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Board independence and analysts' forecast accuracy: *R&D* perspective

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ABSTRACT

Research and development (*R&D*) activities are essential for firm growth and profitability. However, *R&D* activities also exacerbate information complexity in the financial markets. Therefore, the accuracy of earnings forecasts suffers when *R&D* expenses are high. This study aims to examine whether board independence can mitigate the adverse effect of high *R&D* expenditure on analysts' forecasts. Using a sample of 11,645 annual observations from 1997 to 2016, we find that board independence improves analysts' forecast accuracy for *R&D*-intensive firms. The improvement is more pronounced in firms with low analyst coverage and powerful CEOs. These results are robust with an alternative measure of information asymmetry, a dynamic generalized method of moments (GMM) model and a quasi-natural experiment based on the Sarbanes-Oxley Act of 2002 to address endogeneity concerns.

1. Introduction

Research and development (*R&D*) activities are essential to firm growth and profitability. In the US, business funding of *R&D* has grown from $2.2 billion in 1955 to $463.7 billion in 2019, representing a compound annual growth rate of 8.5% (Sargent, 2021). Chan et al. (2001) find that the *R&D*-intensive technology sector and pharmaceutical industry account for 40% of the market value of the S&P 500 firms in 1999. Bates et al. (2009) report that average capital expenditures (% of assets) were more than double the average *R&D* expenditures (8.9% vs. 3.2%) in the 1980 s. In the 2000 s, *R&D* has exceeded capital expenditures (6.7% vs. 5.4%). However, *R&D* is also a significant source of information asymmetry in the financial markets. The Accounting Standards Codification (ASC) requires that *R&D* expenses be immediately reported in financial statements. However, the financial statements also do not provide much information about how the *R&D* money is spent. As a result, it is difficult for investors to determine whether a major write-down on the income statement indicates future financial trouble or a potential increase in profitability from successful *R&D* activities.

Furthermore, *R&D* activities are typically firm-specific. It is difficult for investors to evaluate a firm's *R&D* by observing the outcomes of other firms' *R&D* activities (Aboody & Lev, 2000). Therefore, *R&D*-intensive firms are likely to have less informative share prices in the financial market. Information complexity, asymmetry, uncertainty, and lack of public information can impair analysts' ability to process information and provide valuable recommendations for *R&D*-intensive firms. Investors and equity analysts would generally discount the information asymmetry at the firms' cost. The accuracy of earnings forecasts is also lower in firms with high *R&D* expenses because analysts' forecasts depend on the quality and quantity of firms' financial information disclosure (Byard et al.,

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2006).

Although governance literature suggests that board independence improves the general information environment around a firm (Dechow et al., 1996; Beasley, 1996; Chen & Jaggi, 2000), it is not entirely clear whether board independence can improve the forecast accuracy for *R&D*-intensive firms. This study examines the relationship between corporate board independence and the accuracy of earnings forecasts. Our findings suggest that board independence increases forecast accuracy in firms with high *R&D* expenses but not in firms with low *R&D* expenses. These results are robust after controlling for a wide array of variables at both firm and board levels. Our results suggest that board independence can improve earnings forecast when a firm's information environment is opaque due to its high *R&D* expense and associated information complexity. We find that after controlling for other board-level characteristics, such as board size and gender diversity, board independence appears to be an effective mechanism to improve price informativeness for firms with high R&D expenses.

Lim (2001) and Mansi et al. (2011) find that forecast errors decrease as more analysts cover a firm. Our analyses also show that analyst coverage is an important factor in improving forecast accuracy. If board independence can reduce forecast errors for *R&D*-intensive firms, we expect board independence to play a more critical role when the *R&D*-intensive firms have low analyst coverage. We test such a hypothesis and find that board independence improves the forecast accuracy of *R&D*-intensive firms more pronouncedly when firms do not have adequate analyst coverage. Our results suggest that the market relies on independent directors to improve the information environment in *R&D*-intensive firms when other information-transparency-enhanced mechanisms (e.g., coverage by financial analysts) are weak.

Previous studies suggest that board independence and CEO power often play opposite roles in firms' oversight, monitoring, and management (DeBoskey et al., 2019; Adams & Ferreira, 2007; Muttakin et al., 2018; Combs et al., 2007). To show board independence can provide incremental improvement in analysts' forecasts, we conduct our analyses in firms with high CEO power vs. in firms with low CEO power. Interestingly, we find that board independence reduces forecast errors in high *R&D* firms only when CEO power is high, but not when CEO power is low. These results highlight that independent directors play a critical role in high *R&D* firms (high information complexity) when board oversight is weak because of powerful CEOs. It implies that the less informative environment created by *R&D* expenditure can be further improved by board independence effectively.

To ensure our analyses are robust, we first control for a wide range of variables correlated with forecast errors in our panel data with firm and year-fixed effects to minimize impact from the unobservable time-invariant and cross-sectional invariant factors. We then use idiosyncratic volatility, a widely-accepted measure of information asymmetry (Lee & Mauck, 2016; Dang et al., 2015; Jiang et al., 2009; Moeller et al., 2007; He & Wang, 1995), as an alternative measure of information asymmetry to confirm our results still hold. Next, to address the endogeneity issues, we use the generalized method of moments (GMM) model developed for dynamic panel estimation by Arellano and Bond (1991). The GMM analysis provides consistent results. We also conduct our analyses using winsorized variables to ensure that extreme observations do not drive our results. To further address the endogeneity problem, especially the concern of time-varying omitted variables, we conduct a further robustness test by utilizing the exogenous shock to board independence from the passage of SOX and subsequent changes in listing requirements by NYSE and Nasdaq. The results show that the increase of percent of independent directors due to regulation reduces the analysts' forecast errors in high R&D firms. It suggests the negative relation between board independence and forecast errors is likely to be unidirectional.

This study contributes to several strands of finance, accounting, and governance literature. This study adds to the accounting and governance literature by documenting important evidence of independent directors' ability to improve forecast accuracy in high *R&D* firms. Although existing literature has shown that independent directors improve voluntary disclosure (Eng & Mak, 2003; Patelli & Prencipe, 2007; Gisbert & Navallas, 2013), there is limited evidence of how the market values such voluntary disclosure, especially for firms with high *R&D* activities. Existing literature also reports that better corporate governance improves the analyst's forecast accuracy and firm transparency (e.g., Byard et al., 2006; Armstrong et al., 2014), but no study investigates whether board independence can reduce forecast errors in *R&D*-intensive firms. In addition, it is costly for firms to disclose details of their *R&D* activities. Since *R&D* activities have increased dramatically in the past decades, it is important and timely to investigate which governance mechanism works effectively and efficiently to alleviate the negative effect of high *R&D* expenses. Our study takes a more focused approach from the *R&D* perspective. This study suggests that board independence is particularly important to high *R&D* firms. If a firm cannot disclose much about its *R&D* expenditure, increasing board independence can be a powerful tool to increase its price informativeness. Our study also suggests that independent directors are more effective when firms have low analyst coverage and powerful CEOs. Therefore, market participants should consider the interaction between board independence and these two factors when analyzing firms' information environment.

2. Literature review and development of hypotheses

Existing studies suggest that *R&D* activities significantly add to firm information asymmetry (Chan et al., 1990; Aboody & Lev, 2000; Boon & Raman, 2001). It makes financial analysts' task of producing reliable earnings forecasts difficult, resulting in an increased deviation between actual earnings and analysts' forecasts (Barron et al., 2002; Amir et al., 2010). However, governance literature suggests that board independence increases the extent and the quality of disclosures by a firm. For example, Beasley (1996) finds that board independence reduces the likelihood of reporting misleading financial statement information (quality of reporting). Armstrong et al. (2014) show that firms following a regulatory shock, which significantly increased the proportion of independent directors on boards, saw significant improvement in corporate transparency or reduced information asymmetry. Dechow et al. (1996) find that earnings manipulation is more likely when the board of directors is dominated by insiders. Chen and Jaggi (2000) find that the comprehensiveness of a firm's financial disclosures is positively associated with board independence. In the same vein of thinking, Chen et al. (2015) show that independent directors reduce earning management significantly for firms with low information acquisition costs. Byard et al. (2006) report that board independence can reduce forecast errors. These findings suggest that board independence improves the information environment of a firm, and an improved information environment can reduce analyst forecast errors. Therefore, we posit:

Hypothesis I. **.** Board independence improves forecast accuracy more pronouncedly for *R&D*-intensive firms.

