk download.

We construct six measures of a firm's annual innovation output based on the patent application year.[9] PATENT is the natural logarithm of 1 plus the firm's total number of patent applications filed in a year that are eventually granted. To correct for truncation, we construct the class-adjusted patent count by dividing

[7]We consider five cultural dimensions based on a director's nationality: power distance, individualism, uncertainty avoidance, masculinity, and long-term orientation (Hofstede (1984)). We obtained the cultural scores in 2013 from http://www.clearlycultural.com, which provides the Hofstede cultural index scores for 50 countries. If a director is from a country not on the list (less than 1% of all directors), we use a neighboring country with similar language, religion, and economic conditions. We explain the meaning of the five cultural measures in the Supplementary Material.

[8]Because the maximum rank sum of the 20 components is 100 ($5 \times 20 = 100$), we scale the indexes by 100 to make the composite diversity index range between 0 and 1.

[9]We use the application year instead of the grant year because the application year is closer to the actual time of innovation (Hall, Jaffe, and Trajtenberg (2001)).

a patent by the average number of patents of all firms in the same technology class for that year (see Hall et al. (2001), Seru (2014)). Therefore, our second measure, ADJ_PATENT, is the natural logarithm of 1 plus a firm's total class-adjusted patent count in a year. To measure the quality of innovation, we use a patent's citation count, which is related to the social and economic value it has created. The citation count is also subject to truncation bias because it takes time for a patent to accumulate citations. To mitigate the truncation bias, we adjust the citation count by scaling the number of citations of a given patent by the average number of citations received by all patents in the same technology class that year. Therefore, our third measure, CITATION, is the natural logarithm of 1 plus a firm's total class-adjusted citation count in a year. Our fourth measure, ADJ_MV, is the natural logarithm of 1 plus the adjusted market value of the firms' new patents. Following Kogan et al. (2017), a patent's market value is calculated as the firm's market capitalization right before the patent announcement multiplied by the firm's market-adjusted stock return over the 3-day window around the announcement. Then, a patent's adjusted market value is the ratio of a patent's market value over the average market value of all patents in the same technology class that year. The fifth measure, AVG_EXT_CITATION, is the natural logarithm of 1 plus the average number of non-self-citations per patent received by the firm's patents in a year. Finally, ADJ_AVG_EXT_CITATION is the natural logarithm of 1 plus the firm's average external citation count scaled by the average number of external citations of all patents in the same technology class in that year. We follow Hall et al. (2001) by including both industry and year fixed effects in the regressions to address any remaining truncation bias.

C. Control Variables

First, we control for the levels of various board characteristics in the regressions to ensure our results are driven by the dispersion of characteristics across board members (i.e., the second moment of the distribution of these characteristics) rather than by their levels (i.e., the first moment of the distribution in these characteristics).[10] Specifically, we control for the average age of the board members, the proportion of female directors on the board, the proportion of board directors with PhD degrees, the proportion of directors with business-founding experience, the average tenure of directors, the average number of external board seats held by the directors, the proportion of independent directors on the board, the proportion of politically connected directors, the proportion of directors with military experience, the proportion of directors who were born during the Great Depression, and the directors' average cultural scores (power distance, individualism, uncertainty avoidance, masculinity, and long-term orientation).

Second, we control for the following firm characteristics that could affect a firm's innovation output: firm age, size, leverage, R&D, profitability, tangibility, cash flow, cash holding, Tobin's Q, firm risk, stock liquidity, and institutional ownership. The Appendix provides detailed variable definitions.

[10]We thank the referee for making this point.

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D. Summary Statistics

Table 1 presents summary statistics. To mitigate the effects of outliers, we winsorize all continuous variables at the 1st and 99th percentiles. Panel A shows the statistics of board diversity variables. The mean (median) of the board diversity index is 0.605 (0.600) and the standard deviation is 0.060. Among the six subindexes, board experience diversity has the largest standard deviation (0.029), followed by cultural diversity (0.025), demographic diversity (0.023), and professional diversity (0.022). Panels B, C, and D present summary statistics for the innovation measures, board characteristics, and firm-level control variables, respectively. Finally, Panel E reports the annual average scores of board diversity index.

III. Empirical Results

A. Board Diversity and Innovation Output

We use the following baseline regression to examine the relation between board diversity and innovation output:

$$(1) \quad \text{INNOVATION}_{i,t+3} = \alpha + \beta_1(\text{BRD\_DIVERSITY})_{i,t} + \sum_{j=2}^{n} \beta_j (\text{Control})_{i,t} + \mu_{i,t},$$

where the dependent variable is firm i's annual innovation output, as measured by PATENT in year $t+3$. Measuring innovation output in year $t+3$ reflects the long-term nature of the innovation process. On the right side of equation (1), the main variable of interest is BRD_DIVERSITY, the board diversity index. We follow Hall et al. (2001) by including both year and industry fixed effects to mitigate the truncation bias.[11] We cluster standard errors at the firm level in all regressions.

Table 2 reports the regression results. The independent variables include BRD_DIVERSITY as well as the industry and year dummies in column 1. We add additional variables for board characteristics in column 2, firm-level characteristics in column 3, and both board and firm characteristics in columns 4 and 5. We replace the industry and year dummies by their interactions in column 4. The firm fixed effect model is not used due to a lack of within-firm variation on board diversity.

We find that the estimated coefficient of BRD_DIVERSITY is significantly positive across all five columns. In terms of statistical significance, BRD_DIVERSITY is significant at the 5% level (t-statistic $=2.43$) in column 5 with the full set of control variables. In terms of economic significance, a 1-standard-deviation improvement in BRD_DIVERSITY will increase the value of PATENT by 0.049 ($=0.810 \times 0.060$), which represents 5.73% of its mean.

We find that the level of many board characteristics is significantly related to corporate innovation. As column 5 shows, corporate innovation is negatively related to the proportion of directors born during the Great Depression but positively related to the number of external board seats and the

[11] We classify industries by the 2-digit SIC code.

TABLE 1
Summary Statistics

Table 1 reports the summary statistics of board diversity indexes (Panel A), innovation measures (Panel B), board characteristics (Panel C), and firm characteristics (Panel D). Panel E reports the annual average scores of board diversity indexes. Variables in Panel A and E are defined in the Supplementary Material and those in Panel B–D are defined in the Appendix.

