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ORIGINAL RESEARCH

Innovation, institutional ownerships and board diversity

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Abstract
This work investigates the relationships between institutional ownership, board diversity, and corporate innovation in US-listed firms. Institutional investors play a crucial role in a firm's operation and exert considerable influence on the efficient monitoring of innovative investment. Theory predicts that institutional ownership has a positive effect on innovation investment. However, we find that active institutional investors drove this positive relationship. For those passive institutional investors, this impact is negative. However, a banker on the board can change the effect from negative to positive for passive institutional investors. Firms with female directors, a high presence of audit committee, or a large proportion of ethnic minority directors on board have a significant and positive impact on innovation, including R&D investments and the number of patents. The enactment of Sarbanes–Oxley Act (SOX) in 2002 made information more transparent to investors and narrowed the gap between active and passive institutional investors on innovation. The findings are robust to addressing endogeneity concerns and causal relationships using the IV-2SLS, Difference-in-Differences approaches, and alternative methodology.

Keywords Institutional ownerships · Board diversity · Innovation · ESG · Sarbanes–Oxley Act

JEL Classification G28 · G32 · O31 · H41

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1 Introduction

Globalization and technological revolution have compelled corporations to improve their competitive advantage, and innovation is recognized as the main engine of a firm's long-run growth. Exploring determinants of innovation is increasingly challenging for executives and is a growing interest for economists.[1] Innovation demands knowledge, capital, technology, and human talents. These factors are not easily obtained from individuals but are much more accessible by institutions.

Theory suggests that institutional ownership is an important mechanism in influencing managers to invest efficiently and maximize firm value. For example, Leland and Pyle (1977) state that an increase in institutional ownership is a good signal on reducing asymmetric information and revealing the higher quality of the underlying project. Aghion et al. (2013) indicate that firms with higher institutional ownership are more likely to invest in innovation because financing innovative activities require a long-term and stable capital structure. However, limited empirical evidence supports this prediction. Furthermore, most of the extant researches does not clearly distinguish the types of institutional investors, and regard institutional investors as homogeneous. Whether the types of institutional investors—active and passive, influence the pace of corporate innovation differently remains an unresolved issue.

This paper is inspired by the notation that different institutional investors have different incentives to monitor their investee firms (Cremers and Nair 2005). While passive institutional investors do not exert effort in monitoring firms (Chen and Miller 2007), active institutional investors are more willing to collect private information about invested firms and provide professional advising and monitoring. As a result, if investors possess inside information about a firm, they may foster corporations to invest in high-quality, innovative projects. Consequently, institutional ownerships constitute a crucial factor that influences firm innovation.

To have inside information, institutional investors usually have a seat of directors on board. Besides monitoring, these long-term investors from institutions also provide advising function to corporation decisions including innovation activity. Beside the sophistication and voting power from institutions, the board members attributes, such as profession, gender, and ethnicity also play an important role on affecting innovation decisions. Building on the foundation of upper echelons theory, Hambrick (2007) and Berger et al. (2014) argue that experiences and personalities of executives significantly influence their interpretations of the situations they encounter and in turn, affect corporate decision. Thus, the cognitive frames of the board members are important to firm activities and outcomes. Diverse professions on boardroom influence the firm's strategic direction by providing cognitive conflict and constructive debate which may result in innovative ideas (Hillman et al. 2002; Miller and Triana 2009).

Wiersema and Bantel (1992) argue that diversity in demographic traits help bring a diversity of information sources, leading to more creative or innovative brainstorming. We thus propose that a board may affect innovation via its diversity attributes. Greater diversity in gender and ethnicity traits lead to increased monitoring, such that managerial opportunism becomes less prevalent. Besides, a growing number of banks have a seat on the board

[1] See Li and Simerly (2002), Lee and O'Neill (2003), and Ortega-Argilés et al. (2005) for early empirical growth studies, and Czarnitzki and Kraft (2009), Dong and Gou (2010), and Choi et al. (2012) for more recent confirmations based on richer data.

or a long-term ownership stake in the businesses of their clients also provide a prospective advising to a firm. In the US, over 30% of the largest firms have bankers on board (see, e.g., Kroszner and Strahan 2001). Ferreira and Matos (2008) explore ownership and board links of bankers worldwide and point out that institutional ownerships replace direct bank ownership gradually. Corporations exhibit relative advantages in accessing funds, advising, and monitoring when a banker has a seat on board or holds ownership. We, therefore, expect that a board with professional directors (e.g., bankers or members of the audit committees) or expertise are more competitive, assertive, and willing to engage in innovative activities.

Extant literature exploration of the relationship between ownership structure and firm innovation ignores the function of board diversity.[2] For example, David et al. (2001) examine the impact of institutional ownerships on R&D investments and suggest that institutional ownerships increase R&D inputs for short- and long-terms. By contrast, Graves and Waddock (1990) previously indicate a negative relationship between innovation activities and institutional investors, who tend to look at short-term performance. While results of ownership and innovation are mixed, the increasing demand for director diversity recently led researchers to examine diversity's impact on boardroom behaviors. However, a salient aspect of existing literature is the absence of studies on the effects of board diversity on innovation.

This study narrows the gap in the literature by providing a novel perspective at how institutional ownerships and board diversity within the modern enterprise may help improve firm innovation in the US. US listed firms make an excellent testing ground for investigating this topic because of their high proportion of institutional ownerships compared to firms of other countries. In fact, institutions held 70% of the equity in US firms during our sample period, indicating a compound annual growth rate of 3.9% over the last 15 years. Furthermore, unlike other countries where data are trivial, unobtainable or of poor quality, the US offers access to high-quality data on institutional ownerships, board diversity, innovation investment, and patents.

A concern of this study is that institutional ownerships are not exogenous random variables. Instead, they are endogenously affected by many factors (Demsetz and Lehn 1985; Aggarwal et al. 2011). To address issues related to the endogeneity of institutional ownerships, we used the instrumental variables approach. We first employ a firm's presence in theStandard and Poor's 500 (SP500) index as an instrument to instruct institutional ownership.[3] Duggal and Millar (1999) indicate that institutional ownership significantly determined by a firm's presence in this index. SP500 is representative for regularly listed firms and is relatively stable over time. As such, many institutional investors prefer to invest in firms included in this index. Besides, institutional investors also steadily hold shares of large (high market-value) firms because large capitalization is associated with high liquidity and investment safety. Following Elyasiani and Jia (2010), we use firm capitalization as the second instrument. SP500 and firm capitalization are good instruments given that they are likely to influence institutional ownerships but are unlikely to impact firm innovative activities directly.

[2] Choi et al. (2011), Choi et al. (2012), Czarnitzki and Kraft (2009), Lee and O'Neill (2003) ect.

[3] We tried to employ a firm's ESG (environmental, social, and governance) scores as the instrument to instruct institutional ownerships (e.g., Dyck et al. 2019). The results are very significant. However, as very limited firms in our sample period disclose ESG scores, the observations reduce dramatically. To maintain sufficient observations, we remove the ESG instrument.

Furthermore, we examine the effects of board diversity by the proportion of ethnic minorities, the percentage of the audit committee, and if the board includes female appointees. Additionally, this research focuses on firm R&D expenditure and combines that information with the NBER Patent Database, USPTO and IPTECH[4] Patent Databases. The patent count could connect the output of R&D activities and innovation investment (Deng et al. 1999). Moreover, biases due to firm heterogeneity and endogeneity problem are a concern in our analysis. We choose a set of control variables and 2SLS regression to address the endogeneity issue. The difference-in-differences (DID) analysis and an alternative measure and methodology are conducted for the robustness check. The results remain similar.

Our findings reveal a positive relationship between institutional ownership and R&D investment: firms with high institutional ownership have significantly higher R&D investment and innovation output as measured by the number of patents. In particular, we find that the positive relation between institutional ownership and innovation is mainly driven only by active institutional investors rather than by passive institutional investors. Noticeable, the impact of these passive institutional investors turn out to be significantly positive on innovation when a banker has a seat on the board. Our findings also indicate that firms with more directors serving as audit committee members, higher proportion of ethnic minority, or females on the board have higher innovation investment and patents.

Finally, earlier literature recognizes that highly innovative firms face difficulties in attracting equity capital, especially, institutional investment (Bushee 1998; Graves and Waddock 1990), due to the high level of information asymmetry. However, the Sarbanes–Oxley (SOX hereafter) Act in 2002 is strongly believed to reduce information asymmetry, thus benefiting all firms (Engel et al. 2007). Our results show that while the SOX Act benefits innovations of all firms, passive institutional investors benefit more than active ones. Thus, the SOX Act narrows the gap between active and passive investors in innovation investment and reduces the competitive advantage of active investors in innovation. In addition, this study suggests that the implementation of the SOX Act mitigates the differences between active and passive institutional investors. Further, this effect erodes the differential impact on innovation of active versus passive investors.

The remaining parts of this paper is organized as follows. In Sect. 2, we briefly review relevant literature. Section 3 describes the data and methodology, followed by empirical results in Sect. 4 and the conclusions in Sect. 5.

2 Literature review

Innovation is the process of developing new technological knowledge to generate a higher-quality or lower-cost product than those previously available (O'Sullivan 2000). Many prominent scholars have consistently stressed innovation's importance as the key to economic development and business growth (Cohen and Klepper 1996; Zahra and Covin 1995). In fact, innovation activities considerably benefit enterprises, but are often cited as risky investments with high probability of failure and uncertain return. Therefore, an

[4] The IPTECH Patent Database is a comprehensive patent analysis platform with global patent search and analysis tools developed by Taiwan LianYing Technology Co., Ltd. in 2003. This database platform integrates the patent database website of various countries. We double-checked two databases for some uncertainty.

innovation investment is an investment decision that may generate conflicts between shareholders and managers.

Agency theory suggests that managers are risk averse due to concerns about their undiversified human capital (Fama 1980), and literature investigates how managers can be motivated to make risky choices through various corporate governance mechanisms. These mechanisms comprise both internal and external methods, such as monitoring by the board of directors and shareholders. Existing literature has increasingly focused on the role of corporate governance mechanism in influencing firm performance (Munari et al. 2010). This study sheds new light on the literature by investigating how institutional ownership and board diversity influence firm innovation.

2.1 Institutional ownership and innovation

An emerging stream of literature is examining the causes and effects of institutional ownership and revealing a continuing expansion of their role in corporate governance. Institutional investors have become the dominant investors in the financial markets of many countries, and have become prevalent as means of a common collective ownership type. With their sophistication and high ownership, institutional investors are more likely to monitor and discipline managers (Elyasiani and Jia 2010). Thus, such investors play a vital role in influencing managers to invest efficiently and maximize firm value (Bushee 1998). An empirical study by David et al. (2001) find that large ownership stakes held by institutional investors grant them the power to influence R&D investments. Similarly, Hoskisson et al. (2002) test the relationship between governance and corporate innovation strategies and uncover evidence that professional investment fund managers preferred acquiring external innovation.

Conversely, Graves and Waddock (1990) reveal a negative relationship between innovation activities and institutional investors who would look more at short-term performance. Using a sample of Korean firms, Choi et al. (2012), determine that institutional ownership has a positive effect on firm innovation performance. In a study of 303 Chinese hi-tech manufacturing businesses, Jiang et al. (2013) report that institutional ownership has a positive relation with internal R&D activities, but a negative relationship with innovation performance (new product). A general implication of these findings is that institutional investors equipped with strong information-processing capacity and voting power can motivate top managers to pursue innovation projects with prospects. Rong et al. (2017) employ Chinese data and find that the effect of institutional investors on firm patenting mainly comes from mutual funds. Chang et al. (2019) found that higher institutional ownership leads to more innovations, including higher citations and patents. However, existing literature examining this issue views institutional investors as homogeneous. We explore this issue by separating the institutional investors into active and passive types and adding board diversity details for more governance insight.

2.2 Board diversity and innovation

The board of directors is one of the key internal corporate governance mechanisms to "control agency problems and mitigate information asymmetry between the firm and outside stakeholders" (Fama and Jensen 1985). While many researchers study the influence of board characteristics on firm performance, studies on its impact on firm innovation are limited. For example, Tseng et al. (2013) find a positive relationship between board size

and innovation ability. Dong and Gou (2010) uncover evidence that the presence of independent outside directors and director ownership leads to superior innovation investments. However, these studies treate directors as a homogenous group without controlling for their personal characteristics, such as ethnicity, gender, and qualifications. Building on the upper echelons theory (Hambrick and Mason 1984; Hambrick 2007), we argue that variations in these characteristics may explain the difference in innovative effort or risk-taking investments among firms.

2.2.1 Gender diversity

Gender diversity is defined as the percentage of women in the board and proxy by the gender composition in boardroom (Marinova et al. 2015; Byoun et al. 2016). Literature has reported a drastic increase in the number of female directors and professionals in the last few decades around the world. Women now are getting the important education and performing their duties well. If the female directors' qualifications and caliber are confirmed then gender diversity is one of the major signals of board diversity (Hafsi and Turgut 2013). A study for US firms between 1993 and 1998 shows that board gender diversity leads to improved firm performance by raising return on assets (Erhardt et al. 2003). Governance reforms indicate the importance of gender diversity in boardroom (Adams and Ferreira 2009).

Gender diversity are effective because female directors tend to take their roles very seriously in boardrooms and show less problems of attendance (Singh and Vinnicombe 2004). Besides, boards with gender diversity are provided with a better understanding of the marketplace thus possible to have better decision-making capabilities (Carter et al. 2003). More notably, Adams and Funk (2012) find that female directors exhibit increased sensitivity to social and environmental issues and are more risk-seeking than their male counterparts. Deore et al. (2021) find that board gender diversity is positively associated with the quantum, impact, and risk of innovations. If one believes that the investment in innovation projects is risky, we would expect that gender diversity of the board may moderate the impact on firm innovation.