Past studies suggest that information asymmetry attracts more financial analysts to follow firms with high *R&D* activities and improve information asymmetry (Barth et al., 2002). Palmon and Yezegel (2012) show that without adequate analysts who acquire private information, *R&D*-intensive firms' share prices are less informative. If insufficient financial analyst coverage exists in firms with high R&D activities, the accuracy of these earnings forecasts is more likely to suffer. Since independent board directors can improve information transparency, it is reasonable to assume that independent directors will play a more significant role in mitigating the information asymmetry in high *R&D* firms with low analyst coverage. Therefore, we conjecture:

Hypothesis II. Independent directors reduce forecast errors for *R&D*-intensive firms more significantly when analyst coverage is low.

Some studies argue that CEO power affects the effectiveness of board independence. DeBoskey et al. (2019) find that board independence can reduce the elevated earnings announcement tone associated with powerful CEOs. A powerful CEO tends to elevate earnings announcement tone that may lead to an increase in earnings forecast errors. However, if the firm has an independent board, this board will counteract this exaggerated tone with its positive impact on information asymmetry. Therefore, we expect a more pronounced negative correlation between forecast errors and board independence in firms with powerful CEOs than in those without powerful CEOs. Muttakin et al. (2018) show that board capital and CEO power play opposite roles in corporate social responsibility disclosure. Combs et al. (2007) report that an outside-director-dominated board is needed to check a powerful CEO. Therefore, board independence would matter more for firms with high CEO power than those with low CEO power.

Additionally, Adams and Ferreira (2007) show that CEOs are willing to share more information with a friendly board than an unfriendly board. Since a powerful CEO is more likely to have a friendly board,[1] the powerful CEO is likely to disclose more useful information to reduce information asymmetry. This enhanced disclosures could be particularly helpful for firms with high information asymmetry. In addition, Boyd (1995), Jensen and Meckling (1995), and Li et al. (2019) show that unified CEOs reduce coordination and information acquisition costs, which can be especially beneficial to firms operating in a competitive and dynamic environment. Therefore, based on the current findings, we hypothesize:

Hypothesis III. **.** Board independence improves forecast accuracy in *R&D*-intensive firms more significantly when CEO power is high.

3. Data and methodology

3.1. Sample construction and data sources

This study uses firms' annual fundamental data from Compustat, stock returns from the Center for Research in Security Prices (CRSP), board of director characteristics data from Institutional Shareholder Services (ISS), and analysts' earnings forecasts data from IBES. We only include the US common stocks (CRSP share codes 10 and 11) and exclude financial services firms (SIC codes 6000–6999) and regulated utility firms (SIC codes 4900–4999). We limit our sample end-year to 2016 to eliminate the effects of the 2016 election and the 2017 tax reform following previous studies (Barro & Furman, 2018; Wagner et al., 2018; Occhino, 2020, among others). After intersecting each of the above datasets and dropping observations with missing values, our primary sample covers the period 1998–2016 and consists of 11,645 firm-year observations.

3.2. Model specification

This study hypothesizes that board independence improves analyst forecast accuracy for R&D-intensive firms. This hypothesis is tested using panel regression models with *Forecast Error* as the dependent variable and the interaction term between *% Ind. Directors* and *High R&D* as the primary independent variable. *Forecast Error* is defined as the absolute difference between the IBES consensus forecast of annual earnings (median) and the actual earnings reported by IBES, scaled by stock price (Lang & Lundholm, 1996; Duru & Reeb, 2002; Byard et al., 2006). *% Ind. Directors* is the percentage of independent directors on a corporate board. *R&D* is research and development expenses divided by total assets. *High R&D* is a dummy variable coded as one for a firm whose *R&D* expenses are greater than the cross-sectional median value and zero otherwise. The models used in this study control for a comprehensive set of firm-level, board-level, and analyst-level variables. These control variables are drawn from existing literature and include (1) *Market-to-Book,* which is defined as total assets plus market value of equity less book value of equity and deferred taxes, all divided by total assets, where market value of equity is computed as common shares outstanding times price, (2) *Firm Size,* which is defined as the logarithmic value of firm sales (Barry & Brown, 1984; Atiase, 1985; Brown et al., 1987), (3) *Forecast Age,* which is defined as the average difference

[1] A poweful CEO typically has more influence over the board, for example, serving as the chairman, therefore, he/she is more likely to have a "friendly" board.

(in days) between the forecast date and the date of earnings announcements across all available analysts' forecasts (Byard et al., 2006), (4) *Volatility,* which is defined as the standard deviation of return on equity over the last 10-year period (Gu & Wang, 2005), (5) *Analyst Coverage,* which is defined as the logarithmic value of the number of analysts following a firm (Lim, 2001), (6) *Earnings Surprise,* which is defined as the absolute value of the difference between the current year's earnings per share (*EPS*) and last year's *EPS*, divided by price (Lang & Lundholm, 1996; Gul et al., 2013), (7) *Loss,* which is a dummy variable coded as one for firms that report negative net income before extraordinary items and zero otherwise (Gu & Wang, 2005), (8) *Leverage*, which is calculated as the total long-term debt plus portion of long-term debt in current liabilities divided by total assets, (9) *Tobin'Q*, which is market value of equity plus total assets minus stockholders' equity divided by total assets, (10) *Payout Ratio*, which is cash dividends divided by total assets, and (11) *Firm Age*, which is a firm's current fiscal year minus first time it showed up in the Compustat database. The models in this study also control for both firm and year-fixed effects and use standard errors clustered on both firm and year levels.

The baseline model of this study is shown below, where *t* represents time and *i* represents firm:

$$\begin{aligned} Forecast\ \ Error_{i,t} = {} & \alpha_0 + \beta_1 \%Ind.DirectorsxHigh\ \ R\&D_{i,t-1} + \beta_2 \%Ind.Directors_{i,t-1} + \beta_3 High\ \ R\&D_{i,t-1} + \beta_4 R\&D_{i,t-1} \\ & + \beta_5 Market - to - Book_{i,t-1} + \beta_6 Firm\ \ Size_{i,t-1} + \beta_7 Forecast\ \ Age_{i,t-1} + \beta_8 Volatility_{i,t-1} \\ & + \beta_9 Analyst\ \ Coverage_{i,t-1} + \beta_{10} Earnings\ \ Surprise_{i,t-1} + \beta_{11}\ \ Loss_{i,t-1} + \beta_{12}\ \ Leverage_{i,t-1} \\ & + \beta_{13}\ \ Tobin's\ \ Q_{i,t-1} + \beta_{14}\ \ Payout\ \ Ratio_{i,t-1} + \beta_{15}\ \ Firm\ \ Age_{i,t-1} + \delta_1 Firm\ \ Dummy + \delta_2 Year\ \ Dummy + \varepsilon_{i,t} \end{aligned} \tag{1}$$

In the models controlling for board characteristics, we use *Board Size*, which is the total number of board members and *% Female Directors*, which is the percentage of female directors on a board. Similarly, to control for CEO characteristics, we include *CEO Duality*, which is a dummy variable coded as one for a firm whose CEO holds the chair position of the board and zero otherwise, *CEO Holdings*, which is the total number of shares of the company that its CEO holds, and *CEO Tenure*, which is the length of service in years as the CEO in the current firm.