Variable	Mean	Std. Dev.	Min.	P25	Median	P75	Max
Panel A. Board Diversity Indexes							
BRD_DIVERSITY	0.605	0.060	0.400	0.567	0.600	0.644	0.867
DEMOGRAPHIC_DIVERSITY	0.089	0.023	0.030	0.070	0.090	0.100	0.150
EDUCATIONAL_DIVERSITY	0.062	0.019	0.020	0.050	0.050	0.080	0.100
PROFESSIONAL_DIVERSITY	0.090	0.022	0.040	0.070	0.090	0.110	0.150
EXPERIENCE_DIVERSITY	0.150	0.029	0.070	0.130	0.150	0.170	0.250
MANAGERIAL_TRAIT_DIVERSITY	0.060	0.013	0.050	0.050	0.050	0.070	0.100
CULTURAL_DIVERSITY	0.154	0.025	0.150	0.150	0.150	0.150	0.250
Panel B. Innovation Measures							
PATENT	0.855	1.425	0.000	0.000	0.000	1.113	8.357
ADJ_PATENT	0.587	1.498	0.000	0.000	0.000	0.455	10.824
CITATION	0.159	0.589	0.000	0.000	0.000	0.000	6.642
ADJ_MV	0.527	1.359	0.000	0.000	0.000	0.306	8.561
AVG_EXT_CITATION	0.149	0.391	0.000	0.000	0.000	0.000	3.807
ADJ_AVG_EXT_CITATION	0.148	0.358	0.000	0.000	0.000	0.000	3.324
UNKNOWN	0.235	0.531	0.000	0.000	0.000	0.000	3.973
TECH_PROXY	0.876	0.254	0.000	0.901	1.000	1.000	1.000
TOP1_CITE	0.137	0.461	0.000	0.000	0.000	0.000	4.127
TOP10_CITE	0.321	0.810	0.000	0.000	0.000	0.000	6.021
MIDDLE_CITE	0.649	1.274	0.000	0.000	0.000	0.698	8.168
NO_CITE	0.475	1.093	0.000	0.000	0.000	0.000	7.423
Panel C. Board Characteristics							
BRD_AGE	4.085	0.073	3.728	4.043	4.092	4.134	4.323
BRD_FEMALE	0.092	0.087	0.000	0.000	0.091	0.143	0.667
BRD_PHD	0.067	0.111	0.000	0.000	0.000	0.105	0.857
BRD_FOUNDER	0.024	0.060	0.000	0.000	0.000	0.000	0.500
BRD_TENURE	2.130	0.447	0.000	1.863	2.169	2.431	3.455
BRD_EXT_SEAT	1.035	0.275	0.182	0.821	1.022	1.237	2.005
BRD_INDEPENDENCE	0.766	0.116	0.000	0.700	0.786	0.857	1.000
BRD_POLITICAL_CONNECTION	0.008	0.030	0.000	0.000	0.000	0.000	0.375
BRD_MILITARY	0.004	0.024	0.000	0.000	0.000	0.000	0.500
BRD_DEPRESSION_BABY	0.060	0.100	0.000	0.000	0.000	0.100	0.704
POWER_DISTANCE	0.400	0.010	0.130	0.400	0.400	0.400	0.680
INDIVIDUALISM	0.907	0.021	0.170	0.910	0.910	0.910	0.910
UNCERTAINTY_AVOIDANCE	0.461	0.015	0.230	0.460	0.460	0.460	0.860
MASCULINITY	0.620	0.012	0.160	0.620	0.620	0.620	0.785
LONG_TERM_ORIENTATION	0.291	0.016	0.280	0.290	0.290	0.290	0.870
Panel D. Firm Characteristics							
SIZE	7.495	1.670	4.167	6.298	7.363	8.528	12.183
AGE	2.714	0.896	0.000	2.197	2.713	3.427	4.382
LEV	0.554	0.246	0.072	0.374	0.552	0.731	0.976
ROA	0.114	0.113	−0.378	0.053	0.107	0.165	0.410
CASH	0.096	0.115	0.000	0.018	0.051	0.131	0.565
CF	0.028	0.111	−0.583	0.010	0.038	0.077	0.243
TOBINS_Q	0.569	0.240	0.104	0.392	0.563	0.737	1.168
TANGIBLE	0.225	0.226	0.000	0.043	0.150	0.334	0.878
R&D	0.030	0.060	0.000	0.000	0.000	0.033	0.335
TURNOVER	1.674	1.437	0.092	0.748	1.234	2.085	8.139
RISK	0.110	0.064	0.027	0.062	0.090	0.131	0.364
IO	0.615	0.256	0.000	0.364	0.670	0.813	1.000

Panel E. Average Board Diversity Scores by Year

Variable	2001	2002	2003	2004	2005	2006	2007
BRD_DIVERSITY	0.601	0.607	0.616	0.609	0.609	0.601	0.599
DEMOGRAPHIC_DIVERSITY	0.088	0.092	0.090	0.087	0.087	0.089	0.088
EDUCATIONAL_DIVERSITY	0.058	0.059	0.061	0.062	0.063	0.063	0.063
PROFESSIONAL_DIVERSITY	0.091	0.094	0.094	0.093	0.0933	0.087	0.084
EXPERIENCE_DIVERSITY	0.153	0.149	0.148	0.153	0.151	0.148	0.149
MANAGERIAL_TRAIT_DIVERSITY	0.061	0.063	0.063	0.059	0.058	0.060	0.060
CULTURAL_DIVERSITY	0.150	0.150	0.159	0.156	0.157	0.155	0.154
No. of obs.	1,011	1,008	1,091	1,372	1,546	2,396	2,426

TABLE 2

Relation between Board Diversity and Corporate Innovation

Table 2 reports the results of the baseline regression in equation (1). The dependent variable is corporate innovation as measured by PATENT. The main variable of interest is BRD_DIVERSITY, the composite board diversity index. The t-statistics (in parentheses) are based on firm-level clustered standard errors. The table also presents the number of observations and R^2 values for each regression. *, **, and *** indicate statistical significance at the 10%, 5%, and 1% levels, respectively. All other variables are defined in the Appendix.

	PATENT$_{t+3}$				
Dependent Variable	1	2	3	4	5
BRD_DIVERSITY	2.737***	1.953***	0.963***	0.828**	0.810**
	(6.62)	(4.79)	(3.14)	(2.43)	(2.43)
BRD_AGE		1.253***		0.026	0.040
		(3.49)		(0.08)	(0.12)
BRD_FEMALE		1.248***		0.460**	0.530**
		(4.80)		(2.05)	(2.35)
BRD_PHD		1.252***		0.765***	0.753***
		(5.18)		(3.70)	(3.58)
BRD_FOUNDER		0.908**		0.986***	1.034***
		(2.33)		(3.16)	(3.33)
BRD_TENURE		−0.115		−0.118	−0.114
		(−1.22)		(−1.25)	(−1.02)
BRD_EXT_SEAT		1.092***		0.315***	0.352***
		(10.90)		(3.62)	(4.13)
BRD_INDEPENDENCE		0.771***		0.182	0.277*
		(4.30)		(1.13)	(1.77)
BRD_POLITICAL_CONNECTION		1.222*		1.010	0.726
		(1.68)		(1.51)	(1.31)
BRD_MILITARY		−1.269		0.647	−1.018
		(1.31)		(0.73)	(−1.14)
BRD_DEPRESSION_BABY		−1.351***		−0.591**	−0.546**
		(−5.01)		(−2.32)	(−2.21)
POWER_DISTANCE		2.480		1.773	1.403
		(0.75)		(0.61)	(0.50)
INDIVIDUALISM		1.940		0.170	0.308
		(1.13)		(0.11)	(0.21)
UNCERTAINTY_AVOIDANCE		1.365		1.551	1.893
		(0.76)		(0.98)	(1.24)
MASCULINITY		−0.195		−0.746	−0.605
		(−0.08)		(−0.35)	(−0.29)
LONG_TERM_ORIENTATION		1.013		1.349	1.140
		(0.36)		(0.58)	(0.51)
SIZE			0.399***	0.370***	0.364***
			(16.24)	(14.39)	(14.28)
AGE			0.113***	0.173***	0.169***
			(4.39)	(5.52)	(5.36)
LEV			−1.372***	−1.352***	−1.284***
			(−3.90)	(−3.81)	(−3.66)
ROA			1.721***	1.674***	1.769***
			(6.24)	(6.20)	(6.63)
CASH			0.038	0.036	0.013
			(0.21)	(0.20)	(0.07)
CF			−0.255	−0.172	−0.247
			(−1.12)	(−0.76)	(−1.09)
TOBINS_Q			0.987***	0.898***	0.849***
			(2.87)	(2.61)	(2.50)
TANGIBLE			0.043	0.035	0.025
			(0.21)	(0.17)	(0.13)
R&D			6.428***	6.186***	5.709***
			(12.31)	(11.84)	(11.22)