2.2.2 Ethnic diversity

While the nationality of corporate directors around the world is gaining increasing attention, race and ethnicity seem to have become important dimensions of board diversity in the US. The role of diversity in board composition is well documented, and the emphasis has been on both gender and ethnicity. Carter et al. (2003) find a significant positive relationship between the proportion of ethnic minority directors on boardroom and Tobin's Q. Similarly, by using a sample of firms in Norway and Sweden, Oxelheim and Randøy (2003) determine a significantly higher value for enterprises that have outsider Anglo-American board members.

Tseng et al. (2013) argue that variety could bring firms more flexibility in today's volatile environment, and the diverse ethnicity of directors is benefits firms by encouraging better investment decision. Ethnic diversity may bring different viewpoint on boardroom (Hillman et al. 2002), break familiar investment patterns, which then opens up a wider range of strategic options to be considered and increased the awareness of innovation and opportunity. We therefore argue that the higher diverse ethnic minority, the better to stimulate

broader discussion for alternative considered, which may facilitate innovation activities of firms. We thus expect that ethnic diversity of boards increases corporate innovation.

2.2.3 Qualification diversity

The board of directors is entrusted with crucial firm decisions, and the quality of decision-making is likely to depend as much on their qualifications, experiences, and skills. Monks and Minow (1995) find that director expertise and occupational characteristics may affect the board's ability to monitor management and enhance firm performance. Raghunandan et al. (2001) recommend strengthening director qualifications and highlighting the crucial role of internal auditors in assisting audit committees in the internal control process. Similarly, Darmadi (2013) examines the effect on financial performance of the educational backgrounds of the directors and the CEO, and concludes that educational qualification is not always a good proxy for managerial quality. The author suggests several factors that need to be considered, such as managerial skills, experiences, networks, and other skills obtained beyond academia.

Dewally and Peck (2010) find that professional directors who are members of audit committees or have previously worked for the government, universities, or business associations, are viewed as management human capital assets of the firm. However, limited research exists on the impact of professional directors on firm innovation. If the qualifications of the director are associated with greater monitoring, then managerial opportunism becomes less prevalent. Therefore, we expect that these high-quality directors will become more competitive, assertive, and more willing to be risk-taking regarding investment in innovation projects.

3 Data and methodology

3.1 Data sources

To construct the sample for this study, we combine data from several sources. The institutional ownership data are obtained from the Thomson Reuters Institutional (13F) Holdings. SEC requires all institutional organizations, companies, universities, and so on, to exercise discretionary management of investment portfolios over US$100 million in equity assets and to report those holdings. All common stock positions greater than 10,000 shares or US$200,000 must be reported. As noted on the WRDS website, the type code variable on the Spectrum is not reliable after 1998. We then follow Bushee (1998) and Bushee et al. (2010)[5] in taking the "reliable" Spectrum type codes and we carry these data forward in time for institutions still in existence after 1998. The information on corporate boards is from the Risk-Metrics database (formerly Investor Responsibility Research Center), which covers S&P 500, S&P Midcap 400, and S&P SmallCap 600 firms for 1996 to 2014. As information on committee membership for 1996 and 1997 are missing, we exclude those years.

[5] Bushee (1998) and Bushee et al. (2010) provide institutional investor classification data (1981–2013) on the website: http://acct3.wharton.upenn.edu/faculty/bushee/

Two databases are utilized for information on the innovation inputs and outputs pursued by sample firms. First, innovation input data are obtained from the Compustat. We define R&D investment (RD_SALE) as the R&D expenditure divided by total sales, measured at the end of fiscal year t. Second, the innovation output data measured by the number of patents were from the Harvard Patent Network Dataverse, which has updated the NBER-2006 database to 2010 (Li et al. 2014). To augment the data, we employ other Patent Databases from Intellectual Property Technology Innovation System (IPTECH) and USPTO to update USA patent data from 2011 to 2013. The above databases provide detailed information on US patents, such as patent assignee names, the number of patents, and the grant year. We use utility patents as a proxy for innovation because it is known as "patents for invention" in the US.[6] We measured innovation output by the natural logarithm of 1 plus the number of patents granted [LN (1 + PATENTS)]. Following He and Tian (2013), we add one to the actual values when calculating the natural logarithm of the number of patents to avoid losing firm-year observations with zero patents.

Finally, we collect firm characteristics (such as firm size, age, cash ratio, leverage, return on assets, and growth opportunity data) from the Compustat Fundamentals Annual database as control variables (explanations and definitions are presented in the following section). After merging the various data sources, we impose three restrictions on the data. First, firms operating in financial sectors (SIC codes 6000–6999) are excluded because they are subject to different regulatory accounting considerations. Second, we exclude all firm-year observations with missing values for explanatory variables. Third, following previous studies, we exclude all variables at the 1st and 99th percentiles to alleviate the effect of outliers (Aivazian et al. 2005; Cleary 1999). Consequently, the final dataset includes 13,565 firm-year observations from 1998 to 2014. Table 1 provides descriptive statistics of the variables.

3.2 Measuring the variables

This section provides the definitions of the dependent and independent variables. Detailed variable definitions are presented in Appendix A.

3.2.1 Innovation

Based on the input and output of innovation activities, we develop the following three proxies for the degree of firm innovation: (i) ratio of R&D expenditure to total sales (RD_SALE), (ii) natural logarithm of 1 plus the number of patents [LN (1 + PATENTS)] registered by a sample firm, and (iii) innovative efficiency, measured by the ratio of patents relative to R&D capitalization. First, we measured innovation input using R&D intensity made by a firm during the fiscal year. We define RD_SALE as the ratio of R&D expenditure (Compustat item XRD) to total sales (Compustat item SALE). Second, we measured innovation output by by the natural logarithm of 1 plus

[6] According to the United States Patent and Trademark Office (USPTO), utility patents issued for "the invention of a new and useful process, machine, manufacture, or composition of matter, or a new and useful improvement thereof, it generally permits its owner to exclude others from making, using, or selling the invention for a period of up to twenty years from the date of patent application filing, subject to the payment of maintenance fees. In recent years, approximately 90% of the patent documents issued by the USPTO were utility patents." *Source*: http://www.uspto.gov/web/offices/ac/ido/oeip/taf/patdesc.htm.

Table 1 Summary statistics

Panel A: descriptive statistics[a]

Variables	Mean	Standard deviation	Q25	Median	Q75
Innovation measures					
RD_SALE	0.1037	0.0691	0.0048	0.0266	0.1034
RD_TA	0.0507	0.0709	0.0050	0.0254	0.0737
PATENTS (RAW)	191.428	601.394	6	25	114
LN(1 + PATENTS)	3.4328	1.8694	1.9459	3.2581	4.7449
IE	1.1305	1.2265	0.1843	0.5612	1.3191
Institutional ownerships					
IO_TOTAL	0.7079	0.1994	0.5965	0.7381	0.8568
IO_ACTIVE	0.5418	0.1821	0.4186	0.5533	0.6696
IO_PASSIVE	0.1955	0.0731	0.1454	0.1881	0.2354
Board diversity					
AUDITING	0.1992	0.0748	0	0.1667	0.3750
ETHNIC_MINORITY	0.1249	0.0888	0	0.1021	0.1820
FEMALE	0.5968	0.4906	0	1	1
GENDER	0.0970	0.0864	0	0.1030	0.1438
Board characteristics					
BOARD_INDEPEND	0.6780	0.1705	0.5600	0.7500	0.8571
BOARD_SIZE	9.2899	2.3681	7	9	12
CEO_DUALITY	0.6733	0.4690	0	0	1
Firm characteristics					
SIZE	7.3589	1.5615	6.2458	7.1843	8.3019
PROFITABILITY	0.0332	0.2052	0.0187	0.0566	0.0947
GROWTH	0.1104	0.1494	-0.0026	0.0746	0.2693
CASHRATIO	0.0950	0.1106	-0.0303	0.0069	0.0820
LEVERAGE	0.1430	0.0864	0.0120	0.1405	0.1609
CAPEX_TA	0.0501	0.0465	0.0220	0.0373	0.0641
LNMKVALT	7.6054	1.6685	6.4435	7.4276	8.6380

Table 1 (continued)

Panel A: descriptive statistics[a]

Variables	Mean	Standard deviation	Q25	Median	Q75
SP500_D	0.2783	0.4482	0	0	1

Panel B: Pearson correlation matrix[b]

Variables	AUDITING	ETHNIC MINORITY	FEMALE	BOARD INDEPEND	BOARD SIZE	CEO DUALITY	SIZE	PROFITABILITY	GROWTH	CASH RATIO	LEVERAGE	CAPEX_TA
AUDITING	1.000											
ETHNIC_MINORITY	−0.115*	1.000										
FEMALE	−0.095*	0.154*	1.000									
BOARD_INDEPEND	−0.213*	0.143*	0.266*	1.000								
BOARD_SIZE	−0.002	0.225*	0.305*	0.104*	1.000							
CEO_DUALITY	0.048*	0.022*	0.045*	0.009	0.075*	1.000						
SIZE	0.007	0.277*	0.342*	0.089*	0.365*	0.136*	1.000					
PROFITABILITY	−0.033*	0.049*	0.082*	0.047*	0.071*	−0.010	0.031*	1.000				
GROWTH	0.031*	−0.042*	−0.069*	−0.075*	−0.044*	0.009	−0.017*	−0.001	1.000			
CASH RATIO	−0.001	−0.007	−0.018	−0.004	−0.022*	−0.008	−0.001	−0.001	0.002	1.000		
LEVERAGE	0.023*	0.039*	0.061*	−0.003	0.127*	0.061*	−0.059*	−0.068*	−0.0001	−0.0001	1.000	
CAPEX_TA	0.038*	−0.074*	−0.075*	−0.093*	−0.002	0.028*	−0.029*	−0.033*	0.001	−0.0012	0.012*	1.000

[a]The table presents the descriptive statistics for a sample of US public firms from 1998 to 2014. Variables are defined as follows: *RD_SALE* is the ratio of R&D expenditure to the book value of total sales. *RD_TA* is the ratio of R&D expenditure to the book value of total assets. Innovation output/ *LN(1 + PATENTS)* is the logarithm of one plus the total number of patents granted to the firms. Innovative efficiency (*IE*) is the ratio of patents relative to the R&D capitalization. Institutional ownerships (*IO_TOTAL, IO_ACTIVE* and *IO_PASSIVE*) are the percentage of shares owned by total institutional ownership, active and passive institutional investors, respectively. *AUDITING, ETHNIC_MINORITY* and *GENDER* are ratios of the numbers of directors who are audit committee members, ethnic minority, and women scaled by board size, respectively. *FEMALE* is a dummy variable, which equals 1 if the board has at least one female director, 0 otherwise. *BOARD_SIZE* is the number of directors on the board. *BOARD_INDEPEND* is the proportion of independent directors on the board. *CEO_DUALITY* is a dummy variable, which equals 1 if the CEO also acts as a chairman of the board, 0 otherwise. Firm size (*SIZE)* is measured by the natural logarithm of total assets. *PROFITABILITY* is the ratio of net income to the book value of total assets. *GROWTH* opportunities are measured by firm sale growth [(Sales $_t$ − Sale $_{t-1}$)/ Sales $_{t-1}$]. *CASHRATIO* is total cash and cash equivalents to its total assets. *CAPEX_TA* is the capital expenditure ratio, which is capital expenditure divided by total assets. Firm's market capitalization (*LNMKVALT)* is the natural logarithm of the market value of the firm. Standard and Poor's 500 index dummy (*SP500_D*) is set to 1 if the firm is in the S& P 500 index, 0 otherwise

[b]This Panel shows the Pension correlation coefficients for the firm and board variables. All variables are as described in Appendix A. Figures with * represent the statistical significance at the 1% levels

the number of patents granted to firms [LN (1 + PATENTS)]. Following He and Tian (2013), we add one to the actual values when calculating the natural logarithm of the number of patents to avoid losing firm-year observations with zero patents. Finally, to address relative input (research effort, such as R&D expenses)/output (patent numbers) problems, we employ innovative efficiency (IE) as another dependent variable. Innovative efficiency in year t is measured as patents granted in year t scaled by the R&D capitalization in years *t-2* to *t-6*. Following the definitions of Hirshleifer et al. (2013), the formula of IE are specified as below.

$$IE_{i,t} = \frac{Number\ of\ Patent_{i,t}}{(RD_{i,t-2} + 0.8xRD_{i,t-3} + 0.6xRD_{i,t-4} + 0.4xRD_{i,t-5} + 0.2xRD_{it-6})}$$

where $RD_{i,t-2}$ denotes R&D expenditure (Compustat item XRD) in fiscal year ending in year t-2, and so on.

3.2.2 Institutional Ownerships

Total institutional ownerships (IO_TOTAL): IO_TOTAL is the ratio of institutional ownerships to total shares outstanding at the end of each fiscal year. Following Ferreira and Matos (2008) and Aggarwal et al. (2011), we set institutional ownerships to zero if the firm is not held by any institution in the Thomson Reuters Institutional (13F) Holdings. According to David et al. (2001), institutional investors care about the stability of the firm and focus on long-term investment to maximize their benefits. With sophistication and significant shareholdings, institution investors have the power to influence the allocation of scarce resources for competitive and challenging investments, such as innovation, and monitor how investments are being utilized. We, therefore, expect a positive relationship between institutional ownership and firm innovation.