To assess the relationship between board independence and analyst forecast accuracy while accounting for the possible endogeneity in the panel data, we use the generalized method of moments (GMM) model developed for dynamic panel estimation by Arellano and Bond (1991), Arellano and Bover (1995), and Blundell and Bond (1998). The GMM approach has several advantages. For example, it incorporates the time series elements of the data while controlling for firm-specific effects and allows lagged dependent variables to be included as regressors. Following Arellano and Bover (1995) and Blundell and Bond's (1998) work, the regression models are defined as,

$$y_{it} = \alpha + \sum_l \kappa_l y_{it-l} + \beta X_{it} + \eta_i + \varepsilon_{it} \tag{2}$$

where y is a given dependent variable (*Forecast Error*); *X* represents a matrix of explanatory variables other than the lagged value of *Forecast Error*; η is an observed firm-specific effect, and ε is the error term. The subscripts *i* and *t* stand for firm and time, respectively, while *l* stands for the number of lags used in the GMM model. We also include time dummies to account for year effects. To remove any firm-specific impacts that may be triggered by time-invariant unobserved heterogeneity, We modify Eq. (2) by taking the first difference of all variables:

$$\Delta y_{it} = \alpha + \kappa_l \sum_l \Delta y_{it-l} + \beta \Delta X_{it} + \Delta \varepsilon_{it}, l > 0 \tag{3}$$

Taking the first differences of each variable can lead to the change of the error term correlated with the change of the lag of the dependent variable. Thus, this can violate the assumptions of no serial correlation and exogeneity. Therefore, the system GMM methodology is applied to estimate Eq. (3). Following Arellano and Bover (1995) and Blundell and Bond (1998), the first differenced variables (Eq. (3) are used as instruments for the equation in levels (Eq. (2)). The system of equations is presented as follows,

$$\begin{bmatrix} y_{it} \\ \Delta y_{it} \end{bmatrix} = \alpha + \kappa \begin{bmatrix} y_{it-p} \\ \Delta y_{it-p} \end{bmatrix} + \beta \begin{bmatrix} X_{it} \\ \Delta X_{it} \end{bmatrix} + \varepsilon_{it} \tag{4}$$

We use the Sargan (1958) test to examine over-identifying restrictions proposed by Arellano and Bond (1991) and to test the validity of the instruments used in the model. The null hypothesis (instruments are valid) is accepted in all instances.

4. Empirical findings

4.1. Summary statistics

Panel A in Table 1 shows the summary statistics of the dependent and independent variables. All statistics are calculated after winsorizing the variables at the 1st and 99th percentiles to eliminate the impact of outliers. The mean *Forecast Error* is 0.006, which means that the difference between forecasted earnings and the corresponding actual earnings is about 0.6% of the stock price. However, a lower value for the median (0.002) indicates that some firms in the sample have significantly higher forecast errors than the sample mean suggests. The statistics of *Forecast Error* agree with what is reported in the literature. For example, the mean value of

Table 1
Summary statistics and Pearson's correlation coefficients.

Panel A: Summary statistics

Variable	Mean	SD	Min	Max	Q1	Median	Q3
Forecast Error	0.006	0.024	0.000	0.506	0.001	0.002	0.004
Idiosyncratic Volatility	0.244	0.112	0.091	1.089	0.156	0.206	0.316
R&D	0.032	0.054	0.000	0.552	0.000	0.005	0.043
High R&D	0.546	0.498	0.000	1.000	0.000	1.000	1.000
% Ind. Directors	0.737	0.148	0.000	1.000	0.667	0.769	0.857
Market-to-Book	2.013	1.249	0.639	9.476	1.229	1.633	2.343
Firm Size	7.613	1.474	0.474	11.115	6.607	7.500	8.551
Forecast Age	106.651	22.472	45.000	215.667	93.328	105.667	119.477
Volatility	0.259	0.836	0.005	9.238	0.047	0.083	0.157
Analyst Coverage	2.160	0.772	0.000	3.296	1.674	2.277	2.752
Earnings Surprise	0.026	0.057	0.000	0.947	0.005	0.011	0.025
Loss	0.138	0.345	0.000	1.000	0.000	0.000	0.000
Leverage	0.214	0.175	0.000	2.802	0.061	0.205	0.321
Tobin's Q	1.726	1.316	0.066	17.398	0.936	1.340	2.060
Payout Ratio	0.015	0.032	0.000	1.030	0.000	0.006	0.020
Firm Age	3.166	0.590	1.386	4.111	2.708	3.178	3.664
Board Size	9.156	2.241	3.000	21.000	8.000	9.000	11.000
% Female Directors	0.113	0.099	0.000	0.667	0.000	0.111	0.167
CEO Duality	0.281	0.449	0.000	1.000	0.000	0.000	1.000
CEO Holdings	1.297	4.447	0.000	209.000	0.000	0.022	0.926
CEO Tenure	1.555	0.783	0.000	3.178	1.099	1.609	2.079

Panel B: Pearson's correlation coefficients

Variables	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)	(15)	(16)	(17)	(18)	(19)
(1) Forecast Error	1																		
(2) Idiosyncratic Volatility	0.100[a]	1																	
(3) R&D	0.020[b]	0.039[a]	1																
(4) % Ind. Directors	-0.017[c]	-0.230[a]	0.022[b]	1															
(5) Market-to-Book	-0.131[a]	-0.015[c]	0.290[a]	-0.072[a]	1														
(6) Firm Size	-0.076[a]	-0.070[a]	-0.298[a]	0.183[a]	-0.047[a]	1													
(7) Forecast Age	0.061[a]	-0.012	-0.038[a]	-0.075[a]	-0.015[c]	-0.172[a]	1												
(8) Volatility	0.061[a]	-0.015[c]	0.084[a]	0.063[a]	0.089[a]	-0.004	-0.023[b]	1											
(9) Analyst Coverage	-0.147[a]	-0.058[a]	0.006	0.132[a]	0.222[a]	0.553[a]	-0.154[a]	0.012	1										
(10) Earnings Surprise	0.454[a]	0.116[a]	0.028[a]	-0.016[c]	-0.158[a]	-0.084[a]	-0.008	0.098[a]	-0.128[a]	1									
(11) Loss	0.298[a]	0.146[a]	0.217[a]	-0.012	-0.167[a]	-0.180[a]	0.029[a]	0.053[a]	-0.114[a]	0.308[a]	1								
(12) Leverage	0.096[a]	0.104[a]	-0.212[a]	0.069[a]	-0.189[a]	0.232[a]	-0.022[b]	0.206[a]	0.071[a]	0.093[a]	0.112[a]	1							
(13) Tobin's Q	-0.132[a]	-0.004	0.293[a]	-0.085[a]	0.984[a]	-0.085[a]	-0.011	0.071[a]	0.211[a]	-0.158[a]	-0.161[a]	-0.187[a]	1						
(14) Payout Ratio	-0.056[a]	-0.041[a]	-0.057[a]	0.046[a]	0.253[a]	0.120[a]	-0.042[a]	0.057[a]	0.041[a]	-0.095[a]	-0.116[a]	0.038[a]	0.228[a]	1					
(15) Firm Age	-0.019[b]	-0.062[a]	-0.140[a]	0.196[a]	-0.121[a]	0.412[a]	-0.095[a]	-0.014	0.034[a]	-0.020[b]	-0.078[a]	0.116[a]	-0.140[a]	0.183[a]	1				
(16) Board Size	-0.047[a]	0.009	-0.200[a]	0.120[a]	-0.076[a]	0.589[a]	-0.107[a]	0.021[b]	0.266[a]	-0.065[a]	-0.093[a]	0.239[a]	-0.101[a]	0.121[a]	0.397[a]	1			

(continued on next page)

Table 1 (*continued*)