(continued on next page)

TABLE 2 (continued)
Relation between Board Diversity and Corporate Innovation

	$PATENT_{t+3}$				
Dependent Variable	1	2	3	4	5
TURNOVER			0.043 (1.60)	0.041 (1.58)	0.040 (1.50)
RISK			0.544* (1.74)	0.212 (0.66)	0.411 (1.34)
IO			0.180* (1.68)	0.187* (1.66)	0.181* (1.65)
Industry effects	Yes	Yes	Yes	—	Yes
Year effects	Yes	Yes	Yes	—	Yes
Industry-year effects	No	No	No	Yes	No
No. of obs.	10,850	10,850	10,850	10,850	10,850
R^2	0.332	0.406	0.508	0.557	0.524

proportion of female directors, independent directors, directors with PhD degrees, and directors with business-founding experience. As for the economic significance, while a 1-standard-deviation increase in BRD_DEPRESSION_BABY will decrease the value of PATENT by 0.055 $(=-0.546\times 0.100)$, or 6.43% of its mean, a 1-standard-deviation increase in BRD_FEMALE, BRD_PHD, BRD_FOUNDER, BRD_EXT_SEAT, and BRD_INDEPENDENCE will increase the value of PATENT by 0.046 $(=0.530\times 0.087)$, 0.084 $(=0.753\times 0.111)$, 0.062 $(=1.034\times 0.060)$, 0.097 $(=0.352\times 0.275)$, and 0.032 $(=0.277\times 0.116)$, representing 5.38%, 9.82%, 7.25%, 11.35%, and 3.74% of the mean of PATENT, respectively.[12] Overall, the results here suggest that corporate innovation is correlated to both the level and dispersion of various board characteristics, with comparable economic significance.

Among firm characteristics, we find innovation output to be negatively related to leverage but positively related to size, age, profitability, Tobin's Q, R&D expense ratio, and institutional ownership, consistent with prior studies (e.g., Fang, Tian, and Tice (2014)).

B. Nonlinear Relation between Innovation and Board Diversity

The results thus far show that the overall relation between board diversity and corporate innovation is positive, suggesting that diversity fosters innovation. However, the pursuit of board diversity is not without costs. Differences among directors can create communication barriers and coordination problems in the boardroom, protracting the decision-making process. The cost–benefit tradeoff of board diversity indicates that its relation with corporate innovation could be nonlinear. To examine the potential nonlinear relation between board diversity and firm innovation, we employ the following piecewise regression models, where 0.7111 is the 95th percentile of BRD_DIVERSITY:[13]

[12]To estimate the economic significance, we use the estimated coefficients in column 5 of Table 2 and the standard deviations in Panel C of Table 1.

[13]We use the SAS NLIN function to identify the cutoff point of BRD_DIVERSITY that best fits two adjoined lines in the piecewise regression.

$$\text{(2)} \quad \text{INNOVATION}_{i,t+3} = \alpha + \beta_1(\text{BRD\_DIVERSITY} < 0.7111)_{i,t} + \beta_2(\text{BRD\_DIVERSITY} \geq 0.7111)_{i,t} + \sum_{j=3}^{n} \beta_j(\text{Control})_{i,t} + \mu_{i,t}$$

$$\text{BRD\_DIVERSITY} < 0.7111 = \begin{cases} \text{BRD\_DIVERSITY} & \text{If BRD\_DIVERSITY} < 0.7111 \\ 0.7111 & \text{If BRD\_DIVERSITY} \geq 0.7111 \end{cases}$$

$$\text{BRD\_DIVERSITY} \geq 0.7111 = \begin{cases} 0 & \text{If BRD\_DIVERSITY} < 0.7111 \\ \text{BRD\_DIVERSITY} - 0.7111 & \text{If BRD\_DIVERSITY} \geq 0.7111 \end{cases}$$

Table 3 reports the piecewise regression results. While the estimated coefficient of BRD_DIVERSITY < 0.7111 remains significantly positive, that of the variable BRD_DIVERSITY ≥ 0.7111 is −0.143, with a t-statistic of −0.56. The regression results show that the relation between diversity and innovation outputs becomes insignificant after diversity reaches a very high level, indicating that the benefits of board diversity are offset by its costs.

C. Advising versus Monitoring: Cross-Sectional Tests

The balance between the benefits and costs of board diversity can also vary across firms. In this section, we employ cross-sectional tests to examine if the beneficial effects of board diversity vary in firms' internal characteristics and external

TABLE 3

Nonlinear Relation between Board Diversity and Innovation

Table 3 reports the piecewise regression results of equation (2):

$$\text{INNOVATION}_{i,t+3} = \alpha + \beta_1(\text{BRD\_DIVERSITY} < 0.7111)_{i,t} + \beta_2(\text{BRD\_DIVERSITY} \geq 0.7111)_{i,t} + \sum_{j=3}^{n} \beta_j(\text{Control})_{i,t} + \mu_{i,t}$$

$$\text{BRD\_DIVERSITY} < 0.7111 = \begin{cases} \text{BRD\_DIVERSITY} & \text{If BRD\_DIVERSITY} < 0.7111 \\ 0.7111 & \text{If BRD\_DIVERSITY} \geq 0.7111 \end{cases}$$

$$\text{BRD\_DIVERSITY} \geq 0.7111 = \begin{cases} 0 & \text{If BRD\_DIVERSITY} < 0.7111 \\ \text{BRD\_DIVERSITY} - 0.7111 & \text{If BRD\_DIVERSITY} \geq 0.7111. \end{cases}$$

The dependent variable is PATENT. The regression controls for both year and industry fixed effects. The t-statistics (in parentheses) are based on firm-level clustered standard errors. The table also presents the number of observations and the R^2 values for each regression. *, **, and *** indicate statistical significance at the 10%, 5%, and 1% levels, respectively.

Dependent Variable	PATENT_{t+3}
BRD_DIVERSITY < 0.7111	0.962***
	(2.88)
BRD_DIVERSITY ≥ 0.7111	−0.143
	(−0.56)
Control variables	Yes
Industry effects	Yes
Year effects	Yes
No. of obs.	10,850
R^2	0.524

monitoring strength.[14] The two main functions of the board are monitoring and advising managers. Strong external governance disciplines managers, rendering board monitoring less imperative and enabling directors to contribute more of their limited resources to advising. Therefore, we first split the sample based on the strength of external governance mechanism: independent institutional ownership, external takeover threat, and market competition. Table 4 summarizes the three cross-sectional test results.