Institutions, which are long-term investors, could serve as board members to monitor managers for mitigating information asymmetry and influencing the decisions of innovation activity. Following Bushee (1998) and Bushee et al. (2010), we classify "the different types of investors into active and passive institutional investors. Active institutional investors are investment companies, independent investment advisors, and public pension funds. Passive institutional investors include insurance companies, private pension fund, and others". Active institutional ownership (IO_ACTIVE) is the sum of the holdings of all active institutional investors to total shares outstanding at the end of each year. Passive institutional ownership (IO_PASSIVE) is the sum of the holdings of the ownership by passive institutions to total shares outstanding. As mentioned, while passive institutional investors do not exert effort in monitoring their investee firms (Chen and Miller 2007), active institutional investors are more advantageous because of their strong information-processing capacity and their willingness to gather private information about investee companies. Thus, if investors know inside information, they may foster corporations to invest in high-quality innovative projects.

3.2.3 Board diversity

Qualification diversity (AUDITING): we use AUDITING, which is measured as the percentage of directors serving on the audit committee to characterize professional directors in the firm. Theoretical literature suggests that higher quality management teams may invest

in long-run value oriented projects. Given that innovative projects are among these long-run value-enhancing projects, we expect that a board composed of members with higher skill, experience, and expertise will invest more in innovative projects and have greater extent of innovative output.

Ethnic diversity (ETHNIC_MINORITY): we consider ethnic diversity by the proportion of the ethnic minority (African-American, Hispanic, and Asian) on the board. Prior literature suggests that diverse ethnicity of members of the council would bring different perspectives, promote better understanding of the cultural and market place, and offer new ideas for problem solving (see e.g., Carter et al. 2003). Therefore, we expect a positive relationship between ethnic diversity and innovation.

Gender diversity (FEMALE): we use a female appointment dummy variable (FEMALE), which is set to one, if the firm has at least one female director on board as a proxy for gender diversity. Women are argued as "paying more attention to communication, collaboration, personnel development, and networking" (Claes 1999). Moreover, female directors display increasing sensitivity to social and environmental issues and are more risk-seeking than their male counterparts (Adams and Funk 2012). If such notions are true, then we expect that women would be more efficient in working with senior management to directly enhance firm innovation.

3.2.4 Control variables

Our choice of control variables is motivated by their potential relevance as noted in prior literature. Our control variables fall into two different categories: board and firm characteristics.

Board characteristics: Following previous studies, we control a series of board characteristics that may influence the innovation capacity of a firm. These variables include board size, board independence, and CEO duality. Board size (BOARD_SIZE) is measured by the number of directors serving on the board. Literature indicates that the functioning of a board can affect the quality of managerial decision and firm performance (Fama and Jensen 1983). We predict that a larger size of the board of directors will result in better performance in terms of firm innovation.

Board independence (BOARD_INDEPEND) is measured by the percentage of independent directors on the board of directors of the company. Independent directors are usually from universities, research institutions, and law firms. According to the characteristics of this group, Baysinger and Hoskisson (1990) prove that "independent-outside directors could improve R&D investment in companies given their long-term orientation". Therefore, we expect that independent directors have a positive effect on firm innovation. CEO duality (CEO_DUALITY) is defined as a dummy variable that equals 1 when the chairman of the board also serves as CEO, and 0 otherwise. A dual CEO benefits the firm if CEO works closely with the board to create firm value (Brickley et al. 1997). However, such situation makes it easier for the him or her to assert control of the board and consequently make more difficult for shareholders in terms of monitoring and disciplining the management (Lehn and Zhao 2006). Based on these arguments, we predict an ambiguous relation between CEO duality and the firm innovation investment efficiency.

Firm characteristics: To isolate the effect of institutional ownership and board diversity on innovation output, we control firm characteristics documented as important innovation determinants by previous studies. The first control variable is firm size (SIZE), which is

measured by the natural logarithm of total assets (Compustat item AT). Firm size reflects the present and the prospects for innovation (Craig and Dibrell 2006). Hall and Ziedonis (2001) argue that large firms and capital-intensive firms undertake more innovation activities. We expect that firm innovation positively correlates with firm size.

Return on Assets (ROA) captures profitability. We define ROA as the net operating income (Compustat item NI) divided by the book value of total assets (Compustat item AT). Hitt et al. (1991) finds a negative relation between ROA and patent intensity. However, Fang et al. (2014) report that firm profitability has a positive effect on the level of firm innovation.

Firm Leverage (LEVERAGE) is the ratio of total debt (Compustat item DLC + DLTT) to total assets (Compustat item AT). Generally, bank managers would require collateral for innovation loans. If firms do not obtain sufficient cash inflow and need external debt financing, they may show less innovative projects (Czarnitzki and Kraft 2009). Accordingly, we expect firm leverage to be negatively related to firm innovation.

We further include sale growth (GROWTH) as proxy for firm growth opportunities. GROWTH is measured as the average of the total sales (Compustat item SALES) growth over the sample period. Increase or decrease in sale growth provides a signal of the firms' innovation activities. Therefore, we expect a positive relationship between sales growth rate and innovation. Cash ratio (CASH RATIO) is measured by total cash (Compustat item CH) to total assets (Compustat item AT). Cash ratio shows the percentage of company assets held in cash and marketable securities. CAPEX_TA is the capital expenditure ratio, which is measured by capital expenditure (Compustat item CAPX) divided by total assets. A large capital expenditure might indicate that such firm has significant growth opportunities. We then expect that cash ratio and capital expenditure ratio are positively related to R&D investment. We employ two-digit SIC dummies to control for the industry effects.

3.3 Empirical models

This study investigates the nature of the relationship between the institutional ownerships, board diversity, and firm innovation. Such investigation entails regressing firm innovation (INNOVATION) in corporate operations on variables that capture institutional ownership, board diversity influence, and controlling for other board characteristics, firm characteristics, industry effect, and event factors. The regression specifications are as follows:

$$INNOVATION_{it} = \beta_0 + \beta_1 INSTITUTION_{it} + \beta_2 BOARD\,DIVERSITY_{it} + \beta_3 CONTROLS_{it} + \varepsilon_{it} \quad (1)$$

$$Where\ INSTITUTION_{it} = \alpha_0 + \alpha_2 CONTROLS_{it} + \alpha_3 INSTRUMENTS_{it} + \omega_{it} \quad (2)$$

Subscripts i and t indicate firm and time, respectively. Variable definitions are as follows: *INNOVATION* is a proxy for firm innovation in corporate operations. *INSTITUTION* is a collection of proxies that capture the power of institutional investors (such as institutional ownership in total, active institutional ownership, and passive institutional ownership) to influence corporate innovation investment decisions. A concern is that institutional ownerships are not exogenous random variables, but are endogenously affected by many factors (Demsetz and Lehn 1985; Aggarwal et al., 2011). To address issues related to the endogeneity of the institutional ownerships, we use the instrumental variables approach.

We first employ the Standard and Poor's 500 index (SP500_D) as an instrumented variable (see, e.g., Duggal and Millar 1999). Standard and Poor's is an index that is representative for regularly listed firms and is relatively stable over time. As such, many institutional

investors prefer to invest in firms included in this index. A dummy variable SP500_D is used, which is set to 1 if the firm is in the S& P 500 index and 0, otherwise. SP500_D is likely to influence institutional ownership because fund managers are typically benchmarked against this index, but is unlikely to have direct impact on firm innovation. Additionally, institutional investors prefer to steadily hold large stocks (high market-value) because large capitalization is associated with high liquidity and investment safety (Elyasiani and Ja, 2010). Hence, we use market capitalization as the second instrument. Market capitalization (LNMKVALT) is measured by the log of the firm value (Compustat item MKVALT).

We first build a model using the above instrumental variables and all exogenous variables in the innovation equation to predict institutional ownerships. Given that equations are estimated using the same data, their error terms may be correlated. Therefore, we adopt a 2SLS regression to address the endogeneity issue and correlated errors between equations. The first stage model is shown as Eq. (2). A fitted value of institutional ownerships, computed by using first-stage estimates, is used to replace the observable institutional ownerships in the second stage. The second stage model is shown in Eq. (1):

$$INNOVATION_{it} = \beta_0 + \beta_1 INSTITUTION_{it} + \beta_2 BOARD\ DIVERSITY_{IT} + \beta_3 CONTROLS_{it} + \varepsilon_{it} \quad (1)$$

where, *BOARD DIVERSITY* is a collection of variables that capture AUDITING (percentage of directors who also are audit committee members), ETHNIC_MINORITY (proportion of the ethnic minority in the board), and FEMALE APPOINTMENT dummy variable. *CONTROLS* are a set of variables comprising control board and firm characteristics, as well as industry effects. We specifically control for board size, board independence, CEO duality, firm size, profitability (ROA), growth opportunities, cash ratio, capital expenditure ratio, and industry dummy variables.[7] ε and ω are the error terms.

We employ the Hausman specification test (Hausman 1978) to confirm the existence of endogeneity. Further, the identification test and excluded-instruments F- test provide the check for the soundness and adequacy of instruments. Table 2 presents the Hausman test results. We first regress institutional ownership variables on the selected instrumental variables and the rest of the exogenous variables as the model in Eq. (2). The initial regressions of institutional ownership variables against instrumental and exogenous variables resulted in a p-value for instrumental variables that are small enough to conclude that SP500_D and LNMKVALT are the best instruments. After that step, the residuals of institutional ownerships (IO_TOTAL, IO_ACTIVE and IO_PASIVE) equations are plugged, one by one, into the original regression of Eq. (1). The results in Columns (2), (4), and (6) of Table 2 show that these residuals are statistically significant. Furthermore, the Hausman test for endogenous of IO_TOTAL, IO_ACTIVE, and IO_PASIVE show the F-value of 485.94, 20.25, and 6.47 with p-value of 0.000, respectively. These results indicate that IO_TOTAL,

[7] We include industry dummy variables (industry fixed effects) instead of firm fixed effects in empirical models because the data shows the opportunities for innovation to differ among industries. However, we do control the firm characteristics in our sample instead of firm fixed effects. This aligns with much of corporate finance literature, where authors use industry-fixed effects in panel data regression.

Similarly, the year effects are designed later in the section when we examine whether the enactment of the SOX Act in 2002 affects the relationship between institutional ownership and firm innovation investment. Accordingly, we employ the multivariate difference-in-differences (DID) analysis with the 5-year window centered on the event year. To make the model specification consistent, we designed it in the DID section in which the pre- and post- event covered all the years. Noticeably, our model is 2SLS than OLS, with some more concerns included.

Table 2 Hausman test for endogenous problem

VARIABLES	Total Institutional Ownership		Active Institutional Ownership		Passive Institutional Ownership	
	(1)	(2)	(3)	(4)	(5)	(6)
	IO_TOTAL	RD_SALE	IO_ACTIVE	RD_SALE	IO_PASSIVE	RD_SALE
Institutional ownerships						
IO_TOTAL		0.072**				
		(0.031)				
IO_ACTIVE				0.086*		
				(0.037)		
IO_PASSIVE						−0.039
						(0.046)
Board diversity						
AUDITING	−0.143***	2.269***	−0.120***	0.151**	−0.015	0.096*
	(0.020)	(0.123)	(0.018)	(0.111)	(0.011)	(0.049)
ETHNIC_ MINORITY	−0.071***	1.142***	−0.019	0.190***	−0.011	0.154***
	(0.018)	(0.075)	(0.016)	(0.071)	(0.009)	(0.039)
FEMALE	−0.011***	0.176***	−0.005	0.015*	0.003	0.008*
	(0.004)	(0.015)	(0.003)	(0.015)	(0.002)	(0.008)
Board characteristics						
BOARD_INDE-PEND	0.100***	1.340***	0.073***	0.276***	0.012***	0.004
	(0.005)	(0.067)	(0.004)	(0.047)	(0.002)	(0.013)
BOARD_SIZE	−3.400***	53.78***	−2.833***	−3.405*	−0.475***	−0.875
	(0.118)	(2.266)	(0.107)	(1.787)	(0.120)	(0.585)
CEO_DUALITY	−0.024***	0.315***	−0.037***	−0.117***	0.006***	−0.033***
	(0.003)	(0.019)	(0.003)	(0.025)	(0.002)	(0.008)
Firm characteristics						
SIZE	−0.030***	0.538***	−0.033***	0.022	0.006***	−0.003
	(0.002)	(0.021)	(0.001)	(0.022)	(0.001)	(0.006)
PROFITABIL-ITY	0.106***	1.436***	0.080***	0.313***	0.042***	0.229***
	(0.008)	(0.077)	(0.008)	(0.059)	(0.005)	(0.034)
GROWTH	0.004	0.041***	0.001	0.074***	−0.004**	0.072***
	(0.004)	(0.016)	(0.004)	(0.016)	(0.002)	(0.008)
CASH RATIO	0.008**	−0.134***	0.005*	−0.004	8.03e-05	−0.011
	(0.003)	(0.012)	(0.003)	(0.012)	(0.003)	(0.010)
LEVERAGE	−0.165***	2.558***	−0.175***	−0.405***	0.020**	−0.088**
	(0.016)	(0.130)	(0.015)	(0.126)	(0.009)	(0.043)
CAPEX_TA	0.017	0.199	−0.036	0.355**	0.013	0.051
	(0.029)	(0.137)	(0.026)	(0.148)	(0.015)	(0.089)
IO_TOTAL_HAT		14.07***				
		(0.638)				
IO_ACTIVE_ HAT				2.650***		
				(0.589)		
IO_PASSIVE_ HAT						3.382***
						(0.356)
Instrumental variables						
SP500_D	0.015***		0.031***		0.015***	
	(0.004)		(0.004)		(0.002)	