Panel B: Pearson's correlation coefficients

Variables	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)	(15)	(16)	(17)	(18)	(19)
(17) % Female Directors	-0.026[a]	-0.122[a]	-0.111[a]	0.241[a]	0.020[b]	0.366[a]	-0.074[a]	0.054[a]	0.157[a]	-0.061[a]	-0.053[a]	0.124[a]	-0.007	0.113[a]	0.200[a]	0.308[a]	1		
(18) CEO Duality	0.006	0.180[a]	-0.034[a]	-0.045[a]	-0.025[a]	0.047[a]	-0.050[a]	-0.027[a]	-0.033[a]	-0.023[b]	-0.014	0.037[a]	-0.031[a]	-0.036[a]	0.012	0.027[a]	0.008	1	
(19) CEO Holdings	0.013	-0.086[a]	-0.013	-0.019[b]	-0.002	-0.112[a]	0.060[a]	-0.024[a]	-0.080[a]	0.009	0.01	-0.081[a]	0.001	0.049[a]	-0.075[a]	-0.128[a]	-0.053[a]	-0.062[a]	1
(20) CEO Tenure	-0.039[a]	-0.101[a]	-0.011	0.050[a]	0.016[c]	0.014	0.015[c]	-0.044[a]	0.041[a]	-0.041[a]	-0.064[a]	-0.027[a]	0.024[a]	0.005	0.036[a]	-0.051[a]	-0.029[a]	0.084[a]	0.203[a]

Notes: This table reports the summary statistics and Pearson's correlation coefficients of the variables examined in this study. The appendix provides the definitions of all variables. The sample consists of 11,645 annual observations spanning from the fiscal year 1997–2016. Two-sided statistical significance at 1%, 5%, and 10% is indicated as a, b, and c, respectively.

Table 2
Board independence.

Panel A: Estimation of Eq. (1) and its expanded versions

	(1) Forecast Error	(2) Forecast Error	(3) Forecast Error	(4) Forecast Error	(5) Forecast Error
% Ind. Directors x High R&D	-0.0083	-0.0083	-0.0086	-0.0086	-0.0073
	[− 2.42]* *	[− 2.44]* *	[− 2.48]* *	[− 2.50]* *	[− 2.30]* *
% Ind. Directors	0.0063	0.0061	0.0060	0.0059	0.0042
	[1.51]	[1.49]	[1.46]	[1.44]	[1.64]
High R&D	0.0061	0.0062	0.0063	0.0064	0.0021
	[2.24]* *	[2.27]* *	[2.30]* *	[2.33]* *	[0.84]
R&D	0.0254	0.0255	0.0250	0.0251	0.0183
	[0.73]	[0.73]	[0.72]	[0.73]	[2.31]* *
Market-to-Book	-0.0004	-0.0004	-0.0004	-0.0004	-0.0002
	[− 0.85]	[− 0.84]	[− 0.86]	[− 0.85]	[− 0.17]
Firm Size	0.0001	0.0001	0.0000	-0.0000	0.0003
	[0.12]	[0.08]	[0.04]	[− 0.01]	[0.66]
Forecast Age	0.0001	0.0001	0.0001	0.0001	0.0001
	[3.57]* **	[3.57]* **	[3.56]* **	[3.55]* **	[6.63]* **
Volatility	0.0002	0.0002	0.0002	0.0002	0.0002
	[0.69]	[0.69]	[0.67]	[0.66]	[0.64]
Analyst Coverage	-0.0039	-0.0039	-0.0038	-0.0038	-0.0040
	[− 3.75]* **	[− 3.74]* **	[− 3.78]* **	[− 3.76]* **	[− 8.15]* **
Earnings Surprise	0.1157	0.1157	0.1157	0.1157	0.1367
	[3.80]* **	[3.80]* **	[3.80]* **	[3.80]* **	[34.96]* **
Loss	0.0091	0.0091	0.0091	0.0091	0.0099
	[4.52]* **	[4.52]* **	[4.51]* **	[4.51]* **	[15.86]* **
Board Size		0.0001		0.0001	-0.0000
		[0.37]		[0.43]	[− 0.15]
% Female Directors		0.0028		0.0025	0.0009
		[1.10]		[1.00]	[0.27]
CEO Duality			0.0017	0.0017	0.0019
			[1.50]	[1.50]	[3.14]* **
CEO Holdings			-0.0001	-0.0001	-0.0001
			[− 2.07]*	[− 2.07]*	[− 1.50]
CEO Tenure			-0.0003	-0.0003	-0.0004
			[− 0.84]	[− 0.82]	[− 1.48]
Leverage	0.0049	0.0049	0.0050	0.0050	0.0063
	[1.48]	[1.47]	[1.50]	[1.49]	[3.24]* **
Tobin's Q	-0.0002	-0.0002	-0.0001	-0.0001	-0.0004
	[− 0.29]	[− 0.30]	[− 0.26]	[− 0.27]	[− 0.50]
Payout Ratio	-0.0038	-0.0040	-0.0032	-0.0034	-0.0042
	[− 0.51]	[− 0.54]	[− 0.45]	[− 0.47]	[− 0.53]
Firm Age	-0.0001	-0.0002	0.0002	0.0001	0.0003
	[− 0.05]	[− 0.10]	[0.08]	[0.03]	[0.28]
Constant	-0.0019	-0.0020	-0.0018	-0.0019	0.0001
	[− 0.23]	[− 0.23]	[− 0.21]	[− 0.21]	[0.03]
Observations	11,645	11,645	11,645	11,645	11,645
Adjusted R-squared	0.2808	0.2807	0.2814	0.2813	
Firm FE	YES	YES	YES	YES	NO
Year FE	YES	YES	YES	YES	NO
Firm RE	NO	NO	NO	NO	YES

Panel B: The Hausman Test

b = consistent under Ho and Ha; obtained from fixed effect
B = inconsistent under Ha, efficient under Ho; obtained from random effect
Test: Ho: difference in coefficients not systematic
chi2(38) = (b-B)'[(V_b-V_B)^(−1)](b-B) = 518.82
Prob>chi2 = 0.0000

Panel C: Estimation of Eq. (1) and its expanded versions using only nonzero R&D expense firms

	(1) Forecast Error	(2) Forecast Error	(3) Forecast Error	(4) Forecast Error	(5) Forecast Error
% Ind. Directors x High R&D	-0.0085	-0.0085	-0.0087	-0.0088	-0.0067
	[− 2.01]*	[− 2.02]*	[− 2.04]*	[− 2.05]*	[− 1.98]* *
% Ind. Directors	0.0060	0.0060	0.0057	0.0057	0.0058
	[1.19]	[1.19]	[1.13]	[1.14]	[2.14]* *
High R&D	0.0065	0.0066	0.0067	0.0067	0.0021
	[1.93]*	[1.95]*	[1.96]*	[1.98]*	[0.81]
R&D	0.0283	0.0284	0.0279	0.0279	0.0275

(*continued on next page*)

Table 2 (*continued*)

Panel C: Estimation of Eq. (1) and its expanded versions using only nonzero R&D expense firms