1. Independent Institutional Ownership

Institutional monitoring has long been considered an important governance solution to the agency issue. Because not all institutional investors are effective monitors due to potential business ties with their portfolio firms (e.g., bank-affiliated institutions), we follow the literature by calculating the ownership of independent institutional investors, which include public pension funds, investment companies, and independent advisors (e.g., Brickley, Lease, and Smith (1988), Chen, Harford, and Li (2007), Cornett, Marcus, Saunders, and Tehranian (2007)). We split the sample based on independent institutional ownership (IIO) and assign an observation to the high-IIO (low-IIO) subsample if its IIO is in the top (bottom) tercile of all sample firms in a year. We run the baseline regression separately for the two subsamples, including all the control variables in column 5 of Table 2. Column 1 of Table 4 compares the results. The estimated coefficient of board diversity is positive and highly significant, with a *t*-statistic of 4.73 in the high-IIO subsample compared to a *t*-statistic of 1.69 in the low-IIO subsample. The χ^2 test shows that the estimated coefficients of board diversity are significantly different in the two subsamples, with a χ^2 statistic of 3.34 (p-value = 0.067). As independent institutional investors provide important external monitoring, rendering

TABLE 4

Cross-Sectional Tests: External Governance Strength

Table 4 compares the regression results for firms with strong versus weak external governance, as measured by independent institutional ownership (IIO) (column 1), takeover threat (column 2), and market competition (column 3). The dependent variable is corporate innovation as measured by PATENT. The main variable of interest is BRD_DIVERSITY, the composite board diversity index. The table also reports the results of the χ^2 tests on the difference in the coefficients on the diversity index between the subsamples. All regressions control for year and industry fixed effects. The *t*-statistics (in parentheses) are based on firm-level clustered standard errors. *, **, and *** indicate statistical significance at the 10%, 5%, and 1% levels, respectively.

	$PATENT_{t+3}$					
	IIO		Takeover Threat		Market Competition	
	1		2		3	
Dependent Variable	High	Low	High	Low	High	Low
BRD_DIVERSITY	1.155***	0.707*	0.932***	0.542	0.947***	0.601
	(4.73)	(1.69)	(3.91)	(1.43)	(3.79)	(0.60)
Control variables	Yes	Yes	Yes	Yes	Yes	Yes
Industry effects	Yes	Yes	Yes	Yes	Yes	Yes
Year effects	Yes	Yes	Yes	Yes	Yes	Yes
No. of obs.	3,611	3,599	3,677	3,592	3,650	3,582
R^2	0.572	0.601	0.537	0.533	0.584	0.531
Difference in coeff.	0.448*		0.390*		0.346*	
χ^2 statistic (p-value)	3.34		2.84		3.71	
	(0.067)		(0.092)		(0.054)	

[14]We thank the referee for suggesting many cross-sectional tests in this section.

board monitoring capacity less imperative, the results reported here suggest that the beneficial impact of a diverse board on innovation is largely due to the board's advising function.

2. External Takeover Threat

Next, we split the sample based on external takeover threat, another external governance mechanism (Haan and Riyanto (2006)). Using principal component analysis, we calculate a takeover threat score for each firm-year observation based on the following three takeover threat measures used in the literature: an industry-specific takeover probability calculated as the relative frequency of takeovers in a firm's industry over the past 3 years (Agrawal and Knoeber (1998)), a dummy variable that equals 1 if the firm is acquired in the 7-year period after the current year in question (Agrawal and Knoeber (1998)), and a state antitakeover index that is the count of five state statutes (the control share acquisition, fair price, business combination, poison pill endorsement, and constituency statutes) as in Bebchuk and Cohen (2003).[15] We split the sample based on the takeover threat score and assign an observation to the high-takeover-threat (low-takeover-threat) subsample if the takeover threat score is in the top (bottom) tercile of all sample firms in a year.

As column 2 of Table 4 shows, the estimated coefficient of board diversity is 0.932 and statistically significant, with a t-statistic of 3.91, in the high takeover threat subsample but is not significant in the low-takeover-threat subsample. The χ^2 test shows that the estimated coefficients of board diversity are significantly different in the two subsamples.

3. Market Competition

We now turn to the potential impact of product market competition on the link between board diversity and corporate innovation. Competitive pressure from the product market disciplines managers, rendering the board monitoring function less imperative. Giroud and Mueller (2011) show that firms in competitive industries benefit less from better corporate governance. To measure competition, we calculate the Herfindahl-Hirschman Index (HHI) of each industry as the sum of the squared market shares of all the Compustat firms in that industry. Higher values of HHI indicate greater market concentration and lower competition in the industry. We split the sample based on the HHI scores and assign an observation to the low-competition (high-competition) subsample if its HHI is in the top (bottom) tercile of all sample firms in a year. We run the baseline regression model separately for the two subsamples; column 3 of Table 4 compares the results. The estimated coefficient of board diversity is 0.947 and statistically significant in the high-competition subsample, with a t-statistic of 3.79, but is not significant in the low-competition subsample. The χ^2 test shows that the estimated coefficients of board diversity are significantly different in the two subsamples. Consistent with previous results on IIO and external takeover threat, the result that board diversity is only significantly related to innovation in competitive industries reinforces the

[15]Since a higher state takeover index indicates stronger legal protection against hostile takeovers (i.e., lower takeover threat), we use five minus the state takeover index for the principal component analysis.

notion that the beneficial impact of a diverse board on innovation is mainly due to the board's advising function.

Overall, the results in Table 4 show that corporate innovation benefits more from board diversity when external governance is stronger, which suggests that the advising function is the main channel through which board diversity enhances innovation. Next, we conduct three additional cross-section tests to examine which types of firms tend to benefit more from the superior advising function of a diverse board.

4. Board Experience

First, we split the sample based on director experience. We expect the beneficial effect of a diverse board to be more pronounced when the directors have more experience. We classify a board as experienced if at least one of its directors has filed any patent(s) and/or has business-founding experience. We split the sample into experienced and inexperienced director subsamples and run the baseline regressions separately for the two subsamples.[16] As column 1 of Table 5 shows, the estimated coefficient of board diversity in the experienced subsample is 1.531, with a *t*-statistic of 4.70, and 0.980 in the inexperienced subsample, with a *t*-statistic of 1.90. The difference between the two coefficients is 0.551, with a χ^2 statistic of 2.95 (p-value = 0.091). The result that the impact of board diversity on innovation is more pronounced when directors are more experienced further confirms the superior advisory capacity of diverse boards.

5. Innovation-Intensive Industries

Next, we split the sample firms based on the varying levels of innovative intensity across industries. We expect firms in innovation-intensive industries to

TABLE 5

Cross-Sectional Tests: Advising Benefits

Table 5 compares the regression results for firms with experienced versus inexperienced directors (column 1), operating in industries with high versus low innovation (column 2), and with complex versus noncomplex operations (column 3). The dependent variable is corporate innovation as measured by PATENT. The main variable of interest is BRD_DIVERSITY, the composite board diversity index. The table also reports the results of the χ^2 tests on the difference in the coefficients on the diversity index between the subsamples. All regressions control for year and industry fixed effects. The *t*-statistics (in parentheses) are based on firm-level clustered standard errors. *, **, and *** indicate statistical significance at the 10%, 5%, and 1% levels, respectively.