Table 2 (continued)

VARIABLES	Total Institutional Ownership		Active Institutional Ownership		Passive Institutional Ownership	
	(1)	(2)	(3)	(4)	(5)	(6)
	IO_TOTAL	RD_SALE	IO_ACTIVE	RD_SALE	IO_PASSIVE	RD_SALE
LNMKVALT	0.011***		0.003**		−0.012*	
	(0.002)		(0.002)		(0.001)	
Constant	0.611***	−8.251***	0.544***	2.529***	0.164***	0.099
	(0.030)	(0.435)	(0.028)	(0.371)	(0.017)	(0.113)
Industry effects	Yes	Yes	Yes	Yes	Yes	Yes
Observations	10,610	10,610	9916	9916	5871	5871
R-squared	0.194	0.253	0.201	0.223	0.107	0.216
F-Value	155.35***	123.33***	150.76***	97.72***	41.68***	55.53***
Hausman test of endogeneity	(1) IO_TOTAL_HAT = 0		(2) IO_ACTIVE_HAT = 0		(3) IO_PASSIVE_HAT = 0	
	F(1, 10,580) = 485.94 Prob > F = 0.000		F(1, 9886) = 20.25 Prob > F = 0.000		F(1, 5841) = 36.47 Prob > F = 0.000	

This table reports the results of the Hausman test for the endogenous problem of *INSTITUTION* variables in the firm innovation equation. *INSTITUTION* variables are instrumented by the Standard and Poor's 500 index dummy (*SP500_D*) and firm's market capitalization (*LNMKVALT)*. Columns (1), (3), and (5) show the results of the estimated model for *IO_TOTAL, IO_ACTIVE* and *IO_PASSIVE*, respectively using the above instrumental variables and all exogenous variables in Eq. (1)

$$INSTITUTION_{it} = \alpha_0 + \alpha_2 CONTROLSs_{it} + \alpha_3 INSTRUMENTS_{it} + \omega_{it.} \quad (2)$$

The residuals of *IO_TOTAL, IO_ACTIVE* and *IO_PASSIVE* equations are subsequently plugged one by one into the innovation Eq. (1) as the second stage of Hausman test

$$INNOVATION_{it} = \beta_0 + \beta_1 INSTITUTION_{it} + \beta_2 BOARD\,DIVERSITY_{it} + \beta_3 CONTROLSs_{it} + \boldsymbol{\beta_4 INSTITUTION\_HAT_{it}} + \epsilon_{it}.$$

Columns (2), (4), and (6) report the results that the residuals *IO_TOTAL_HAT*, *IO_ACTIVE_HAT* and *IO_PASSIVE_HAT* are statistically significant. See Appendix A for variable definitions. The standard errors of estimated coefficients are clustered by the firm and displayed in parentheses. Figures with * , **, and *** represent the statistical significance at the 10%, 5%, and 1% levels, respectively

IO_ACTIVE, and IO_PASIVE are endogenous in terms of their relationships with firm innovation, and thus 2SLS is necessary and is justified.

4 Empirical results

4.1 Descriptive statistics

Table 1 Panel A provides descriptive statistics for the full sample. We present the means, medians, standard deviations, Q25, and Q75, for key variables. The average firm has a R&D investment of 10.37% to total sales and 5.07% of total assets. The median of RD_SALES is 2.66%, demonstrating that US firms have spent much on R&D investment, and R&D varies widely across firms. Table 3 Panel A illustrates the R&D distribution showing that more than 20% of firms have no R&D expenditure, and few firms have high R&D ratio. Most of R&D distributions are less than 10%. Table 3 Panel B reports industry distribution. In terms of R&D to total sales, four sectors represent more

Table 3 Distribution of firm innovation, institutional ownerships, and board diversity

Panel A: R&D distribution[a]

	R& D/ total asset ratio		R& D/ total sales Ratio		R&D capital/total assets	
%	*N*	%	*N*	%	*N*	%
0	2955	21.78	2955	21.78	2047	21.99
0–1	1783	13.14	1588	11.71	921	9.89
1–2	1566	11.54	1351	9.96	1030	11.06
2–3	1320	9.73	1308	9.64	731	7.85
3–5	1427	10.52	1227	9.05	967	10.39
5–7	1028	7.58	940	6.93	622	6.68
7–10	1160	8.55	842	6.21	609	6.54
10+	1222	9.01	1147	8.46	902	9.69
15+	573	4.22	1072	7.90	564	6.06
20+	186	1.37	476	3.51	328	3.52
25+	169	1.25	212	1.56	190	2.04
30+	95	0.70	130	0.96	86	0.92
35+	24	0.18	67	0.49	65	0.70
40+	19	0.14	39	0.29	54	0.58
45+	12	0.09	20	0.15	31	0.33
50+	3	0.02	19	0.14	21	0.23
55+	4	0.03	12	0.09	22	0.24
60+	7	0.05	13	0.10	11	0.12
65+	3	0.02	9	0.07	4	0.04
70+	2	0.01	12	0.09	10	0.11
75+	2	0.01	7	0.05	9	0.10
80+	0	0.00	9	0.07	4	0.04

Table 3 (continued)

Panel A: R&D distribution[a]

	R& D/ total asset ratio		R& D/ total sales Ratio		R&D capital/total assets	
%	*N*	%	*N*	%	*N*	%
85+	0	0.00	0	0.00	5	0.05
90+	2	0.01	6	0.04	6	0.06
95+	0	0.00	7	0.05	5	0.05
100+	3	0.02	97	0.72	66	0.71
Total	13,565	100	13,565	100	9310	100

Panel B: firm innovation and institutional ownerships across industries

Industries	N	RD_TA	RD_SALE	LN(1+PATENTS)	IE	IO_TOTAL[b]	IO_ACTIVE	IO_PASSIVE
Agriculture	47	0.0718	0.1040	5.6356	2.5216	0.7015	0.5285	0.2058
Chemicals	717	0.0252	0.0278	4.1283	2.0043	0.7015	0.5107	0.2217
Computers	2840	0.0975	0.2676	3.5410	0.7998	0.7258	0.5633	0.1782
Durable Manufacturers	4505	0.0481	0.0681	3.1304	1.0973	0.7223	0.5595	0.1957
Extractive Industries	798	0.0145	0.0147	3.2785	1.6095	0.7497	0.5633	0.2041
Food	692	0.0095	0.0094	2.5943	0.7013	0.5584	0.4208	0.2098
Mining and Construction	472	0.0043	0.0039	2.2201	4.0134	0.7418	0.5746	0.1942
Pharmaceuticals	625	0.1355	0.6209	4.4394	1.1793	0.7140	0.5302	0.2021
Retail	2325	0.0016	0.0042	1.6179	0.6801	0.7387	0.5799	0.1911
Services	1555	0.0164	0.0223	1.8089	1.1994	0.7523	0.5945	0.1804
Textiles and Printing	1212	0.0158	0.0135	2.6050	1.3633	0.6749	0.5224	0.2141

Table 3 (continued)

Panel B: firm innovation and institutional ownerships across industries

Industries	N	RD_TA	RD_SALE	LN(1 + PATENTS)	IE	IO_TOTAL[b]	IO_ACTIVE	IO_PASSIVE
Transportation	1039	0.0194	0.4091	2.9907	1.1427	0.6735	0.5211	0.1790
Utilities	1221	0.0021	0.0069	1.2548	0.4615	0.5665	0.3921	0.1764
Other	60	0.0326	0.0247	4.8889	0.9438	0.5442	0.4094	0.1782
Total	13,565	0.0507	0.1037	3.4328	1.1305	0.7079	0.5418	0.1955

Panel C: firm innovation and institutional ownerships across years

YEAR	RD_TA	RD_SALE	LN(1 + PATENTS)	IE	IO_TOTAL	IO_ACTIVE	IO_PASSIVE
1998	0.0597	0.0871	3.7225	0.8500	0.5724	0.4344	0.2047
1999	0.0560	0.3668	2.0513	0.8760	0.5598	0.4200	0.1872
2000	0.0554	0.1685	2.2711	1.1437	0.5777	0.4431	0.1869
2001	0.0661	0.2855	1.7847	1.2038	0.5951	0.4640	0.1832
2002	0.0578	0.1207	2.0842	1.2121	0.6623	0.4947	0.1972
2003	0.0476	0.0819	2.1897	1.1663	0.6650	0.4994	0.1638
2004	0.0454	0.0708	3.6135	1.4396	0.7547	0.5595	0.2111
2005	0.0463	0.0681	0.5925	1.4636	0.7735	0.5556	0.2071
2006	0.0468	0.0794	2.0097	1.3579	0.8031	0.5787	0.2277
2007	0.0456	0.0775	2.5655	1.4482	0.8251	0.5979	0.2134
2008	0.0520	0.1020	2.5579	1.6695	0.7957	0.5893	0.2290
2009	0.0464	0.1032	2.6422	1.6126	0.8025	0.6824	0.1691
2010	0.0446	0.0798	2.8429	1.4115	0.7974	0.6302	0.1489
2011	0.0448	0.0663	2.8818	1.5416	0.7886	0.6358	0.1427
2012	0.0455	0.0673	2.9927	1.4649	0.7787	0.6107	0.1565
2013	0.0445	0.0708	3.0676	1.6098	0.7060	0.5636	0.2076
2014	0.0440	0.0674			0.6551		

Table 3 (continued)

Panel C: firm innovation and institutional ownerships across years

YEAR	RD_TA	RD_SALE	LN(1 + PATENTS)	IE	IO_TOTAL	IO_ACTIVE	IO_PASSIVE
Total	0.0507	0.1037	3.4328	1.1305	0.7079	0.5418	0.1955

Panel D: comparison T-test for institutional ownerships among R& D/total sales[c]

RD_SALE	IO_TOTAL	IO_ACTIVE				IO_PASSIVE				
		TOTAL	IO_INVEST-EST	IO_INDE PEND	IO_PPF	TOTAL	IO_BANK	IO_INSUR-ANCE	IO_CPF	IO_UFE
Q1(< 25%)	0.7330	0.5831	0.1300	0.4125	0.0287	0.1934	0.1268	0.0402	0.0075	0.0018
Q2 (25%–50%)	0.6784	0.5087	0.1129	0.3584	0.0299	0.2085	0.1381	0.0432	0.0048	0.0023
Q3 (50%–75%)	0.7098	0.5382	0.1186	0.3852	0.0303	0.2028	0.1322	0.0430	0.0053	0.0028
Q4 (> 75%)	0.6593	0.5041	0.1117	0.3562	0.0284	0.1896	0.1242	0.0416	0.0053	0.0019
Total	0.7079	0.5418	0.1152	0.3678	0.0588	0.1955	0.1275	0.0604	0.0055	0.0021
T-test (Q4-Q1)	16.9759***	19.8805***	12.7153***	14.8969***	0.8832	1.0954	1.1592	−1.0095	4.4785***	−1.0366

Panel E: Comparison t-test for Institutional Ownerships among R& D/Total Assets

RD_TA	IO_TOTAL	IO_ACTIVE				IO_PASSIVE				
		TOTAL	IO_INVEST-EST	IO_INDE-PEND	IO_PPF	TOTAL	IO_BANK	IO_INSUR-ANCE	IO_CPF	IO_UFE
Q1(< 25%)	0.7324	0.5830	0.1300	0.4124	0.0286	0.1935	0.1268	0.0403	0.0075	0.0018
Q2 (25%–50%)	0.6906	0.5179	0.1161	0.3660	0.0298	0.2077	0.1379	0.0430	0.0049	0.0022
Q3 (50%–75%)	0.7084	0.5376	0.1199	0.3821	0.0305	0.2016	0.1325	0.0431	0.0050	0.0026
Q4 (> 75%)	0.6570	0.5022	0.1108	0.3552	0.0285	0.1901	0.1242	0.0416	0.0053	0.0020
Total	0.7079	0.5418	0.1152	0.3678	0.0588	0.1955	0.1275	0.0604	0.0055	0.0021
T-test (Q4-Q1)	17.3984***	20.4080***	13.4653***	4.4711***	0.4486	0.9739	1.1327	−0.9291	4.4711***	−1.3247

Table 3 (continued)

[a]This table presents the distribution of main variables using a sample of US public firms from 1998 to 2014. Panel A reports innovation input distribution for the full sample. Panel B reports firm innovation and percentage of institutional ownership across industries, in which finance industries are excluded from the sample. Panel C shows the change in innovation and institutional ownership variables over time. Panels D and E present the comparison t-test for institutional ownerships among R& D/ total sales and R& D/ total assets. All variables are defined in Appendix A.

[b]The value of total institutional ownerships is smaller than the total of passive plus active institutional ownerships because they are obtained from different databases. The total institutional ownership data are obtained from Thomson Reuters Institutional (13f) Holdings-Stock Ownership Summary database; whereas Institutional Investor Classification Data are obtained from Thomson Reuters-S34 Master File on the WRDS website. The two ownership databases are related, but the levels of coverage differ slightly. The S34 Master File data source is the actual 13F Form filed with the SEC on a quarterly basis by institutional money managers. These data are aggregated to a managerial level (ID key = MGRNO), whereas the Stock Ownership Summary data show the total institutional ownerships at the firm level.