	(1) Forecast Error	(2) Forecast Error	(3) Forecast Error	(4) Forecast Error	(5) Forecast Error
	[0.80]	[0.80]	[0.80]	[0.80]	[3.62]* **
Market-to-Book	-0.0005	-0.0005	-0.0005	-0.0005	-0.0006
	[− 1.07]	[− 1.07]	[− 1.09]	[− 1.09]	[− 0.66]
Firm Size	0.0001	0.0001	0.0000	-0.0000	0.0008
	[0.10]	[0.07]	[0.02]	[− 0.02]	[1.97]* *
Analyst Age	0.0001	0.0001	0.0001	0.0001	0.0001
	[3.14]* **	[3.13]* **	[3.13]* **	[3.12]* **	[6.40]* **
Volatility	0.0002	0.0002	0.0002	0.0002	0.0003
	[0.59]	[0.59]	[0.60]	[0.60]	[0.78]
Analyst Coverage	-0.0040	-0.0040	-0.0040	-0.0040	-0.0039
	[− 3.96]* **	[− 3.94]* **	[− 3.95]* **	[− 3.94]* **	[− 7.89]* **
Earnings Surprise	0.1207	0.1207	0.1208	0.1208	0.1393
	[3.80]* **	[3.80]* **	[3.81]* **	[3.80]* **	[34.91]* **
Loss	0.0079	0.0078	0.0079	0.0079	0.0086
	[4.09]* **	[4.09]* **	[4.08]* **	[4.08]* **	[13.55]* **
Board Size		0.0001		0.0001	-0.0001
		[0.44]		[0.52]	[− 0.55]
% Female Directors		0.0014		0.0011	0.0013
		[0.53]		[0.41]	[0.39]
CEO Duality			0.0018	0.0018	0.0015
			[1.71]	[1.71]	[3.18]* **
CEO Holdings			-0.0001	-0.0001	0.0000
			[− 1.59]	[− 1.57]	[0.20]
CEO Tenure			-0.0003	-0.0003	-0.0004
			[− 0.70]	[− 0.69]	[− 1.55]
Leverage	0.0040	0.0040	0.0040	0.0040	0.0068
	[1.30]	[1.29]	[1.31]	[1.30]	[3.49]* **
Tobin's Q	-0.0001	-0.0001	-0.0001	-0.0001	-0.0001
	[− 0.24]	[− 0.24]	[− 0.21]	[− 0.20]	[− 0.11]
Payout	0.0044	0.0043	0.0048	0.0047	0.0049
	[1.10]	[1.05]	[1.10]	[1.06]	[0.57]
Firm Age	0.0002	0.0001	0.0003	0.0002	0.0011
	[0.08]	[0.04]	[0.14]	[0.09]	[1.26]
Constant	-0.0027	-0.0028	-0.0022	-0.0023	-0.0084
	[− 0.29]	[− 0.30]	[− 0.23]	[− 0.24]	[− 2.34]* *
Observations	7881	7881	7881	7881	7881
Adjusted R-squared	0.2692	0.2691	0.2703	0.2702	
Firm FE	YES	YES	YES	YES	NO
Year FE	YES	YES	YES	YES	NO
Firm RE	NO	NO	NO	NO	YES

Notes: In Panels A and C, column (1) reports the results of estimating Eq. (1), and columns (2) through (4) report the results of estimating the expanded versions of Eq. (1). The models under columns (2) through (4) expand Eq. (1) by including board characteristic variables, CEO-related variables, and both board characteristic and CEO-related variables, respectively. The models under columns (1) through (4) use fixed effects and column (5) reports the result of estimating the model under column (4) using random effects. In Panel A, we use the full sample. In Panel C, the sample excludes observations with zero *R&D* expenses. The appendix provides the definitions of all variables. *t*-statistics within square brackets are based on standard errors clustered on both firm and year. Two-sided statistical significance at 1%, 5%, and 10% is indicated as ***, **, and *, respectively. In Panel B, the result of Hausman test of no fixed effect in Eq. (1) is reported.

forecast error in Francis at el. (2019) is also 0.006.[2] The mean *R&D* is 0.032, which indicates that the firms spend approximately 3.2% of total assets on *R&D* activities. The first quartile (Q1) of *R&D* is 0. It suggests that at least 25% of firms in our sample do not have any *R&D* expenses. Therefore, the winsorization of *R&D* expenses only scales back the top 1% highest *R&D* expenses. The average *R&D* expense is downward adjusted. The summary statistics are also consistent with existing literature, such as Lu and Wang (2015).[3] The mean *% Ind. Directors* is 0.737, which suggests that independent directors hold approximately 74% of the board seats. The result is consistent with previous literature (e.g. Armstrong et al., 2014, Chen et al., 2015). The dummy variable *High R&D* has an average of 0.546, which means 54.6% of firms are classified as firms with higher *R&D* expenses, or *R&D*-intensive firms, over the entire period. We do not observe any abnormal data distributions for the rest of the variables in our study compared to what is reported in the literature (Francis et al., 2019; He et al., 2019; He et al., 2020, among others).[4] Please see Appendix for definitions of all variables.

[2] Francis at el. (2019) have a similar sample period (2003–2016) as ours.

[3] Lu and Wang (2015) use sample from 1999 to 2009. Their R&D (scaled by total assets as ours) is 0.027

[4] Our results are similar/comparable to what reported in these papers, but not exactly the same due to different definitions of variables and sample period.

Table 3
Board independence and analyst coverage.

	(1)Low Analyst Coverage Forecast Error	(2)High Analyst Coverage Forecast Error
% Ind. Directors x High R&D	-0.0369	-0.0037
	[− 2.17]* *	[− 0.96]
% Ind. Directors	0.0131	0.0058
	[1.51]	[1.27]
High R&D	0.0212	0.0038
	[1.78]*	[1.29]
R&D	0.1422	-0.0069
	[0.94]	[− 1.28]
Market-to-Book	0.0025	-0.0006
	[0.51]	[− 1.65]
Firm Size	-0.0001	0.0009
	[− 0.02]	[0.62]
Forecast Age	0.0001	0.0000
	[2.34]* *	[3.63]* **
Volatility	-0.0015	0.0007
	[− 1.28]	[1.23]
Analyst Coverage	-0.0037	-0.0032
	[− 1.67]	[− 3.02]* **
Earnings Surprise	0.1028	0.1124
	[1.89]*	[3.95]* **
Loss	0.0157	0.0067
	[4.47]* **	[4.05]* **
Board Size	-0.0008	0.0000
	[− 2.31]* *	[0.33]
% Female Directors	-0.0016	0.0038
	[− 0.17]	[1.69]
CEO Duality	0.0033	0.0011
	[1.10]	[1.39]
CEO Holdings	-0.0003	0.0001
	[− 2.18]* *	[0.86]
CEO Tenure	-0.0005	-0.0004
	[− 0.39]	[− 1.27]
Leverage	0.0295	-0.0016
	[2.45]* *	[− 0.57]
Tobin's Q	-0.0061	0.0004
	[− 1.21]	[1.16]
Payout Ratio	-0.0034	0.0003
	[− 0.17]	[0.07]
Firm Age	-0.0041	-0.0002
	[− 0.35]	[− 0.17]
Constant	0.0075	-0.0055
	[0.17]	[− 0.54]
Observations	2721	8713
Adjusted R-squared	0.2837	0.3220
Firm FE	YES	YES
Year FE	YES	YES

Notes: This table shows the results of estimating the expanded version of Eq. (1), which includes both board characteristics and CEO-related variables, on low and high analyst coverage subsamples. The high analyst coverage subsample consists of firms for which the number of financial analysts covering these firms is greater than the cross-sectional median value, and the low analyst coverage subsample consists of the remaining firms. The appendix provides the definitions of all variables. *t*-statistics within square brackets are based on standard errors clustered on both firm and year. Two-sided statistical significance at 1%, 5%, and 10% is indicated as ***, **, and *, respectively.

Panel B in Table 1 reports the Pearson's correlation coefficients with significance level. For abbreviation, we only discuss the correlations among the key variables. First, *% Ind. Directors* is negatively correlated with *Forecast Error* as expected. It provides the first evidence that board independence improves forecast accuracy. Second, *R&D* expense is positively correlated with *Forecast Error*, consistent with the evidence in existing studies that higher *R&D* increases information complexity (Aboody & Lev, 2000). Third, *Idiosyncratic Volatility* is positively correlated with *Forecast Error* and *R&D* expense. Since *Idiosyncratic Volatility* is often used as a proxy for information asymmetry, positive correlations are expected. We also observe a strong significant negative correlation between *% Ind. Directors* and *Idiosyncratic Volatility*. This result suggests that a higher percentage of independent directors is likely to be associated with a lower idiosyncratic risk in stock returns. Another interesting finding is that board independence is positively correlated with *R&D* expenses. It appears that *R&D*-intensive firms are more likely to have a higher percentage of independent directors, which suggests that *R&D*-intensive firms may find board independence beneficial and choose to have more independent directors on their boards. The other variables correlate with *Forecast Error* in ways consistent with existing studies. For example, *Forecast Age*, *Earnings*

Table 4
Board independence and CEO power.