	$PATENT_{t+3}$					
	Director Experience		Industry Innovation Intensity		Firm Complexity	
	1		2		3	
Dependent Variable	Experienced	Inexperienced	High	Low	Complex	Noncomplex
BRD_DIVERSITY	1.531***	0.980*	0.933***	0.712*	1.305***	0.230
	(4.70)	(1.90)	(3.12)	(1.78)	(4.55)	(0.64)
Control variables	Yes	Yes	Yes	Yes	Yes	Yes
Industry effects	Yes	Yes	Yes	Yes	Yes	Yes
Year effects	Yes	Yes	Yes	Yes	Yes	Yes
No. of obs.	5,432	5,418	3,635	3,625	2,566	2,570
R^2	0.557	0.491	0.534	0.348	0.520	0.458
Difference in coeff.	0.551*		0.221		1.075**	
χ^2 statistic (p-value)	2.95		1.75		4.18	
	(0.091)		(0.186)		(0.041)	

[16] We exclude BRD_FOUNDER from the regressions.

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benefit more from the superior advisory function of diverse boards. We classify an industry as high (low) innovation if the average number of patents of all firms in the industry is in the top (bottom) tercile of all industries in a year.

As column 2 of Table 5 shows, the estimated coefficient of board diversity in high-innovation industries is 0.933, with a t-statistic of 3.12, and 0.712 in the low-innovation industries. However, the difference between the estimated coefficients of board diversity in the two subsamples is not statistically significant at conventional levels, with a χ^2 statistic of 1.75.

6. Firm Complexity

Finally, we split the sample based on the complexity of a firm's operations.[17] Using principal component analysis, we calculate a complexity score based on six variables: the number of business segments, 1 minus the HHI based on business segment sales, the number of geographic segments, 1 minus the HHI based on geographic segment sales, total assets, and the number of employees. We assign an observation to the noncomplex (complex) subsample if its complexity score is in the bottom (top) tercile of all sample firms in a year.

As column 3 of Table 5 shows, the estimated coefficient of board diversity in the complex subsample is 1.305 and statistically significant, with a t-statistic of 4.55, and 0.230 in the noncomplex subsample, with a t-statistic of 0.64. The χ^2 test shows that the estimated coefficients of board diversity are significantly different in the two subsamples.[18] The results suggest that the advisory function of the board is more important for firms with more complex operations.

D. Board Diversity Subindex

Our results so far are based on the board diversity index, which is constructed by combining six subindexes: i) the demographic diversity index, ii) the educational diversity index, iii) the professional diversity index, iv) the director experience index, v) the managerial trait index, and vi) the cultural diversity index. In this section, we regress PATENT against the six subindexes to examine which aspects of board diversity matter the most for corporate innovation. We include the same set of control variables in the regression as in column 5 of Table 2.

Table 6 reports the results. The estimated coefficients of educational diversity and professional diversity are positive and statistically significant at 10% and 1% respectively. As described in detail in the Supplementary Material, educational diversity is based on the variation in degrees and background; professional diversity is based on the variation in expertise, founding experience, and executive positions. The results suggest that the diverse educational backgrounds and professional experiences of board members contribute to the generation of patents. In addition to its statistical significance, the economic significance of professional diversity is sizable. A 1-standard-deviation increase in the professional diversity index will increase PATENT by about 0.051, a 5.94% increase in the mean. The estimated coefficients of director experience, managerial traits, and demographic

[17]The availability of Compustat Segment data reduces the sample size to 7,786.

[18]Our results are robust to the alternative measure of firm complexity defined as 1 minus the firm's HHI based on segment sales.

TABLE 6
Subindexes of Board Diversity

Table 6 reports the effects of six subindexes of board diversity (described in the Supplementary Material) on innovation. The dependent variable is corporate innovation as measured by PATENT. The regression controls for year and industry fixed effects. The *t*-statistics (in parentheses) are based on firm-level clustered standard errors. The table also presents the number of observations and the R^2 values for each regression. *, **, and *** indicate statistical significance at the 10%, 5%, and 1% levels, respectively.

Dependent Variable	$PATENT_{t+3}$
DEMOGRAPHIC_DIVERSITY	0.674
	(0.73)
EDUCATIONAL_DIVERSITY	1.916*
	(1.94)
PROFESSIONAL_DIVERSITY	2.301***
	(3.30)
EXPERIENCE_DIVERSITY	−0.466
	(−0.74)
MANAGERIAL_TRAIT_DIVERSITY	−0.960
	(−0.38)
CULTURAL_DIVERSITY	1.299
	(1.52)
Control variables	Yes
Industry effects	Yes
Year effects	Yes
No. of obs.	10,850
R^2	0.525

and cultural diversity are not statistically significant.[19] To summarize, a board's professional diversity is the diversity subindex that matters the most for innovation productivity, and education diversity is the next most important.[20]

IV. Board Diversity and Innovation Strategies

In this section, we construct indicators of patent quality to measure not only the number of innovative patents but also the strategic direction of innovation undertaken by firms with different board compositions. In particular, we test whether firms with diverse boards pursue exploratory or exploitative innovative strategies. If a diverse board encourages more exploration and thinking outside the box, we would expect these firms to venture into less familiar areas and develop new technologies. Alternatively, firms could choose exploitative strategies by relying on conventional technologies or staying in areas that are more familiar to them.

To test our conjectures, we first calculate the number of patents that a firm files in previously unknown technology classes. We follow Balsmeier et al. (2017) by defining unknown patent classes as USPTO technology classes in which the firm has not applied for any patent since 1976. The variable UNKNOWN is the natural logarithm of 1 plus the number of patents filed in previously unknown areas.

[19]The insignificant effect of demographic and cultural diversity here is consistent with Rhode and Packel (2014), who show that demographic and cultural diversity are driven by social justification rather than firm performance.

[20]We also construct the first principal component of each subindex to examine how each of the six principal components relates to future innovation. We find the results based on the first principal components similar to those reported in Table 6.

Second, we calculate the technological proximity (TECH_PROXY) between the firm's patent portfolio in 1 year and that of the same firm in prior years. Specifically, we follow Balsmeier et al. (2017) and Jaffe (1989) by calculating technological proximity according to the following formula:

$$\text{(3)} \quad \text{TECH\_PROXY}_{it+3} = \sum_{k=1}^{K} f_{ikt+3} f_{ikt+2} \Big/ \left(\sum_{k=1}^{K} f_{ikt+3}^2 \times \sum_{k=1}^{K} f_{ikt+2}^2 \right)^{1/2},$$

where f_{ikt+3} is the fraction of firm i's patents that belong to technology class k in year $t+3$ and f_{ikt+2} is the fraction of firm i's patent portfolio up to year $t+2$ that belongs to technology class k.[21] The variable TECH_PROXY is continuous and ranges between 0 and 1. The higher the technological proximity, the more overlap between the technology class distributions of a firm's patent portfolios over time. For example, the value of 1 indicates that the technology class distribution of a firm's patent portfolio in a year is exactly the same as that of the previous years.

Next, we regress the two new variables separately against the board diversity index to test whether firms with different board compositions remain in or deviate from known research areas. All the independent variables are the same as in column 5 of Table 2. As Table 7 shows, the estimated coefficient of the board diversity index is positive and significant (t-statistic $= 1.91$) when the dependent variable is UNKNOWN, indicating that board diversity is positively related to the number of patents filed in previously unknown areas. We obtain similar results when using technological proximity as a more sophisticated measure of the corporate innovation trajectory. The estimated coefficient of the board diversity index is significantly negative, with a t-statistic of -1.90, when the dependent variable is TECH_PROXY. Overall, the results suggest that diverse boards encourage firms to explore novel technology and venture into previously unfamiliar areas.