[c]RD_SALE is the ratio of R&D expenditure to the book value of total sales. RD_TA is the ratio of R&D expenditure to the book value of total assets. IO_TOTAL, IO_ACTIVE, and IO_PASSIVE are the percentages of shares owned by the total institutional investors, both active and passive. IO_INVESTEST, IO_INDEPEND, and IO_PPF are ratios of total shares owned by investment companies, independent investment advisors, and public pension funds scaled by the total shares outstanding, respectively. IO_BANK, IO_INSURANCE, IO_CPF, and IO_UFE are ratios of total shares owned by banks, insurance companies, private pension funds, and others scaled by the total shares outstanding, respectively. Figures with * represent the statistical significance at the 1% levels.

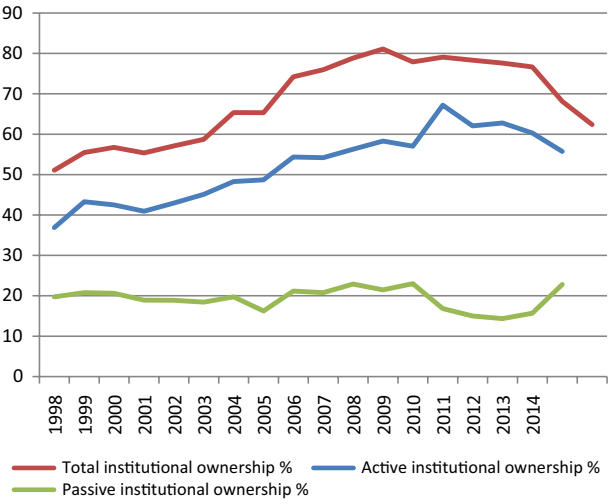

Fig. 1 Institutional ownerships over years, 1998–2014

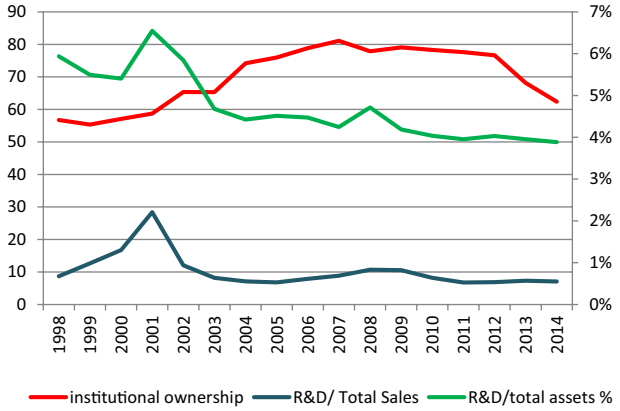

Fig. 2 R&D and institutional ownerships over years, 1998–2014

than 10.37%: agriculture, computers, durable manufacturers, and pharmaceuticals. These industries also have high ratio of R&D to total assets.

The interesting aspect of institutional ownership is that on average, 70% of firm equity is held by institutional investors. Six industries that have high proportion of institutional ownership are computers, extractive, mining and construction, retail, and services. Active and passive institutional investors hold 54% and 19% of the equity, respectively. These results show that this sample firm has high institutional ownership and most firms are active investors. These results further confirm the important role of institutional investors in financing the capital for US firms, as shown in existing literature. Table 2 Panel C shows the time distribution result, which is in line with our prediction, that institutional ownership (both active and passive ones) is higher after the Sarbanes–Oxley Act in 2002. In particular, the mean of institutional ownership before 2002 is about 58% compared with 65% after 2002. The time trend of R&D investment

and institutional ownerships during the sample period are illustrated in Figs. 1 and 2, respectively.

Moreover, the results show that the board size of average firms is 9.29 with about 10% of female directors. The average firm has 14% ethnic minority (African-American, Hispanic, and Asian) in its board and 20% are in the audit committee board. The percentage of independent directors for the median firm is about 70% and 67% of CEOs serve as board chairs. The average firm size (LNTA) is 7.358, which indicates that most firms have huge amounts of assets. ROA of the median firm is 3.32%. The average cash ratio is 0.095 and growth opportunities is 0.1104 with a few firms having negative or extremely high growth rate. Other control variables are displayed in Table 1 Panel A.

Table 1 Panel B presents the Pearson correlation coefficients for board diversity, board characteristic, and firm characteristic variables. Correlations among the internal governance characteristics and firm characteristics are low. This evidence suggests that each board and firm characteristic variable is potentially a candidate for inclusion in board diversity variables as a stand-alone element, rather than merely being highly correlated with other board and firm characteristic variables. We will check this relationship more carefully by running regressions.

4.2 Two-stage least squares (2SLS) regression results

We use the 2SLS regression to examine the relationship among institutional ownerships, board diversity, and corporate innovation using R&D expenditures to sales ratio (RD_SALE) as the dependent variable. Table 4 presents three regressions with different measures of institutional ownerships. Column (1) shows that total institutional ownership (IO_TOTAL) is positively associated with R&D intensity in the sample firms. In Columns (2) and (3), we split institutional investors into active and passive institutional investors (IO_ACTIVE and IO_PASSIVE). We find that active institutional ownership fosters firm-level innovation as measured by the R&D to sales ratio, unlike passive institutional ownership.

In particular, the coefficient of IO_TOTAL is statistically significant at 1% level with a coefficient of 0.325. This value represents one standard deviation (0.1994) increase in total institutional ownership, which increases the magnitude of R&D investment by 0.625% [=0.1994*0.325/0.1037] from the average R&D investment level of 10.37%. Similarly, the coefficient for IO_ACTIVE in Column (2) is 0.437, which is statistically significant. Economically, an increase of active institutional ownership increases the R&D investment ratio by 0.7674% [=0.1821*0.437/0.1037] from its mean value. These results are consistent with the prediction that institution investors in general and active institutional investors in particular, have the power to influence the allocation of scarce resources for innovation investment and monitor the way investments are utilized. With their strong information-processing capacity and large shareholdings, the more active institution ownership a corporate has, the higher the amount of their innovation investment. Our result is in line with the findings of Bushee (1998) and Choi et al. (2011), which confirm that institutional ownership positively fosters firm innovation input. One implication is that active institutional investors are sophisticated investors who have effective monitoring roles and motivate top managers to create a force that encourages sound innovation investment.

Column (3) Table 4 reports the 2SLS regressions of firm innovation regarding the percentage of passive institutional ownership (IO_PASSIVE). A pronounced difference exists between the effect for active and passive investors. The coefficient of IO_PASSIVE is -0.111 and statistically insignificant, suggesting that passive institutional

Table 4 Institutional ownerships, board diversity, and firm innovation

VARIABLES	(1) RD_SALE	(2) RD_SALE	(3) RD_SALE
Institutional ownerships			
IO_TOTAL	0.325***		
	(0.077)		
IO_ACTIVE		0.473*	
		(0.097)	
IO_PASSIVE			−0.111
			(0.119)
Board diversity			
AUDITING	0.185**	0.189**	0.052*
	(0.080)	(0.084)	(0.048)
ETHNIC_MINORITY	0.232***	0.243***	0.114***
	(0.064)	(0.070)	(0.039)
FEMALE	0.028**	0.029*	0.018**
	(0.014)	(0.016)	(0.008)
Board characteristics			
BOARD_INDEPEND	0.041*	0.070***	0.037***
	(0.021)	(0.022)	(0.011)
BOARD_SIZE	5.645***	4.874***	−2.602***
	(0.529)	(0.562)	(0.518)
CEO_DUALITY	−0.010	−0.012	−0.013*
	(0.012)	(0.013)	(0.007)
Firm characteristics			
SIZE	0.114***	0.117***	0.018***
	(0.009)	(0.010)	(0.005)
PROFITABILITY	0.069**	0.092**	0.085***
	(0.035)	(0.036)	(0.025)
FIRM GROWTH	0.068***	0.070***	0.059***
	(0.015)	(0.016)	(0.008)
CASH RATIO	−0.021*	−0.019*	−0.010
	(0.011)	(0.012)	(0.010)
LEVERAGE	0.103	0.080	−0.020
	(0.068)	(0.072)	(0.041)
CAPEX_TA	0.506***	0.473***	0.100
	(0.140)	(0.147)	(0.089)
Constant	0.727***	0.905***	0.615***
	(0.145)	(0.158)	(0.078)
Industry effects	Yes	Yes	Yes
Observations	10,610	9916	5871
R-squared	0.235	0.239	0.277
F-value	105.28***	100.23***	55.86***

This table reports the two-stage least squares regressions of firm innovation on institutional ownership and board diversity, where the ratio of R&D expenditure to total sales (RD_SALE) is a dependent variable

$$INNOVATION_{it} = \beta_0 + \beta_1 INSTITUTION_{it} + \beta_2 BOARD\ DIVERSITY_{it} + \beta_3 CONTROLS_{it} + \varepsilon_{it}, \quad (1)$$

Table 4 (continued)

where institutional ownerships (*INSTITUTION*) variables are treated as endogenous variables and instrumented by the Standard and Poor's 500 index dummy (*SP500_D*) and firm's market capitalization (*LNMKVALT)*. The results of the first stages are shown in Table 2

$$INSTITUTION_{it} = \alpha_0 + \alpha_2 CONTROLSs_{it} + \alpha_3 INSTRUMENTS_{it} + \omega_{it.} \quad (2)$$

In this table, Column (1) repsorts the second stage of the 2SLS estimation results of firm innovation on total institutional ownerships in the firm (*IO_TOTAL*) and board diversity. Column (2) reports the second-stage 2SLS results of firm innovation on active institutional investors (*IO_ACTIVE*) and board diversity. Following Bushee et al. (2010) and Bushee (1998), we separate institutional investors into active and passive investors. Active institutional investors are investment companies, independent investment advisors, and public pension funds. Passive institutional investors are insurance companies, private pension funds, and others. Column (3) report the results of firm innovation on passive institutions (*IO_PASSIVE*). All regressions include a full set of controls as described in Appendix A. The standard errors of estimated coefficients are clustered by firm and displayed in parentheses. Figures with *, **, and *** represent the statistical significance at the 10%, 5%, and 1% levels, respectively

ownership is unimportant in explaining firm innovation investment. Therefore, we conclude that the positive relation between institutional ownership and innovation is mainly driven by active institutional investors.

Moreover, we find that the coefficients of our board diversity proxies (AUDITING, ETHNIC_MINORITY, and FEMALE) are significantly positive, regardless of which institutional ownership variable is included. This finding also implies that better audit quality, higher proportion ethnic minority directors, and a female appointment to the board all result in improving board monitoring and advising, with added willingness for risk-taking investment and positive effect on innovation investment. Specifically, the magnitudes of these effects in Column (1) are as follows: 0.185 indicates that one standard deviation (0.0748) increase in audit quality leads to a 0.1334% [=0.0748*0.185/ 0.1037] increase in R&D investment; 0.232 represents that an increase in standard deviation (0.0888) of the proportion of ethnic minority directors would increase innovation investment by 0.1986% [=0.0888*0.232/ 0.1037]. Similarily, the coefficient of FEMALE is 0.028, indicating that a female appointment to the board increases R&D investment by 0.27% (=0.028/ 0.1037) for business in the sample.

These results confirm the role of internal auditors in assisting audit committees in the corporate governance process (Raghunandan et al., 2001). We also control for a comprehensive set of board and firm characteristics probably affecting firm innovation. Whichever institutional ownership variable we use, control variables show signs as expected on the innovation investment, except for CASHRATIO. Evidently, larger firms, high growth opportunity firms, firms with more operating profits, and companies with a higher number of independent directors on the board are more innovative. These findings are consistent with those in existing literature (Czarnitzki & Kraft, 2009; Fang et al., 2014; Tseng et al., 2013). The overall F-statistic value in all models has a p-value of less than 0.001, indicating that the models have statistically significant explanatory power.

4.3 Robustness checks

4.3.1 The role of banker on the board

In this section, we consider an alternative measure of qualification diversity: banker appointment (BANKING_COMMIT) on the board. We use BANKING_COMMIT as a dummy variable, which equals to 1 if a firm has at least one banker on board providing professional banking services, or 0 otherwise. As noted by Kroszner and Strahan (2001), over 30% of the largest US firms have bankers on their boards. Given the potential link between a banker on the board and solid innovation investment, we examine the benefits of bank monitoring in firm management for innovation by adding banker appointment dummy into Eq. (1). We also add an interaction between INSTITUTION and BANKING_COMMIT to capture the incremental effect of firm innovation investment response of the banker appointment to its institutional ownership. We estimate the following equation:

$$\begin{aligned} INNOVATION_{it} =& \beta_0 + \beta_1 INSTITUTION_{it} + \beta_2 INSTITUTION_{it} \times BANKING\_COMMIT_{it} \\ &+ \beta_3 BANKING\_COMMIT_{it} + \beta_4 BOARD\ DIVERSITY_{it} + \beta_5 CONTROLS_{it} + \varepsilon_{it}. \end{aligned} \tag{3}$$

Table 5 reports the results of the 2SLS in Eq. (3). The results indicate a positive relationship between active institutional ownerships and R&D investment, whereas such relationship is negative for the passive ones, thereby confirming our earlier results. The key coefficient corresponding to interaction terms (β_2) are positive, suggesting that the effects of institutional ownerships are more pronounced when firms have a banker on the board. Table 6 reports the estimation summary to compare the effect of active and passive institutional ownerships between firms with a banker and firms with a non-banker on the board. The result highlights that active institutional ownerships have tangible positive effects on firm innovation, even when firms have no banker on the board. For passive institutional ownership, the result is a negative effect on innovation investment but a positive influence once firms have a banker on the board.