	Low CEO Power *Forecast Error*	High CEO Power *Forecast Error*
% Ind. Directors x High R&D	-0.0089	-0.0081
	[− 1.92]*	[− 0.63]
% Ind. Directors	0.0045	-0.0001
	[0.96]	[− 0.01]
High R&D	0.0070	0.0067
	[1.94]*	[0.71]
R&D	0.0347	0.0175
	[0.77]	[0.57]
Market-to-Book	-0.0006	0.0005
	[− 0.92]	[0.21]
Firm Size	-0.0011	0.0001
	[− 1.14]	[0.02]
Forecast Age	0.0001	0.0000
	[3.41]* **	[0.75]
Volatility	-0.0001	0.0004
	[− 0.22]	[0.43]
Analyst Coverage	-0.0039	-0.0043
	[− 3.49]* **	[− 1.48]
Earnings Surprise	0.1095	0.1512
	[2.69]* *	[4.46]* **
Loss	0.0079	0.0073
	[3.60]* **	[2.62]* *
Board Size	-0.0001	0.0008
	[− 0.31]	[1.45]
% Female Directors	0.0013	0.0048
	[0.36]	[0.41]
CEO Duality	0.0016	0.0014
	[1.62]	[0.70]
CEO Holdings	-0.0000	-0.0022
	[− 0.89]	[− 1.70]
CEO Tenure	-0.0003	0.0016
	[− 0.82]	[1.30]
Leverage	0.0032	0.0039
	[1.00]	[0.44]
Tobin's Q	-0.0001	-0.0013
	[− 0.20]	[− 0.62]
Payout Ratio	-0.0014	0.0294
	[− 0.32]	[1.13]
Firm Age	0.0010	0.0035
	[0.45]	[0.45]
Constant	0.0058	-0.0134
	[0.68]	[− 0.84]
Observations	7815	2069
Adjusted R-squared	0.2871	0.3843
Firm FE	YES	YES
Year FE	YES	YES

Notes: This table shows the results of estimating the expanded version of Eq. (1), which includes board characteristic variables, on subsamples constructed based on *CEO Power*. A CEO is considered to have high power if one the following conditions is met: 1) CEOs perform both Chair and CEO roles, 2) CEOs have higher than median tenure than other CEOs, and 3) CEOs own 5% or more shares of the company. Otherwise, the CEO is considered to have low power. The appendix provides the definitions of all variables. *t*-statistics within square brackets are based on standard errors clustered on both firm and year. Two-sided statistical significance at 1%, 5%, and 10% is indicated as ***, **, and *, respectively.

Surprise, and *Loss* are positively, and *Firm Size*, *Market-to-Book*, *Analyst Coverage, and Board size* are negatively correlated with *Forecast Error* (Duru & Reeb, 2002; Byard et al., 2006; Gu & Wang, 2005; Gul et al., 2013).

4.2. Board Independence and Forecast Error

In Table 2, column (1) reports the results of estimating Eq. (1). Columns (2) through (4) expand Eq. (1) by including board characteristic variables, CEO-related variables, and both board characteristic and CEO-related variables, respectively. These models under columns (1) through (4) are fixed-effects models. To check if the fixed-effect model is the appropriate panel regression method, we estimate the model (4) using random effect and report the results in column (5). In all models, we use the interaction term of *% Ind. Directors x High R&D* to highlight the different impacts of board independence on forecast error between high and low *R&D* firms. The

Table 5
Alternative proxy for information asymmetry.

	(1) *Idiosyncratic Volatility*	(2) *Idiosyncratic Volatility*	(3) *Idiosyncratic Volatility*	(4) *Idiosyncratic Volatility*
% Ind. Directors x High R&D	-0.0463	-0.0462	-0.0457	-0.0456
	[− 2.94]* **	[− 2.94]* **	[− 2.90]* **	[− 2.90]* **
% Ind. Directors	0.0148	0.0143	0.0136	0.0132
	[1.17]	[1.11]	[1.13]	[1.07]
High R&D	0.0349	0.0348	0.0342	0.0341
	[3.13]* **	[3.13]* **	[3.08]* **	[3.07]* **
R&D	0.0077	0.0084	0.0052	0.0058
	[0.24]	[0.26]	[0.15]	[0.17]
Market-to-Book	-0.0050	-0.0049	-0.0050	-0.0049
	[− 1.71]	[− 1.71]	[− 1.75]*	[− 1.75]*
Firm Size	0.0031	0.0032	0.0030	0.0031
	[0.54]	[0.56]	[0.52]	[0.54]
Forecast Age	-0.0000	-0.0000	-0.0000	-0.0000
	[− 0.53]	[− 0.50]	[− 0.48]	[− 0.45]
Analyst Coverage	-0.0023	-0.0022	-0.0020	-0.0019
	[− 0.59]	[− 0.58]	[− 0.52]	[− 0.51]
Earnings Surprise	0.0668	0.0667	0.0676	0.0674
	[3.02]* **	[3.00]* **	[3.13]* **	[3.11]* **
Loss	0.0107	0.0107	0.0107	0.0106
	[2.02]*	[2.01]*	[2.01]*	[2.00]*
Board Size		-0.0003		-0.0003
		[− 0.57]		[− 0.52]
% Female Directors		0.0080		0.0071
		[0.66]		[0.57]
CEO Duality			0.0060	0.0059
			[1.45]	[1.42]
CEO Holdings			0.0002	0.0002
			[1.48]	[1.46]
CEO Tenure			-0.0014	-0.0015
			[− 1.65]	[− 1.64]
Leverage	-0.0039	-0.0037	-0.0042	-0.0040
	[− 0.48]	[− 0.45]	[− 0.52]	[− 0.49]
Tobin's Q	0.0022	0.0021	0.0022	0.0022
	[1.22]	[1.19]	[1.25]	[1.23]
Payout Ratio	0.0042	0.0039	0.0024	0.0021
	[0.16]	[0.15]	[0.09]	[0.08]
Firm Age	-0.0179	-0.0176	-0.0182	-0.0178
	[− 3.01]* **	[− 3.01]* **	[− 3.02]* **	[− 3.04]* **
Constant	0.2762	0.2766	0.2779	0.2783
	[7.59]* **	[7.58]* **	[7.48]* **	[7.47]* **
Observations	11,543	11,543	11,543	11,543
Adjusted R-squared	0.7889	0.7888	0.7891	0.7891
Firm FE	YES	YES	YES	YES
Year FE	YES	YES	YES	YES

Notes: This table shows the results of estimating the expanded version of Eq. (1), which includes both board characteristics and CEO-related variables, with *Idiosyncratic Volatility* replacing *Forecast Error* as the dependent variable. The appendix provides the definitions of all variables. *t*-statistics within square brackets are based on standard errors clustered on both firm and year. Two-sided statistical significance at 1%, 5%, and 10% is indicated as ***, **, and *, respectively.

significant negative coefficients of the interaction term across all models demonstrate that board independence can reduce forecast errors in firms with high *R&D* expenses more than in firms with low R&D expenses. These consistent results provide support for Hypothesis I. The positive significant coefficient of the dummy variable *High R&D* indicates that high *R&D* firms have a higher forecast error after controlling for actual *R&D* expenses. We find that the percentage of independent directors does not reduce forecast errors for firms with low *R&D* expenses (insignificant coefficient of *% Ind. Directors*). Although previous studies report that board independence can reduce forecast errors in general (Byard et al., 2006; Armstrong et al., 2014; Chen et al., 2015 among others), our results suggest such a reduction is only observed in R&D-intensive firms (i.e when information complexity is high). The mean value of the forecast error for high R&D firms is 0.0022 (constant plus the coefficient of *High R&D* dummy) after controlling for all relevant variables. With independent directors on board, R&D-intensive firms will have a lower forecast error by − 0.0073 (Table 2 Model 5) with a 95% confidence interval [− 0.0133 to − 0.00126]. The reduction is economically significant for forecast errors with an average value of 0.0022. Our results indicate that board independence is an effective mechanism to increase price informativeness for analysts in a more complex information environment and provide additional improvement for forecast accuracy. These results are robust to different combinations of control variables at the firm and board levels. The coefficients of the control variables are consistent with the findings in the existing studies. For example, *Forecast Age*, *Earnings Surprise*, *Loss* are positively (Duru & Reeb, 2002; Byard et al., 2006; Gu & Wang, 2005; Gul et al., 2013), *Market-to-Book* and *Analyst Coverage* are negatively (Duru & Reeb, 2002; Gu & Wang, 2005)

Table 6
Robustness tests.