The pursuit of innovation in unknown areas can be risky since it increases the chances of both breakthroughs and failures. Specifically, we expect explorative

TABLE 7

Board Diversity and Innovation Strategies

Table 7 reports the results of regression models, where the dependent variable is either UNKNOWN or TECH_PROXY. The variable UNKNOWN is the logarithm of 1 plus the number of patents filed in previously unknown areas and TECH_PROXY is a continuous measure of whether the firm remains in or deviates from known research areas (i.e., the technological proximity between patents filed in year $t+3$ and the existing patent portfolio held by the same firm up to year $t+2$. The main variable of interest is BRD_DIVERSITY, the composite board diversity index. All regressions control for year and industry fixed effects. The t-statistics (in parentheses) are based on firm-level clustered standard errors. The table also presents the number of observations and the R^2 values for each regression. *, **, and *** indicate statistical significance at the 10%, 5%, and 1% levels, respectively.

Dependent Variable	UNKNOWN_{t+3}	TECH_PROXY_{t+3}
BRD_DIVERSITY	0.270*	−0.102*
	(1.91)	(−1.90)
Control variables	Yes	Yes
Industry effects	Yes	Yes
Year effects	Yes	Yes
No. of obs.	10,850	10,850
R^2	0.249	0.152

[21]Our results are robust to measuring the firm's technological proximity between its patent portfolio in year $t+3$ and that up to year t.

innovation strategies to flatten the probability distribution of innovation quality. In other words, as firms venture into less familiar areas and develop new technologies, they should generate greater numbers of both breakthroughs and marginal inventions, leading to a more flattened distribution with long tails. To measure the quality of innovation, we follow Balsmeier et al. (2017) by splitting all the patents in our sample into four mutually exclusive categories by the number of patent citations received. Breakthroughs are patents receiving a number of citations in the top 1% of the citation distribution within the technology class and application year. Important innovations are patents that fall in the top 10% of the citation distribution within the technology class and application year (excluding the top 1%). On the other end of the distribution, there are patents that receive no citations at all. The remaining patents are classified as incremental innovations, since they receive citations but are not in the top 10%. We use the logarithm of 1 plus the number of patents in each of the aforementioned categories as the dependent variables (i.e., TOP1_CITE, TOP10_CITE, MIDDLE_CITE, and NO_CITE) and regress each of them against the board diversity index. We use the same set of control variables as specified in column 5 of Table 2.

Table 8 reports the results. The estimated coefficients of the board diversity index are 0.726, 0.706, 0.649, and 0.702 when the dependent variables are TOP1_CITE, TOP10_CITE, MIDDLE_CITE, and NO_CITE, respectively. Moreover, the statistical significance of board diversity varies. Specifically, the t-statistics are 2.64, 2.41, 1.60, and 2.15 when the dependent variables are TOP1_CITE, TOP10_CITE, MIDDLE_CITE, and NO_CITE, respectively. The results indicate that firms with diverse boards generate slightly more breakthroughs and patents without citations. In addition to a positive relation between board diversity and innovation output as measured by the firm's patent count, we also find evidence to suggest that board diversity matters for innovation strategies. That is, the increase in patents is mainly due to the tails of the patent quality distribution (i.e., patents with the most citations and those without citations). The evidence is also consistent with earlier findings in this section, that firms with diverse boards

TABLE 8

Board Diversity and Patent Distribution

Table 8 reports the results of regressions regarding board diversity on the distribution of patent citations. The dependent variables are TOP1_CITE (the natural logarithm of 1 plus the number of patents in the top 1% of the citation distribution within the technology class and application year), TOP10_CITE (the natural logarithm of 1 plus the number of patents in the top 10% of the citation distribution within the technology class and application year, excluding the top 1%), MIDDLE_CITE (the natural logarithm of 1 plus the number of patents that are cited but are not in the top 10% of the citation distribution), and NO_CITE (the natural logarithm of 1 plus the number of patents that receive no citations). The main variable of interest is BRD_DIVERSITY, the composite board diversity index. All regressions control for both industry and year fixed effects. The t-statistics (in parentheses) are based on firm-level clustered standard errors. The table also presents the number of observations and the R^2 values for each regression. *, **, and *** indicate statistical significance at the 10%, 5%, and 1% levels, respectively.

Dependent Variable	$TOP1\_CITE_{t+3}$	$TOP10\_CITE_{t+3}$	$MIDDLE\_CITE_{t+3}$	NO_CITE_{t+3}
BRD_DIVERSITY	0.726***	0.706**	0.649	0.702**
	(2.64)	(2.41)	(1.60)	(2.15)
Control variables	Yes	Yes	Yes	Yes
Industry effects	Yes	Yes	Yes	Yes
Year effects	Yes	Yes	Yes	Yes
No. of obs.	10,850	10,850	10,850	10,850
R^2	0.212	0.316	0.412	0.372

adopt an exploration strategy by venturing into unfamiliar areas, resulting in a larger number of both most-cited and uncited patents. Taken together, the results in this section suggest that a diverse board fosters a culture of innovation and creativity, which encourages thinking outside the box and the development of novel technologies.

V. Robustness Checks

A. Instrumental Variable Estimation

The results thus far have been consistent with the notion that board diversity fosters corporate innovation. Nonetheless, we recognize that the potential endogeneity of board diversity makes causality difficult to identify. One source of concern is reverse causality. For example, board diversity could be affected by corporate innovation if more innovative firms attract directors from more diverse backgrounds. To mitigate endogeneity concerns, we first employ the IV approach to check the robustness of our results.

We use the population diversity of the county where the firm is headquartered as the IV for board diversity, following the literature (e.g., Anderson et al. (2011), Davis and Henderson (2008), Fama and Jensen (1983), McPherson and Smith-Lovin (1987), and Pirinsky and Wang (2006)). Since many corporate directors are from the local geographic area of firms' headquarters, a more diverse local population makes it easier for firms to source heterogeneous corporate directors. We collect the sample firms' historical headquarters through their Securities and Exchange Commission filings, including both the 10Q and 10K forms. We follow Anderson et al. (2011) to construct the composite measure of county population diversity (CNY_DIVERSITY) based on the local population distribution of age, race, gender, and employment characteristics.[22] We obtain local economic and demographic information from the U.S. Census Bureau, Bureau of Economic Analysis, and Bureau of Labor Statistics.

Table 9 reports the results of the 2-stage least squares analysis. In the first stage, we regress the board diversity index against CNY_DIVERSITY, the instrumental variable, and the same set of control variables used in column 5 of Table 2. As column 1 shows, the instrumental variable is significant at the 1% level and the Kleibergen-Paap rk Wald F-statistic is 45.29, higher than the 10% critical value of 16.38, indicating the instrument is not weak.

In the second stage, we regress PATENT against the fitted value of board diversity index as well as the control variables. Column 2 of Table 9 shows the estimated coefficient of the fitted value of board diversity is positive and significant at the 1% level, consistent with the ordinary least squares (OLS) regression results.

[22]First, we calculate the age HHI based on the distribution of 18 age brackets in each county; the percentage of female population of the county; the race HHI based on the percentage of six ethnic groups; and the employment HHI based on the percentage of employees among the 19 North American Industry Classification System industries. We then rank the counties into quartiles by each of the four diversity measures. Finally, we sum up the four rankings of each county and divide the sum by 16 to obtain the composite county diversity index, which ranges from 0.25 to 1.