The coefficients for IO_PASIVE and IO_PASIVE×BANKING_COMMIT are -0.301 and 0.418, respectively, and both are significant at the 1% level. Regarding economic magnitude, one standard deviation (0.0731) increase in passive institutional ownership reduces the magnitude of R&D investment by 0.212% [=0.0731*-0.301/ 0.1037] from the average R&D investment level of 10.37%. However, one standard deviation (0.0731) increase in passive institutional ownership increases R&D investment by 0.082% [=0.0731*(0.418—0.301)/ 0.1037] for firms with a banker on the board. This evidence indicates that a banker on the board can change the impact of passive institutional ownership on innovation investment from negative to positive.

Our findings align with Byrd and Mizruchi's (2005) idea, indicating that when bankers serve as providers of professional services, their expertise regarding capital markets can be precious. With a banker on the board, firms could easily borrow funds from the banks with lower spreads or better non-price loan terms (Francis et al. 2012). Moreover, facing a profitable investment, bankers could foster innovation investment through equity finance for these innovative projects.

Table 5 Institutional ownership and banker on the board

VARIABLES	(1) RD_SALE	(2) RD_SALE	(3) RD_SALE
Institutional ownerships			
IO_TOTAL	0.305***		
	(0.077)		
IO_TOTAL × BANKING_COMMIT	0.004		
	(0.050)		
IO_ACTIVE		0.442**	
		(0.097)	
IO_ACTIVE × BANKING_COMMIT		0.028	
		(0.070)	
IO_PASSIVE			−0.301***
			(0.052)
IO_PASSIVE × BANKING_COMMIT			0.418***
			(0.043)
BANKING_COMMIT	−0.080***	−0.087***	−0.319***
	(0.022)	(0.023)	(0.091)
Board diversity			
AUDITING	0.195***	0.104***	0.256***
	(0.097)	(0.102)	(0.165)
ETHNIC_MINORITY	0.228***	0.240***	0.143
	(0.064)	(0.069)	(0.097)
FEMALE	0.029**	0.030**	0.045**
	(0.014)	(0.014)	(0.021)
Board characteristics			
BOARD_INDEPEND	0.045**	0.075***	0.076***
	(0.021)	(0.022)	(0.029)
BOARD_SIZE	5.595***	4.800***	0.341
	(0.527)	(0.560)	(1.443)
CEO_DUALITY	−0.009	−0.013	0.019
	(0.012)	(0.013)	(0.020)
Firm characteristics			
SIZE	0.115***	0.118***	−0.013
	(0.009)	(0.010)	(0.015)
PROFITABILITY	0.070**	0.093***	−0.128**
	(0.035)	(0.036)	(0.063)
GROWTH	0.068***	0.070***	0.085***
	(0.015)	(0.016)	(0.019)
CASH RATIO	−0.021*	−0.019	−0.009
	(0.011)	(0.012)	(0.024)
LEVERAGE	0.106	0.081	0.119
	(0.068)	(0.072)	(0.108)
CAPEX_TA	0.494***	0.456***	0.377
	(0.140)	(0.147)	(0.231)

Table 5 (continued)

VARIABLES	(1) RD_SALE	(2) RD_SALE	(3) RD_SALE
Constant	0.732***	0.910***	0.696***
	(0.144)	(0.158)	(0.196)
Industry effects	Yes	Yes	Yes
Observations	10,610	9916	5871
R-squared	0.237	0.241	0.225
F-value	98.97	94.24	19.16

This table reports the 2SLS regressions of firm innovation on institutional ownership and board diversity, where the ratio of R&D expenditure to total sales (RD_SALE) is a dependent variable
$INNOVATION_{it} = \beta_0 + \beta_1 INSTITUTION_{it} + \beta_2 INSTITUTION_{it} \times BANKING\_COMMIT_{it} + \beta_3 BANKING\_COMMIT_{it}$
$+\beta_4 BOARD\ DIVERSITY_{it} + \beta_5 CONTROLS_{it} + \varepsilon_{it.}$(3)
The interaction term *INSTITUTION*BANKING_COMMIT* captures the differential of firm innovation investment response of a banker appointment on the board to its institutional ownership. *BANKING_COMMIT* is a dummy variable, which equals to 1 if a firm has at least one banker on board providing professional banking services, 0 otherwise. See Appendix A for the variable definitions. The standard errors of estimated coefficients are clustered by the firm and displayed in parentheses. *, **, and *** represent the statistical significance at the 10%, 5%, and 1% levels, respectively

Table 6 Estimation summary of banker on the board

VARIABLES	RD_SALE		
	WITHOUT BANKING_COMMIT	BANKING_COMMIT	DIFFERENCE
IO_TOTAL	0.305	0.309 *(=0.305+0.004)*	0.004
IO_ACTIVE	0.442	0.470 *(=0.442+0.028)*	0.028
IO_PASSIVE	-0.301	0.117 *(=-0.301+0.418)*	0.418***

This table reports the estimation summary for a comparison between firms with a banker on the board and firms without bankers on the board group in Table 5. The model is presented as the following equation:
$INNOVATION_{it} = \beta_0 + \beta_1 INSTITUTION_{it} + \beta_2 INSTITUTION_{it} \times BANKING\_COMMIT_{it}$
$+\beta_3 BANKING\_COMMIT_{it} + \beta_4 BOARD\ DIVERSITY_{it} + \beta_5 CONTROLS_{it} + \varepsilon_{it}$ (3) *BANKING_COMMIT* is a dummy variable, which equals to 1 if a firm has at least one banker on board providing professional banking services, 0 otherwise. Figures with *, **, and *** represent the statistical significance at the 10%, 5%, and 1% levels, respectively

4.3.2 Alternative measures of innovation

We also explore whether our findings are robust to an alternative measure of innovation. We consider two other alternative measures of firm innovation: innovation output and innovative efficiency for this check. Innovation output was measured by the natural logarithm of 1 plus the number of granted patents [LN (1 + PATENTS)], whereas the innovative efficiency (IE) in year t measures the patents granted in year t scaled by the R&D capitalization over the years t-2 to t-6. Results in Table 7 show that institutional ownership- and board diversity-related variables remain robust except AUDITING. The significance and signs are similar compared to the prior results. In particular, the IO_TOTAL coefficients

Table 7 Alternative measures of innovation

	Innovation output		Innovative efficiency			
	(1)	(2)	(3)	(5)	(6)	(7)
VARIABLES	LN(1 + PATENT)	LN(1 + PATENT)	LN(1 + PATENT)	IE	IE	IE
Institutional ownerships						
IO_TOTAL	0.313***			1.121***		
	(0.001)			(0.003)		
IO_TOTAL × BANKING_COMMIT	−0.0721***			−0.380***		
	(0.000)			(0.007)		
IO_ACTIVE		0.274***			1.150***	
		(0.017)			(0.003)	
IO_ACTIVE × BANKING_COMMIT		−0.015			−0.604***	
		(0.031)			(0.009)	
IO_PASSIVE			−0.835***			−0.690***
			(0.001)			(0.014)
IO_PASSIVE × BANKING_COMMIT			−0.696***			−0.140***
			(0.002)			(0.041)
BANKING_COMMIT	−0.069***	−0.006	−0.077***	0.026***	0.036***	0.864***
	(0.000)	(0.015)	(0.001)	(0.004)	(0.004)	(0.011)
Board diversity						
AUDITING	−0.274***	−0.017	−0.306***	−0.854***	−0.871***	−3.808***
	(0.001)	(0.059)	(0.001)	(0.010)	(0.010)	(0.023)
ETHNIC_MINORITY	0.509***	0.083**	0.535***	0.887***	0.908***	0.743***
	(0.000)	(0.035)	(0.001)	(0.007)	(0.007)	(0.012)
FEMALE	0.286***	−0.019	0.300***	0.302***	0.281***	0.235***
	(0.001)	(0.032)	(0.001)	(0.007)	(0.007)	(0.011)

Table 7 (continued)

	Innovation output		Innovative efficiency			
	(1)	(2)	(3)	(5)	(6)	(7)
VARIABLES	LN(1 + PATENT)	LN(1 + PATENT)	LN(1 + PATENT)	IE	IE	IE
Board characteristics						
BOARD_INDEPEND	0.035***	0.005	0.079***	0.193***	0.192***	0.371***
	(0.001)	(0.009)	(0.001)	(0.002)	(0.002)	(0.003)
BOARD_SIZE	0.117***	0.325	1.245***	14.00***	13.90***	40.35***
	(0.004)	(0.285)	(0.009)	(0.031)	(0.031)	(0.084)
CEO_DUALITY	−0.115***	−0.006	−0.123***	−0.176***	−0.177***	−0.268***
	(0.001)	(0.006)	(0.001)	(0.001)	(0.001)	(0.002)
Firm characteristics						
SIZE	−0.042***	−0.012***	−0.050***	0.117***	0.118***	0.152***
	(0.001)	(0.003)	(0.001)	(0.001)	(0.001)	(0.002)
PROFITABILITY	0.045***	0.033	0.177***	1.548***	1.550***	1.031***
	(0.0003)	(0.021)	(0.001)	(0.004)	(0.004)	(0.008)
GROWTH	−0.0359***	−0.002	−0.027***	−0.502***	−0.501***	−0.117***
	(0.0001)	(0.010)	(0.001)	(0.002)	(0.002)	(0.004)
CASH RATIO	−0.00895***	0.001	0.007***	−0.016***	−0.014***	0.0345***
	(0.0001)	(0.007)	(0.001)	(0.001)	(0.001)	(0.002)
LEVERAGE	−0.302***	−0.022	−0.284***	−1.355***	−1.406***	−1.292***
	(0.0005)	(0.037)	(0.001)	(0.009)	(0.009)	(0.013)
CAPEX_TA	0.523***	0.132**	−0.520***	4.642***	4.631***	6.586***
	(0.0007)	(0.055)	(0.001)	(0.013)	(0.013)	(0.019)
Industry effects	Yes	Yes	Yes	Yes	Yes	Yes
Observations	10,610	9,916	5,871	10,600	9,906	5,865

Table 7 (continued)

	Innovation output		Innovative efficiency			
	(1)	(2)	(3)	(5)	(6)	(7)
VARIABLES	LN(1 + PATENT)	LN(1 + PATENT)	LN(1 + PATENT)	IE	IE	IE
R-squared	0.677	0.786	0.879	0.182	0.185	0.329
F-value	42.00***	60.43***	65.66***	41.33***	53.99***	58.42***

This table reports the Poisson estimation results of firm innovation on institutional ownership and board diversity, where the logarithm of one plus the number of patents LN(1 + PATENTS) and innovative efficiency (IE) are used as the dependent variables

$$INNOVATION_{it} = \beta_0 + \beta_1 INSTITUTION_{it} + \beta_2 INSTITUTION_{it} \times BANKING\_COMMIT_{it} + \beta_3 BANKING\_COMMIT_{it} + \beta_4 BOARD\,DIVERSITY_{it} + \beta_5 CONTROLS_{it} + \varepsilon_{it.} (3)$$

The innovative efficiency in year t is measured as patents granted in year t scaled by the R&D capitalization in year t-2 to t-6. Following the definitions of Hirshleifer et al. (2013), the formulas of IE are specified as below

$IE_{i,t} = \frac{Number of Patent_{i,t}}{(RD_{i,t-2} + 0.8xRD_{i,t-3} + 0.6xRD_{i,t-4} + 0.4xRD_{i,t-5} + 0.2xRD_{it-6})}$ $RD_{it\text{-}1}$ denotes firm's R&D expenditure in fiscal year ending in year t-1, and so on. Definitions of all the other variables are reported in Appendix A. The standard errors of estimated coefficients are clustered by firm and displayed in parentheses. *, **, and *** represent the statistical significance at the 10%, 5%, and 1% levels, respectively

are 2.28 and 1.169 on innovation output and innovative efficiency, respectively. The magnitudes of these effects are economically significant, indicating that one unit increase in the standard deviation of institutional ownership (0.1994) leads to a rise of 12.01% in the mean of the number of granted patents and 0.206% [=0.1994*1.12169/ 1.1305] in the average of innovative efficiency (1.1305). Similarly, the coefficient on IO_ACTIVE is 1.15 for innovative efficiency, suggesting that one standard deviation increase in active institutional ownership (0.1821) creates a 0.203% [=0.1821*1.150/ 1.1305] increase in innovative efficiency from its mean value. Furthermore, the coefficients of IO_PASSIVE are -0.835 in the innovation output equation and − 0.690 in the innovative efficiency equation; both are statistically significant. This finding verifies that passive institutional ownership has a negative impact on both innovation output and a firm's innovative efficiency. Our analysis indicates that institutional investor is an important determinant of corporate innovation, and active institutional investors mainly drive this relation.

Evidently, board diversity positively correlates with firm innovation, confirming our earlier results. Besides, nearly all the significance and signs remain except the AUDITING where a negative effect on innovation output appears. Similarly, while bank provides resources and expertise to firms to foster innovation, it motivates innovation expenditure rather than innovation outputs in the same period because patent outputs take a long time to invent. Table 5 Column (3) shows that the coefficient of the interaction between the bank and passive institutional ownership on R&D is positive and significant, with a magnitude of 0.418; however, it is negative on patents. Furthermore, we note that the coefficients of other control variables are highly stable.