	(1) Forecast Error	(2) Forecast Error	(3) Forecast Error
% Ind. Directors x High R&D	-0.0056	-0.0057	-0.0167
	[− 2.28]* *	[− 2.29]* *	[− 2.26]* *
% Ind. Directors	0.0054	0.0049	0.0057
	[1.77]*	[1.67]	[1.05]
High R&D	0.0046	0.0049	0.0129
	[2.32]* *	[2.43]* *	[2.00]* *
R&D	0.0079	-0.0013	0.0359
	[0.45]	[− 0.10]	[2.35]* *
Market-to-Book	-0.0003	0.0035	-0.0019
	[− 0.64]	[4.78]* **	[− 1.05]
Firm Size	-0.0003	-0.0003	0.0050
	[− 0.39]	[− 0.31]	[3.53]* **
Forecast Age	0.0000	0.0000	0.0000
	[3.97]* **	[4.02]* **	[2.88]* **
Volatility	0.0003	0.0002	-0.0014
	[1.01]	[0.33]	[− 1.64]
Analyst Coverage	-0.0034	-0.0030	-0.0061
	[− 4.79]* **	[− 4.58]* **	[− 5.98]* **
Earnings Surprise	0.0923	0.1137	0.0257
	[4.34]* **	[4.60]* **	[4.42]* **
Loss	0.0085	0.0080	0.0081
	[5.13]* **	[5.32]* **	[9.20]* **
Leverage	0.0036	0.0031	0.0111
	[1.57]	[1.35]	[2.76]* **
Tobin's Q	-0.0001	-0.0047	-0.0001
	[− 0.27]	[− 4.91]* **	[− 0.07]
Payout Ratio	-0.0021	0.0046	0.0040
	[− 0.54]	[0.48]	[0.34]
Firm Age	0.0005	-0.0000	-0.0063
	[0.33]	[− 0.00]	[− 1.97]* *
Board Size	0.0000	0.0000	0.0002
	[0.30]	[0.38]	[0.64]
% Female Directors	0.0020	0.0015	0.0038
	[0.91]	[0.69]	[0.60]
CEO Duality	0.0014	0.0013	0.0037
	[1.68]	[1.60]	[4.43]* **
CEO Holdings	-0.0001	0.0000	0.0001
	[− 1.39]	[0.51]	[0.61]
CEO Tenure	-0.0003	-0.0003	-0.0007
	[− 1.05]	[− 1.13]	[− 1.55]
L. Forecast Error			0.1504
			[9.94]* **
Constant	0.0006	0.0011	-0.0113
	[0.10]	[0.18]	[− 1.05]
Observations	11,645	11,645	8645
Adjusted R-squared	0.3379	0.3441	
Firm FE	YES	YES	YES
Year FE	YES	YES	YES
Chi2			514.5

Notes: This table shows the results of estimating the expanded version of Eq. (1), which includes both board characteristic and CEO-related variables. Column (1) reports the panel regression results when only the dependent variable is winsorized at 2% and 98% level, while column (2) reports the results when all variables are winsorized at 2% and 98% levels. Column (3) reports the result of estimating the model using generalized method of moments (GMM). The appendix provides the definitions of all variables. *t*-statistics within square brackets are based on standard errors clustered on both firm and year. Two-sided statistical significance at 1%, 5%, and 10% is indicated as ***, **, and *, respectively.

correlated with *Forecast Error*. We do not observe significant associations between forecast errors and other board characteristics, such as the number of directors and the percentage of female board members.

The Hausman test rejects the null hypothesis, *no fixed effect,* in panel B. Therefore, we only report regression results using fixed-effect models in the following analyses.

To address the concern that zero R&D firms present different kind of information asymmetry from firms with R&D expenses, in panel C, we remove firms with zero R&D to ensure our results are robust. We find that the interaction of board independence and high R&D expenses is still negatively correlated with forecast errors across all models under columns (1) through (5) although the statistical significance has reduced to 10% level.

Table 3 reports the results using subsamples of low and high analyst coverage. The high analyst coverage subsample consists of firms whose number of analysts is greater than the cross-sectional median, and the low analyst coverage subsample consists of the

Table 7
A Quasi-Natural Experiment with the Sarbanes-Oxley Act of 2002.

	Forecast Error
High R&D x Treatment x PostSOX	-0.0024
	[− 2.19]* *
High R&D x PostSOX	-0.0004
	[− 0.63]
High R&D x Treatment	0.0017
	[1.52]
High R&D	0.0002
	[0.27]
Treatment x PostSOX	0.0021
	[2.19]* *
Treatment	-0.0016
	[− 1.75]*
PostSOX	-0.0018
	[− 1.48]
Market-to-Book	-0.0008
	[− 2.80]* *
Firm Size	0.0008
	[0.70]
Forecast Age	0.0001
	[4.57]* **
Volatility	-0.0005
	[− 0.38]
Analyst Coverage	-0.0045
	[− 5.12]* **
Earnings Surprise	0.0911
	[3.79]* **
Loss	0.0142
	[5.70]* **
Constant	0.0009
	[0.11]
Observations	10,574
Adjusted R-squared	0.2602
Firm FE	YES
Year FE	YES

Notes: This table reports the results of a quasi-natural experiment using the exogenous shock in board independence from the passage of the Sarbanes-Oxley Act of 2002 (SOX) and NYSE and Nasdaq regulations approved by SEC. *PostSOX* is a dummy variable coded one for years after 2001 and zero otherwise; *Treatment is a* dummy variable coded one for a firm with board having less than 50% independent directors prior to 2002. The Appendix includes the detailed definitions of all other variables. The sources of the data are IBES, Compustat, and CRSP. The sample period is from the fiscal year 1995–2016. *t*-statistics, in parentheses, are based on standard errors adjusted for serial correlation and heteroskedasticity using the Huber–White sandwich estimator (clustered on industry-level identifier). Two-sided statistical significance at 1%, 5%, and 10% is indicated as ***, **, and *, respectively.

remaining firms. The results show that *% Ind. Directors x High R&D* is statistically significant and negative only in the low analyst coverage subsample. This suggests that independent directors play a more substantial role in reducing forecast error in the absence of adequate financial analysts. We do not observe any significant impact of board independence for high analyst coverage firms, even for high *R&D* forms. These results indicate that independent directors might serve a similar role as financial analysts to reduce information asymmetry and improve forecast accuracy, which supports Hypothesis II.

Next, we test our third hypothesis that board independence improves forecast errors more for high *R&D* firms when CEOs are more powerful. In Table 4, columns 1 and 2 present the results from firms with low and high CEO power. A CEO is considered to have high power if one of the following conditions is met: 1) CEOs perform both Chair and CEO roles, 2) CEOs have higher than median tenure than other CEOs, and 3) CEOs own 5% or more shares of the company. Otherwise, the CEO is considered to have low power. The results show that *% Ind. Directors x High R&D* is significantly negative only in samples with high CEO power, which provides support for our Hypothesis III.