TABLE 9
Instrumental Variable Estimation

Table 9 reports the results from the 2-stage least squares regression. In the first-stage regression, the dependent variable is the board diversity index (BRD_DIVERSITY) and the instrumental variable (IV) is the county diversity index (CNY_DIVERSITY) in column 1. In the second-stage regression, the dependent variable is PATENT (column 2). Columns 3 and 4 report the results with additional variables controlling for local economics and demographic characteristics. GDP_GROWTH, EDUCATION, EMPLOYMENT, and CA_MA are as defined in the Appendix. All regressions include the industry and year fixed effects. The t-statistics (in parentheses) are based on firm-level clustered standard errors. *, **, and *** indicate statistical significance at the 10%, 5%, and 1% levels, respectively.

	BRD_DIVERSITY	$PATENT_{t+3}$	BRD_DIVERSITY	$PATENT_{t+3}$
Dependent Variable	1 1st Stage	2 2nd Stage	3 1st Stage	4 2nd Stage
BRD_DIVERSITY		3.308*** (3.25)		2.583*** (2.82)
CNY_DIVERSITY	0.035*** (6.70)		0.034*** (6.41)	
GDP_GROWTH			0.071 (1.36)	−1.007 (−1.07)
EDUCATION			0.001*** (3.80)	0.011*** (4.90)
EMPLOYMENT			0.003 (0.96)	−0.011 (−0.16)
CA_MA			0.007** (2.51)	0.215*** (7.16)
Control variables	Yes	Yes	Yes	Yes
Industry effects	Yes	Yes	Yes	Yes
Year effects	Yes	Yes	Yes	Yes
No. of obs.	10,511	10,511	10,511	10,511
R^2	0.114	0.517	0.115	0.518
Kleibergen–Paap rk Wald F-statistic	45.29	–	41.45	–

Columns 3 and 4 of Table 9 show the IV estimation results hold after controlling for important local economic and demographic characteristics, including economic growth rate, employment rate, education level, and whether the county is located in California or Massachusetts.

B. Alternative Measures of Innovation

Thus far, we have mainly used PATENT as the measure of innovation. We now test whether the baseline regression results hold when the dependent variable is one of the five alternative innovation measures described in Section II: ADJ_PATENT, CITATION, ADJ_MV, AVG_EXT_CITATION, and ADJ_AVG_EXT_CITATION. Panel A of Table 10 shows the estimated coefficients of the board diversity index remain significantly positive for all five alternative innovation measures.

C. Controlling for CEO Influence

Given the influence of CEOs on firm innovation, we check whether our results hold after controlling for i) CEO fixed effects and ii) four distinct CEO characteristics that the literature has shown are related to corporate innovation: CEO general skills, CEO overconfidence, inventor CEOs, and the deferred compensation of CEOs (see Custodio et al. (2019), Galasso and Simcoe (2011), Hirshleifer et al. (2012), Islam and Zein (2018), and Sunder et al. (2017)). CEO_GENERAL_ABILITY measures the generality of a CEO's human capital based on the CEO's lifetime work experience in publicly traded firms prior to

TABLE 10
Robustness Checks

The dependent variable in Panel A of Table 10 is one of the five alternative measures of innovation. Panel B controls for chief executive officer (CEO) fixed effects in column 1 and four CEO characteristics in column 2. Panel C controls for additional firm and local variables that may affect innovation. All regressions control for industry and year fixed effects. The t-statistics (in parentheses) are based on firm-level clustered standard errors. The table also presents the number of observations and the R^2 values for each regression. *, **, and *** indicate statistical significance at the 10%, 5%, and 1% levels, respectively. All variables are defined in the Appendix.

Panel A. Alternative Measures of Innovation

Dependent Variable	ADJ_PATENT_{t+3}	ADJ_MV_{t+3}	$CITATION_{t+3}$	$AVG\_EXT\_CITATION_{t+3}$	$ADJ\_AVG\_EXT\_CITATION_{t+3}$
BRD_DIVERSITY	0.967**	0.585*	0.418**	0.150**	0.139**
	(2.22)	(1.82)	(2.52)	(2.36)	(2.27)
Control variables	Yes	Yes	Yes	Yes	Yes
Industry effects	Yes	Yes	Yes	Yes	Yes
Year effects	Yes	Yes	Yes	Yes	Yes
No. of obs.	10,850	10,850	10,850	10,850	10,850
R^2	0.305	0.319	0.258	0.292	0.248

Panel B. CEO Influence

	$PATENT_{t+3}$	
Dependent Variable	1	2
BRD_DIVERSITY	0.675***	0.791***
	(3.09)	(2.87)
CEO_GENERAL_ABILITY		0.006
		(1.37)
CEO_OVERCONFIDENCE		0.113***
		(3.83)
CEO_DEFER_COMP		0.197***
		(3.51)
CEO_INVENTOR		0.058*
		(1.67)
Control variables	Yes	Yes
CEO effects	Yes	No
Industry effects	Yes	Yes
Year effects	Yes	Yes
No. of obs.	8,571	6,888
R^2	0.903	0.533

Panel C. Additional Innovation Determinants

	$PATENT_{t+3}$	
Dependent Variable	1	2
BRD_DIVERSITY	0.740**	0.796**
	(2.09)	(2.53)
ANTITAKEOVER_PROVISIONS	0.023***	0.029**
	(2.92)	(2.25)
ANALYST_COVERAGE	0.016*	0.017*
	(1.68)	(1.95)
STOCK_LIQUIDITY	−17.905**	−16.373*
	(−2.46)	(−1.90)
INDUSTRY_HHI	−1.338	−1.201
	(−0.97)	(−1.18)
$INDUSTRY\_HHI^2$	1.063	1.265
	(1.38)	(1.54)
EDUCATION		0.004*
		(1.67)
CA_MA		0.453***
		(2.83)
Control variables	Yes	Yes
Industry effects	Yes	Yes
Year effects	Yes	Yes
No. of obs.	7,461	7,303
R^2	0.538	0.527

the current CEO position;[23] CEO_OVERCONFIDENCE is a dummy variable that equals 1 if the CEO postpones the exercise of vested options that are at least 67% in the money, and 0 otherwise; CEO_DEFERRED_COMP is the ratio of the estimated dollar value of the CEO's options and other deferred compensation to the CEO's total compensation; and CEO_INVENTOR is a dummy variable that equals 1 if the CEO has filed at least one patent, and 0 otherwise. We rely on the U.S. Patent Inventor Database to identify CEO inventors. ExecuComp provides the data to construct our measures of CEO overconfidence and deferred compensation.

Panel B of Table 10 reports the results. The estimated coefficients of the board diversity index are significantly positive in column 1, where we control for CEO fixed effects, and in column 2, where we control for the four CEO characteristics.

D. Additional Robustness Checks

In this section, we test whether our results hold after controlling for additional variables. First, we control for the following variables that the literature shows are related to corporate innovation in column 1 of Panel C in Table 10: antitakeover provisions, analyst coverage, stock liquidity, and industry competition (see Aghion et al. (2005), Atanassov (2013), Chemmanur and Tian (2018), Fang et al. (2014), and He and Tian (2013)). Specifically, ANTITAKEOVER_PROVISIONS is the number of antitakeover provisions in the corporate charter and bylaws obtained from ISS (formerly RiskMetrics) as in Gompers, Ishii, and Metrick (2003); ANALYST_COVERAGE is the logarithm of 1 plus the number of 1-year-ahead analyst earnings forecasts for a firm as reported in Institutional Brokers' Estimate System (I/B/E/S); STOCK_LIQUIDITY is the negative logarithm of 1 plus the high–low spread estimator as in Corwin and Schultz (2012);[24] INDUSTRY_HHI is the revenue-based HHI of an industry as a measure of market competition; and INDUSTRY_HHI^2 is the square of the HHI. Panel C of Table 10 reports the results. In column 2, we add the local variables that are statistically significant in the IV estimation: EDUCATION and CA_MA. The estimated coefficient of board diversity remains significantly positive in both columns after controlling for these additional variables.