4.3.3 The effect of the Sarbanes–Oxley Act 2002

Previous studies indicate that the highly innovative firms face difficulties in attracting equity capital, especially institutional investment (Bushee 1998; Graves and Waddock 1990). One of the main reasons is the high level of information asymmetry between managers and investors, which translates into high monitoring costs for outside shareholders (Jensen and Meckling 1976). The Sarbanes–Oxley Act was strongly believed to generate improvements in terms of financial disclosure and quality of information (Engel et al. 2007). Thus, we examine whether the enactment of SOX Act in 2002 has an effect on the relationship between the institutional ownership and firm innovation investment. Accordingly, we employ the multivariate difference-in-differences (DID) analysis with the 5-year window centered on the event year.

An SOX2002 is a dummy variable, which equals 1 if the year is after 2002; and 0 otherwise. We must first identify a control group unaffected by SOX2002. Despite the mandatory implementation of the SOX Act, the Securities and Exchange Commission allowed small firms (market values of equity under US$75 million) to have more time to comply with the Act (Zhang et al. 2007). On the contrary, the treatment group is an accelerated filer, which includes companies having the market value of equity higher than US$75 million. We create a dummy variable (ACCELERATED_FILER), which equals to 1 if a firm is an accelerated filer; and 0 otherwise. We add the interaction terms to Eq. (1), which estimates the following equation:

Table 8 Evidence from a Quasi-Experiment: The SOX Act Impact

Panel A: difference-in-differences regression results[a]			
	(1)	(3)	(4)
VARIABLES	RD_SALE	RD_SALE	RD_SALE
Institutional ownerships			
IO_TOTAL	0.516***		
	(0.152)		
IO_ACTIVE		0.628***	
		(0.140)	
IO_PASSIVE			−1.031*
			(0.139)
Interaction terms			
IO_TOTAL × SOX2002	−0.265***		
	(0.136)		
IO_TOTAL × ACCELERATED_FILER	−0.327***		
	(0.149)		
IO_TOTAL × SOX2002 × ACCELERATED_FILER	0.562***		
	(0.132)		
IO_ACTIVE × SOX2002		−0.319***	
		(0.105)	
IO_ACTIVE × ACCELERATED_FILER		−0.282***	
		(0.052)	
IO_ACTIVE × SOX2002 × ACCELERATED_FILER		0.485***	
		(0.104)	
IO_PASSIVE × SOX2002			0.125**
			(0.048)
IO_PASSIVE × ACCELERATED_FILER			0.427*
			(0.096)
IO_PASSIVE × SOX2002 × ACCELERATED_FILER			0.553***
			(0.125)
SOX2002	1.342***	1.156***	2.126***
	(0.430)	(0.590)	(0.430)
ACCELERATED_FILER	1.591***	1.093***	3.320*
	(0.999)	(1.748)	(0.155)
Board diversity			
AUDITING	0.052***	0.506*	0.064**
	(0.021)	(0.164)	(0.078)
ETHNIC_MINORITY	0.279**	0.079*	0.181**
	(0.022)	(0.462)	(0.079)
FEMALE	0.021*	0.013*	0.038**
	(0.011)	(0.070)	(0.017)
Board characteristics			
BOARD_INDEPEND	0.070*	0.002*	0.038*
	(0.070)	(0.090)	(0.020)
BOARD_SIZE	5.550***	5.226***	1.399***
	(1.788)	(2.486)	(1.143)

Table 8 (continued)

Panel A: difference-in-differences regression results[a]

	(1)	(3)	(4)
VARIABLES	RD_SALE	RD_SALE	RD_SALE
CEO_DUALITY	−0.030	−0.112	−0.008
	(0.052)	(0.075)	(0.015)
Firm characteristics			
SIZE	0.201***	0.201***	0.035***
	(0.037)	(0.051)	(0.011)
PROFITABILITY	0.159	0.189	0.073*
	(0.107)	(0.146)	(0.038)
GROWTH	0.041*	0.044*	0.058***
	(0.048)	(0.066)	(0.012)
CASH RATIO	−0.006	−0.012	−0.014
	(0.037)	(0.050)	(0.015)
LEVERAGE	1.206***	1.333***	−0.119
	(0.313)	(0.430)	(0.089)
CAPEX_TA	0.156	0.298	0.156
	(0.488)	(0.663)	(0.180)
Constant	0.391***	0.085***	0.246*
	(0.064)	(0.886)	(0.612)
Industry effects	Yes	Yes	Yes
Observations	5,967	5,893	3,829
R-squared	0.452	0.240	0.239
F-value	20.37***	25.66***	40.48***
Clean effect ($\beta_1+\beta_3+\beta_4$)	0.751	0.794	-0.051
Chi-squared ($\beta_1+\beta_3+\beta_4=0$)	39.06***	25.98***	24.15***

Panel B: Diagnostic statistics based on data in the year immediately prior to the SOX event[b,c]

VARIABLES	Mean (Standard deviation)				**t-Statistic**
	Non-accelerated filer		Accelerated filer		
RD_SALE	0.860	(0.589)	0.727	(0.264)	0.252
RD_SALE_{t-2}	0.759	(0.686)	0.662	(0.903)	0.463
IO_TOTAL	0.056	(0.116)	0.251	(0.306)	−1.950
IO_ACTIVE	0.158	(0.165)	0.378	(0.426)	−2.022
IO_PASSIVE	0.013	(0.001)	0.171	(0.078)	−1.042
AUDITING	0.099	(0.139)	0.063	(0.100)	0.792
ETHNIC_MINORIY	0.015	(0.045)	0.040	(0.074)	−0.662
FEMALE	0.388	(0.492)	0.570	(0.495)	−0.536
BOARD_INDEPEND	1.336	(0.437)	1.622	(0.466)	−1.398
BOARD_SIZE	7.510	(1.872)	8.895	(2.597)	−2.993
CEO_DUALITY	0.735	(0.446)	0.803	(0.398)	−1.054
SIZE	2.517	(2.193)	6.190	(2.344)	5.175
PROFITABILITY	−1.239	(4.763)	−0.177	(3.436)	−2.851
FIRM GROWTH	0.687	(0.580)	0.613	(0.558)	0.880

Table 8 (continued)

Panel B: Diagnostic statistics based on data in the year immediately prior to the SOX event[b,c]					
VARIABLES	Mean (Standard deviation)				**t-Statistic**
	Non-accelerated filer		Accelerated filer		
CASHRATIO	− 0.438	(1.444)	− 0.032	(1.944)	− 1.381
LEVERAGE	0.840	(0.417)	0.509	(0.311)	0.990
CAPEX_TA	0.068	(0.289)	0.067	(0.078)	0.221

[a]Panel A of Table 8 reports the results of a difference-in-differences analysis based on the quasi-experiment. The dependent variable is the ratio of R&D expenditure to total sales (RD_SALE), and we use the same control variables as specified in the baseline model of Eq. (1) to isolate all other control effects

$$\begin{aligned} INNOVATION_{it} = {} & \beta_0 + \beta_1 INSTITUTION_{it} + \beta_2 INSTITUTION_{it} \times SOX2002 \\ & + \beta_3 INSTITUTION_{it} \times ACCELERATED\_FILER + \beta_4 INSTITUTION_{it} \times SOX2002 \\ & \times ACCELERATED\_FILER + \beta_5 SOX2002 + \beta_6 ACCELERATED\_FILER \\ & + \beta_7 BOARD\ DIVERSITY_{it} + \beta_8 CONTROLS_{it} + \varepsilon_{it} \end{aligned} \quad (4)$$

We examine the effect of the enactment of Sarbanes–Oxley Act in 2002 on the relationship between institutional ownerships and R&D investment by adding the interaction terms into Eq. (1). Columns (1), (2), and (3) report the estimation results, where the total institutional ownership (IO_TOTAL), active institutional ownership (IO_ACTIVE), and passive institutional ownership (IO_PASSIVE) are independent variables, respectively. ACCELERATED_FILER is a dummy variable, which equals 1 if it is an accelerated filer to comply with the Sarbanes–Oxley Act (firm with a market value of equity higher than US$75 million); 0 if otherwise. SOX2002 is a dummy variable, which equals 1 if the year is after the Sarbanes–Oxley Act in 2002; 0 if otherwise. See Appendix A for the variable definitions. The standard errors of estimated coefficients are clustered by the firm and displayed in parentheses. Figures with $_*$, $_{**}$, and $_{***}$ represent the statistical significance at the 10%, 5%, and 1% levels, respectively [b]Panel B reports mean values, standard deviations, and student *t* -statistics for a difference in the mean values of corporate innovation and all firm attributes across the two respective samples, namely, firms with accelerated filer and firms with non-accelerated filer. All variables in the analysis are based on data in the year immediately prior to the SOX event. Accelerated Filer is an accelerated filer to comply with the Sarbanes–Oxley Act (firm with a market value of equity higher than US$75 million). Non-accelerated filer is a small firm (firm with market values of equity under US$75 million) with extra time to comply with the Sarbanes–Oxley Act

[c]All variables and t-tests are based on time at t-1. We also include the RD_SALE $_{t-2}$ to reconfirm there is no significant difference on RD_SALE $_{t-2}$ two-year before the event

$$\begin{aligned} INNOVATION_{it} = {} & \beta_0 + \beta_1 INSTITUTION_{it} + \beta_2 INSTITUTION_{it} \times SOX2002 \\ & + \beta_3 INSTITUTION_{it} \times ACCELERATED\_FILER + \beta_4 INSTITUTION_{it\ t} \times SOX2002 \\ & \times ACCELERATED\_FILER + \beta_5 SOX2002 + \beta_6 ACCELERATED\_FILER \\ & + \beta_7 BOARD\ DIVERSITY_{it} + \beta_8 CONTROLS_{it} + \varepsilon_{it.} \end{aligned} \quad (4)$$

We first add the interaction of *INSTITUTION*×*SOX2002* to capture the differential effects of institutional ownership on R&D investment due to the enactment of SOX Act. We also add the interaction of *INSTITUTION*×*ACCELERATED_FILER* to compare the effect between the accelerated filer and non-accelerated filer groups. Finally, we interact SOX2002, ACCELERATED_FILER, with INSTITUTION, resulting in the following interacted terms: *INSTITUTION*×*SOX2002*×*ACCELERATED*. We expect that the relationship between innovation investment and institutional ownership variables (IO_TOTAL, IO_ACTIVE, and IO_PASSIVE) are more pronounced for the treatment group over the post-SOX period. The "clean" effect of institutional ownership on innovation arises from the exogenous change in institutional ownership forced on the accelerated filer through a mandate to disclose accurate and complete information.

Table 9 DID estimation summary

VARIABLES		RD_SALE		
		PRE-SOX2002	POST-SOX2002	DIFFERENCE
IO_TOTAL	Non-accelerated filer	0.516	0.251	− 0.265***
	Accelerated filer	0.189	0.486	0.297***
	Difference	−0.327	0.235	0.562***
IO_ACTIVE	Non-accelerated filer	0.628	0.309	−0.319***
	Accelerated filer	0.346	0.512	0.166***
	Difference	−0.282	0.203	0.485***
IO_PASSIVE	Non-accelerated filer	−1.031	−0.906	0.125**
	Accelerated filer	−0.604	0.074	0.678***
	Difference	0.427	0.980	0.553***

This table reports the DID estimation summary for a time comparison before and after the SOX enactment between accelerated filer and non-accelerated filer groups. The model is presented as the following equation:

$$\begin{aligned} INNOVATION_{it} = {} & \beta_0 + \beta_1 INSTITUTION_{it} + \beta_2 INSTITUTION_{it} \times SOX2002 + \beta_3 INSTITUTION_{it} \times ACCELERATED\_FILER \\ & + \beta_4 INSTITUTION_{it} \times SOX2002 \times ACCELERATED\_FILER + \beta_5 SOX2002 + \beta_6 ACCELERATED\_FILER \\ & + \beta_7 BOARD\ DIVERSITY_{it} + \beta_8 CONTROLS_{it} + \varepsilon_{it} \end{aligned} \quad (4)$$

Accelerated Filer is an accelerated filer to comply with the Sarbanes–Oxley Act (firm with a market value of equity higher than US$75 million). Non-accelerated filer is a small firm (firm with market values of equity under US$75 million) with extra time to comply with the Sarbanes–Oxley Act. Figures with *, **, and *** represent the statistical significance at the 10%, 5%, and 1% levels, respectively

Table 8 reports the DID estimation results with the 5-year window centered on the event 2002, which confirms again that total institutional ownership positively relates to firm R&D investment. The coefficient is significant with an even higher magnitude compared with that in Table 4. Interestingly, although the interaction of SOX2002 and passive institutional ownership over the post-SOX period turns out to be significantly positive, the interaction of SOX2002 and active institutional ownership is negative. These findings imply that although the SOX Act requires listed firms to disclose accurate and complete information, the advantages from active institutional investors are reduced. Instead, the passive investors gain significant benefits from the reduction in firm information asymmetry and have increased willingness to invest in highly innovative firms.

In addition, the positive and significant coefficient of *IO_TOTAL*×*SOX2002*×*ACCELERATED_FILER* illustrates the marginal effect of SOX2002 on the institutional ownership–innovation investment relation for accelerated filers. We also find similar results with active and passive institutional investors on their relation with firm innovation for accelerated filers. The results support the perspective that the enactment of Sarbanes–Oxley Act mitigates the level of information asymmetry between businesses and investors (Zhang et al. 2007). Given a reduced degree of information asymmetry post-SOX, highly innovative firms can attract more institutional investments in the post-SOX period. Especially, we find higher effects of passive institutional investment in innovative firms in post-SOX.