4.3. Robustness check

4.3.1. Idiosyncratic volatility as proxy for information asymmetry

In our first robustness check, we use *Idiosyncratic Volatility* as the proxy for information asymmetry to test that board independence can reduce information asymmetry in firms with high *R&D* expenses. In Table 5, column (1) reports the results of estimating Eq. (1), and columns (2) through (4) report the results of estimating the expanded versions of Eq. (1), with *Idiosyncratic Volatility* as the dependent variable. As shown in the table, all models show a significant negative coefficient for the interaction term, consistent with our argument that board independence reduces *R&D*-driven idiosyncratic volatility (information asymmetry). The coefficients of *% Ind. Directors* are not significant in any models, suggesting that board independence does not impact information asymmetry for firms with low *R&D* expenses. Table 5 confirms that board independence can reduce idiosyncratic volatility, a proxy for information asymmetry for *R&D*-intensive firms. It is interesting to see that the percentage of independent directors does not impact idiosyncratic volatility for firms with low *R&D* expenses. These results are consistent with what we observe in the analyst coverage subsample analyses.

4.3.2. *Alternative Percentiles for Winsorization and GMM for Endogeneity*

To further eliminate the possibilities that extreme observations may drive our results, we apply a stricter winsorization to our sample. Column (1) in Table 6 reports the panel regression results when only dependent variable (*Forecast Error*) is winsorized at 2% and 98% levels, while column (2) reports results when all variables are winsorized at 2% and 98% levels. Even after applying higher winsorization thresholds, our results do not change. The interaction term remains significantly negative.

The negative relation between *Forecast Error* and *% Ind. Directors x High R&D* may also be driven by unobservable variables affecting both *Forecast Error* and *% Ind. Directors*. Therefore, we use the generalized method of moments (GMM) model developed for dynamic panel estimation by Arellano and Bond (1991) to address the endogeneity problems. Another reason to use dynamic GMM is to correct the potential dynamic endogeneity problem when the independent variable (forecast errors) is affected by the past values of the dependent variables (time-variant variable such as *R&D* expenses). Li et al. (2021) suggest that a GMM estimator is in general preferable to a fixed effects estimator when there is dynamic endogeneity. The GMM results are presented under column (3) of Table 6, which shows that our main results remain unchanged.

To further address the endogeneity problem, especially the concern of time-varying omitted variables, we conduct a further robustness test by utilizing the exogenous shock to board independence from the passage of SOX and subsequent changes in listing requirements by NYSE and Nasdaq. The regulatory framework changes require most corporate board directors to be independent (Linck et al., 2008; Nguyen & Nielsen, 2010). As a result, firms without majority independent directors were forced to meet the requirement. The mandatory change allows us to examine the endogeneity concerns using the difference-in-differences (DID) model, a powerful and effective method to deal with time-varying omitted variables. We create a dummy variable *PostSOX*, which is coded as one for years after 2001 and zero otherwise (Linck et al., 2009), and a dummy variable *Treatment,* which is coded as one if a firm had less than or equal to 50% independent directors before 2002 but more than 50% after 2001. Therefore, the interaction between these two variables, *Treatment* × *PostSOX*, identifies the firms whose boards were not independent before the shock but became independent after the shock. Finally, *High R&D* is interacted with *PostSOX* (*High R&D* × *PostSOX*), with *Treatment* (*High R&D* × *Treatment*), and with *Treatment* × *PostSOX* (*High R&D* × *Treatment* × *PostSOX*). Then, *Forecast Error* is regressed on all these new variables and other control variables using the following model:

$$\begin{aligned} Forecast\quad Error_{i,t} = {} & \alpha_0 + \beta_1(High\quad R\&D\quad x\quad Treatment\quad x\quad PostSOX)_{i,t-1} + \beta_2(High\quad R\&D\quad x\quad PostSOX)_{i,t-1} \\ & + \beta_3(High\quad R\&D\quad x\quad Treatment)_{i,t-1} + \beta_4 High\quad R\&D_{i,t-1} + \beta_5(Treatment\quad x\quad PostSOX)_{i,t-1} \\ & + \beta_6 Treatment_{i,t-1} + \beta_7 PostSOX_{i,t-1} + \sum_{n=1}^{9}\theta_{n,t-1}\sum_{n=1}^{9} Control\quad Variables_{n,t-1} + \delta_1 Firm\quad Dummy \\ & + \delta_1 Year\quad Dummy + \varepsilon_{i,t} \end{aligned}$$

As shown in Table 7, *HighR&D* × *Treatment* × *PostSOX*, the primary variable of interest, is negatively correlated with *Forecast Error* at 5% significant level. It shows that when a firm increases its independent directors, the forecast error is reduced, and this reduction only happens in high R&D firms. The results provide further robust evidence supporting our main finding that board independence mitigates the adverse effect of information asymmetry on forecast accuracy for high R&D firms.

5. Conclusion

The *R&D* activities exacerbate a firm's information asymmetry problem in the financial markets, making it difficult to forecast earnings accurately. This study examines whether board independence, which improves both the quantity and the quality of disclosures, mitigates the adverse effect of *R&D*-associated information asymmetry on forecast accuracy. The results of this study suggest that board independence conditioned on high *R&D* expenses reduces forecast error. This beneficial effect of board independence is stronger for firms with low analysts' coverage, which indicates that independent directors can complement analysts' roles to disseminate information more effectively in the financial markets. Our study also shows that board independence reduces forecast error for *R&D*-intensive firms more when the firms have powerful CEOs. One practical implication of our study is that R&D-intensive firms should increase independent directors on their boards. The presence of independent directors is even more important for firms that have high R&D but followed a lower number of analysts. These findings add to different branches of finance and accounting literature and have implications for policy decisions to improve transparency in the financial markets.

Appendix: List of variables and their definitions

Variable	Definitions
Forecast Error	The absolute difference between the IBES consensus forecast of annual earnings (median) and the actual earnings reported by IBES, scaled by the stock price.
Idiosyncratic Volatility	FollowingBrockman and Yan (2009), to calculate idiosyncratic volatility, the following regression is estimated: $R_{i,t} = \beta_0 + \beta_1 MktR_{i,t} + \beta_2 MktR_{i,t-1} + \beta_1 IndR_{i,t} + \beta_1 IndR_{i,t-1} + \varepsilon_{i,t}$ Idiosyncratic volatility is the standard deviation of the residuals of the above regression.
% Ind. Directors	The percentage of independent directors on a board.
R&D	Research and development expenses divided by total assets.
High R&D	A dummy variable coded as one for a firm whose *R&D* expenses are greater than the cross-sectional median value and zero otherwise.
CEO Duality	A dummy variable coded as one for a firm whose CEO holds the chair position of the board and zero otherwise.
High Complexity	A dummy variable coded as one for a firm whose number of business segments is greater than the cross-sectional median value and zero otherwise.
High Power CEOs	A dummy variable coded as one if any or two or all following conditions is/are met: 1) CEOs who perform both Chair and CEO roles, 2) CEOs have higher than median tenure than other CEOs, and 3) CEOs who own 5% or more shares of the company. Zero otherwise.
Market-to-Book	Total assets plus the market value of equity less book value of equity and deferred taxes, all divided by total assets, where the market value of equity is computed as common shares outstanding times price.
Firm Size	The logarithmic value of firm sales.
Forecast Age	The average difference (in days) between the forecast date and the date of earnings announcements across all available analysts' forecasts.
Volatility	The standard deviation of return on equity over the last 10-year period.
Analyst Coverage	The logarithmic value of the number of analysts following a firm.
Earnings Surprise	The absolute value of the difference between the current year's earnings per share (*EPS*) and last year's *EPS*, divided by price
Loss	A dummy variable coded as one for firms that report negative net income before extraordinary items and zero otherwise
Leverage	Total long-term debt plus portion of long-term debt in current liabilities divided by total assets
Tobin's Q	The market value of equity plus total assets minus stockholders' equity divided by total assets
Payout Ratio	Cash dividends divided by total assets
Firm Age	Firm's current fiscal year minus first time it showed up in Compustat
Board Size	The total number of directors on a corporate board
% Female Directors	The percentage of female directors on a corporate board
CEO Tenure	The length of service in years as the CEO in the current firm
CEO Holdings	The total number of shares of the company that its CEO holds
CEO_5%	An indicator variable that takes a value of one if the CEO holds 5% or more shares of the firm, and zero otherwise.

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