As a final robustness check, we re-estimate the baseline regression using firm-year observations where the number of patents is not 0, and our main results hold.

VI. Conclusion

In this article, we investigate the relation between board diversity and corporate innovation. We construct a multidimensional diversity index based on

[23]We thank Claudia Custodio for providing the general ability index, which is the first factor of the principal components analysis of the five aspects of a CEO's professional career: past number of i) positions, ii) firms, and iii) industries in which a CEO worked; iv) whether the executive held a CEO position at a different company; and v) whether the CEO worked for a conglomerate firm. Please see Custodio, Ferreira, and Matos (2019) for detailed variable definition.

[24]We put a negative sign in front of the logarithm so that an increase in spread corresponds to lower stock liquidity.

six aspects of director characteristics: education, demographic attributes, cultural attitudes, managerial traits, professional background, and board experience. We find the composite index of board diversity to be positively related to innovation output. Moreover, we compare the innovation strategies undertaken by firms with different board compositions. We find evidence to suggest that firms with diverse boards engage in more exploratory innovation, with the development of new technology in unfamiliar areas. These findings suggest that corporate innovation benefits from the strategic resources brought by directors with different backgrounds. A diverse board fosters a culture of innovation and creativity, which encourages thinking outside the box and ventures into novel technologies.

However, policy makers and shareholders should exercise caution in promoting diversity in the board rooms. Differences between directors can create communication and coordination problems in the boardroom, protracting the decision-making process. We find a nonlinear relation between board diversity and corporate innovation, consistent with the cost–benefit tradeoff of board diversity. Piecewise regressions reveal that the positive relation between diversity and innovation disappears as the board becomes increasingly diverse. Moreover, we find the benefits of board diversity are more pronounced for firms with complex operations, with more experienced directors, and that are subject to stronger external governance, suggesting the benefits are mainly due to the superior advising capacity of diverse boards. Finally, of the six different aspects of board diversity, professional diversity matters the most as far as innovation is concerned.

Appendix. Variable Definitions

PATENT: Natural logarithm of 1 plus the firm's total number of patent applications filed in a year that are eventually granted.

ADJ_PATENT: Natural logarithm of 1 plus the firm's total class-adjusted patent counts in a year, which is patent counts divided by the average number of patents of all firms in the same technology class for that year.

CITATION: Natural logarithm of 1 plus the firm's total class-adjusted citation count in a year.

ADJ_MV: Natural logarithm of 1 plus the adjusted market value of the firms' new patents.

AVG_EXT_CITATION: Natural logarithm of 1 plus the average number of non-self-citations per patent received by the firm's patents in a year.

ADJ_AVG_EXT_CITATION: Natural logarithm of 1 plus the firm's average external citation count, scaled by the average number of external citations of all patents in the same technology class in a year.

UNKNOWN: Natural logarithm of 1 plus the number of patents filed in previously unknown areas.

TECH_PROXY: Technological proximity between the firm's patent portfolio in 1 year and that of the same firm in prior years.

TOP1_CITE: Natural logarithm of 1 plus the number of patents in the top 1% of the citation distribution within the technology class and application year.

TOP10_CITE: Natural logarithm of 1 plus the number of patents in the top 10% of the citation distribution within the technology class and application year (excluding the top 1%).

MIDDLE_CITE: Natural logarithm of 1 plus the number of patents that are cited but are not in the top 10% of the citation distribution.

NO_CITE: Natural logarithm of 1 plus the number of patents that receive no citations.

BRD_AGE: Natural logarithm of the average age of the board members.

BRD_FEMALE: Proportion of female directors on the board.

BRD_PHD: Proportion of board directors with PhD degrees.

BRD_FOUNDER: Proportion of directors with experience founding a business.

BRD_TENURE: Natural logarithm of average director tenure.

BRD_EXT_SEAT: Natural logarithm of the average number of directors' external board seats.

BRD_INDEPENDENCE: Proportion of independent directors.

BRD_POLITICAL_CONNECTION: Proportion of politically connected directors.

BRD_MILITARY: Proportion of directors with military experience.

BRD_DEPRESSION_BABY: Proportion of directors born during the Great Depression.

POWER_DISTANCE: Average power distance scores of directors divided by 100.

INDIVIDUALISM: Average individualism scores of directors divided by 100.

UNCERTAINTY_AVOIDANCE: Average uncertainty avoidance scores of directors divided by 100.

MASCULINITY: Average masculinity scores of directors divided by 100.

LONG_TERM_ORIENTATION: Average long-term orientation scores of directors divided by 100.

CNY_DIVERSITY: Composite measure of county population diversity based on the local population distribution of age, race, gender, and employment characteristics.

EDUCATION: Proportion of county population with the education of high school completion or above.

EMPLOYMENT: County employment rate.

GDP_GROWTH: GDP growth rate during the past 3 years.

CA_MA: Dummy variable which equals to 1 if the firm headquarter is located in either California or Massachusetts, and 0 otherwise.

CEO_GENERAL_ABILITY: Generality of a CEO's human capital based on the CEO's lifetime work experience in publicly traded firms prior to the current CEO position.

CEO_OVERCONFIDENCE: Dummy variable that equals 1 if the CEO postpones the exercise of vested options that are at least 67% in the money, and 0 otherwise.

CEO_DEFERRED_COMP: Ratio of the estimated dollar value of the CEO's options and other deferred compensation to the CEO's total compensation.

CEO_INVENTOR: Dummy variable that equals 1 if the CEO has filed at least one patent, and 0 otherwise.

ANTITAKEOVER_PROVISIONS: Number of antitakeover provisions in the corporate charter and bylaws.

ANALYST_COVERAGE: Natural logarithm of 1 plus the number of 1-year-ahead analyst earnings forecasts for a firm.

STOCK_LIQUIDITY: Negative natural logarithm of 1 plus the high–low spread estimator.

INDUSTRY_HHI: Revenue-based HHI of an industry as a measure of market competition; and

INDUSTRY_HHI^2: Square of INDUSTRY HHI.

SIZE: Natural logarithm of total assets (in $millions).

AGE: Natural logarithm of 1 plus the number of years since the firm's first appearance in the Center for Research in Security Prices (CRSP).

LEV: Total debt divided by total assets.

ROA: Operating income before depreciation divided by total assets.

CASH: Cash holdings divided by total assets.

CF: Sum of income before extraordinary items and depreciation divided by total assets.

TOBINS_Q: (Assets + year-end closing price × year-end number of outstanding shares − book equity)/assets.

TANGIBLE: Property, plants, and equipment divided by total assets.

R&D: R&D expenditures divided by total assets.

TURNOVER: Average ratio of the monthly trading volume to the number of shares outstanding over the fiscal year.

RISK: Natural logarithm of the standard deviation of stock daily returns in the fiscal year.

IO: Percentage of institutional ownership.

Supplementary Material

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