An underlying assumption of the DID analysis is that the two groups of firms in comparison have similar characteristics or that the two groups of firms had a parallel path before the SOX2002 event. We find that this condition is met. We conducted t-tests to examine whether the innovation investment and firm characteristics in the year immediately before the event are different across the accelerated and non-accelerated filer. The results in Panel B of Table 8 reveal no significant differences in innovation investment

Table 10 Alternative measures of board diversity and quantile two-stage least squares

	2SLS	(2) Quantile Two-Stage Least Square		
		(Q25)	(Q50)	(Q75)
VARIABLES	RDSALE	RDSALE	RDSALE	RDSALE
Institutional ownerships				
IO_TOTAL	0.316***	0.767***	1.536***	2.464***
	(0.077)	(0.070)	(0.081)	(0.143)
Board diversity				
AUDITING	0.196**	0.100***	0.211***	0.361***
	(0.080)	(0.009)	(0.009)	(0.022)
ETHNIC_MINORITY	0.225***	0.069***	0.157***	0.264***
	(0.064)	(0.007)	(0.008)	(0.015)
FEMALE		0.010***	0.020***	0.034***
		(0.001)	(0.001)	(0.003)
GENDER	0.123*			
	(0.065)			
Board characteristics				
BOARD_INDEPEND	0.0466**	0.079***	0.158***	0.249***
	(0.020)	(0.007)	(0.009)	(0.015)
BOARD_SIZE	5.586***	2.758***	5.646***	9.054***
	(0.530)	(0.251)	(0.313)	(0.520)
CEO_DUALITY	−0.010	−0.019	−0.036***	−0.054***
	(0.012)	(0.002)	(0.002)	(0.004)
Firm characteristics				
SIZE	0.115***	0.022***	0.041***	0.063***
	(0.009)	(0.002)	(0.002)	(0.005)
PROFITABILITY	0.070**	0.116***	0.231***	0.396***
	(0.035)	(0.015)	(0.019)	(0.039)
GROWTH	0.0678***	0.001	0.001	0.004
	(0.015)	(0.001)	(0.003)	(0.007)
CASH RATIO	−0.021*	−0.008***	−0.018***	−0.031***
	(0.011)	(0.003)	(0.002)	(0.005)
LEVERAGE	0.104	0.131***	0.257***	0.403***
	(0.068)	(0.011)	(0.013)	(0.029)
CAPEX_TA	0.508***	0.009*	0.0186**	0.021*
	(0.140)	(0.006)	(0.008)	(0.023)
Constant	0.728***	−0.411***	−0.863***	−1.421***
	(0.145)	(0.050)	(0.059)	(0.092)
Industry effects	Yes	Yes	Yes	Yes
Observations	10,610	10,610	10,610	10,610
R^2	0.234			
Pseudo R^2		0.153	0.239	0.289
F-value	105.31***			
Test	F-value		P-value	
[q25] institutional own = [q50] institutional own	125.38		0.000	
[q50] institutional own = [q75] institutional own	64.27		0.000	

Table 10 (continued)

	2SLS	(2) Quantile Two-Stage Least Square		
		(Q25)	(Q50)	(Q75)
VARIABLES	RDSALE	RDSALE	RDSALE	RDSALE
[q25] institutional own = [q75] institutional own	153.40		0.000	

This table reports the 2SLS and Quantile Two Stage Least Square regressions of firm innovation on institutional ownership and board diversity, where the ratio of R&D expenditure to total sales (RD_SALE) is a dependent variable

$$INNOVATION_{it} = \beta_0 + \beta_1 INSTITUTION_{it} + \beta_2 BOARD\ DIVERSITY_{it} + \beta_3 CONTROLS_{it} + \varepsilon_{it,} \quad (1)$$

where institutional ownership (*INSTITUTION*) variables are treated as endogenous variables and instrumented by the Standard and Poor's 500 index dummy (*SP500_D*) and the firm's market capitalization (*LNMKVALT)*

$$INSTITUTION_{it} = \alpha_0 + \alpha_2 CONTROLS_{it} + \alpha_3 INSTRUMENTS_{it} + \omega_{it.} \quad (2)$$

Column (1) reports the second stage of 2SLS estimation results of firm innovation on total institutional ownerships in the firm (*IO_TOTAL*) and board diversity in which the GENDER variable is the ratio of the number of female directors on a firm's board scaled by board size. Column (2) reports the Quantile Two Stage Least Square results of firm innovation on IO_TOTAL and board diversity. All regressions include a full set of controls as described in Appendix A. The standard errors of estimated coefficients are clustered by firm and displayed in parentheses. Figures with *, **, and *** represent the statistical significance at the 10%, 5%, and 1% levels, respectively

and firm characteristics in terms of board diversity, sale growth, cash ratio, firm leverage, and capital expenditure ratio between the two groups. These results provide more confidence that the DID estimate reflects a causal effect of SOX200 on corporate innovation investment.

Table 9 reports the DID estimation summary for a time comparison before and after the SOX enactment between the non-accelerated filer and accelerated filer. For the non-accelerated filer groups, the results support our expectation that the sign effect of institutional ownership (IO_TOTAL, IO_ACTIVE, and IO_PASSIVE) remains after the enactment of SOX. For the accelerated filer group, the results show a significant change. In particular, one standard deviation (0.1821) increase in active institutional ownership increases the magnitude of R&D investment by 0.607% [=0.1821*0.346/ 0.1037] from the average R&D investment level of 10.37% per-SOX and increase by 0.899% [=0.1821*0.512/ 0.1037] post-SOX. By contrast, one standard deviation (0.0731) increase in passive institutional ownership reduces the magnitude of R&D investment by 0.432% [=0.0731*(−0.604)/0.1037] from the average R&D investment level of 10.37% per-SOX. However, the sign changes post-SOX such that one standard deviation (0.0731) increase in passive institutional ownership increases the magnitude of R&D investment by 0.052% [=0.0731*(0.074)/0.1037] from its mean value. The results suggest that the SOX Act benefits all the investors but benefits more from passive institutional ownership. Thus, the SOX Act narrows the gap such that previously large competitive advantage in terms of information asymmetry is narrowed down. The study suggests that as the SOX Act is increasingly implemented, the differences between the active and passive institutional investors diminish; this reduction erodes the differential influence on innovation of active versus passive investors. In sum, the effect of institutional ownership on innovation is robust over the DID model specifications and controls.

Table 11 Complementary analysis of gender diversity

VARIABLES	(1) RDSALE	(2) RDSALE	(3) RDSALE
Institutional ownerships			
IO_TOTAL	1.228***		
	(0.154)		
IO_TOTAL × FEMALE	− 1.093***		
	(0.148)		
IO_ACTIVE		1.563***	
		(0.208)	
IO_ACTIVE × FEMALE		− 1.499***	
		(0.198)	
IO_PASSIVE			− 2.540***
			(0.395)
IO_PASSIVE × FEMALE			2.504***
			(0.390)
Board diversity			
AUDITING	0.191**	0.226***	0.079
	(0.082)	(0.087)	(0.052)
ETHNIC_MINORITY	0.236***	0.220***	0.076*
	(0.065)	(0.072)	(0.042)
FEMALE	0.836***	0.896***	0.441***
	(0.110)	(0.116)	(0.072)
Board characteristics			
BOARD_INDEPEND	− 0.021	− 0.021	0.047***
	(0.023)	(0.025)	(0.012)
BOARD_SIZE	6.977***	6.698***	− 3.348***
	(0.550)	(0.583)	(0.563)
CEO_DUALITY	− 0.004	0.004	− 0.011
	(0.012)	(0.014)	(0.008)
Firm characteristics			
SIZE	0.125***	0.133***	0.020***
	(0.010)	(0.011)	(0.006)
PROFITABILITY	0.002	0.004	− 0.048*
	(0.037)	(0.039)	(0.027)
GROWTH	0.071***	0.072***	0.047***
	(0.015)	(0.016)	(0.008)
CASH RATIO	− 0.025**	− 0.0228*	− 0.014
	(0.011)	(0.012)	(0.010)
LEVERAGE	0.152**	0.143*	− 0.031
	(0.070)	(0.075)	(0.044)
CAPEX_TA	0.533***	0.516***	0.032
	(0.143)	(0.152)	(0.096)
Constant	0.153	0.218	1.012***
	(0.170)	(0.185)	(0.104)
Industry effects	Yes	Yes	Yes
Observations	10,610	9916	5871
R-squared	0.200	0.182	0.175

Table 11 (continued)

VARIABLES	(1) RDSALE	(2) RDSALE	(3) RDSALE
F-value	98.90	91.93	48.76

This table reports the 2SLS regressions of firm innovation on institutional ownership and board diversity, where the ratio of R&D expenditure to total sales (RD_SALE) is a dependent variable

$$INNOVATION_{it} = \beta_0 + \beta_1 INSTITUTION_{it} + \beta_2 INSTITUTION_{it} \times FEMALE + \beta_3 BOARD\ DIVERSITY_{it} + \beta_4 CONTROLS_{it} + \varepsilon_{it.} \quad (4)$$

The interaction term INSTITUTION*FEMALE captures the differential of firm innovation investment response of a female appointment on the board to its institutional ownership. FEMALE is a dummy variable, which equals 1 if the board has at least one female director, 0 otherwise. See Appendix A for the variable definitions. The standard errors of estimated coefficients are clustered by the firm and displayed in parentheses. Figures with *, **, and *** represent the statistical significance at the 10%, 5%, and 1% levels, respectively

4.3.4 Complementary analysis of gender diversity

In this section, we consider an alternative measure of gender diversity: woman director ratio (GENDER). We measure women director ratio as the number of female directors on a firm's board scaled by board size. Results are presented in Table 10 Column (1). The coefficient estimates on GENDER is positive and significant at the 10% level, suggesting that gender diversity is positively associated with corporate innovation investment. This finding is consistent with the idea of Low et al. (2015), indicating that more gender diverse boards add value by improving board monitoring and bringing new perspectives to the board, which are beneficial to firm investments. Other key estimates are again consistent with the results in Table 4.

We further examine the role of active and passive institutional investors in innovation where women are present on the corporate boards. In this respect, we add the interactions between INSTITUTION and FEMALE to create Model (5). The remaining independent and control variables are the same as in the previous model:

$$INNOVATION_{it} = \beta_0 + \beta_1 INSTITUTION_{it} + \beta_2 INSTITUTION_{it} \times FEMALE_{it} + \beta_3 BOARD\ DIVERSITY_{it} + \beta_4 CONTROLS_{it} + \varepsilon_{it} \quad (5)$$

Passive institutional investors are less likely to serve as a board committee (Chen and Miller 2007) and they welcome even small improvements in governance relative to firms. Prior research mentions the value of board diversity, suggesting that female directors offer diverse viewpoints, promote lively discussion to the boardroom (Letendre 2004) and transparency (Upadhyay and Zeng 2014). Therefore, we would expect a gender diversity foster more innovation investment in firms while institutional investors are passive. On the contrary, active institutional investors are more likely to have a seat on board to monitor managers and influence the corporate decision (David et al. 2001). It could be that active investors would bring flexibility and new perspectives on investment into the boards to maximize their interests, leading to higher innovation investment. We expect that the benefits of control by active institutional investors would be higher in firms with gender diversity.

Table 11 summarizes the results of complementary analyses. We analyze the interacted effect of the gender diversity and institutional ownership on innovation. The results remain similar on the impacts of IO_TOTAL, IO_ACTIVE and IO_PASSIVE on RD_SALE, including both signs and significances. The IO_ACTIVE × FEMALE presents a negative effect on RD_SALE (with a coefficient of − 1.499), statistically significant at 1% level, while IO_PASSIVE × FEMALE has a positive effect at the same significance (with a coefficient of 2.504). It reconfirms that active institutional investors in firms without female gender show a stronger impact on corporate innovation investment (with a coefficient of IO_ACTIVE = 1.563) than those with female gender on the board (coef. IO_ACTIVE + coef. IO_ACTIVE × FEMALE = 1.563–1.499 = 0.064).

As for the passive institutional ownership, the impact on firm innovation is negative, it is particularly negative in firms without female gender on board (coef. IO_PASSIVE = coef. IO_PASSIVE + coef. IO_PASSIVE × FEMALE = − 2.540 + 2.504 = − 0.036). Therefore, the positive impact of the active institutional investor on innovation is wide in firms without gender diversity on board. On the contrary, the negative impact of passive investors on innovation is significantly narrow for firms with a female on the board. Our results confirm the presence of diverse directors on the board in fostering corporate innovation. Nonetheless, the advantage of gender diversity to innovation is more significant for passive institutional investors than active investors.

4.3.5 An alternative methodology

We again perform the Instrumental Variable Quantile Regression (hereafter IV-QR) to address the concerns of the patent distribution problems for additional robustness check. Its key difference between IV-QR and OLS and 2SLS lies in the following: instead of solving for a "conditional mean," the quantile model solves for a "conditional quantile". The IV-QR is the same as the original quantile regression, except for incorporating instrumental variables to account for endogeneity (Chernozhukov and Hansen 2008). Unfortunately, no official Stata commands exist for this model, compelling us to follow Asongu and Kodila-Tedika (2015) and utilize the naïve quantile regression in this paper. The coefficient estimate results are divided based on quantiles and presented in Table 10. The results indicate an increasing coefficient of institutional ownership as the quantile increases. The results also show a significant different effect of institutional ownership between low and high quantile.

Our results of the relations between institutional investors, board diversity, and firm innovation are robust after implementing the difference-in-differences analysis, IV-quantile regression, and alternative measures of firm innovation.

5 Conclusions

This paper examines how institutional investors and board diversity jointly reshape the role of corporate governance and influence a firm's innovation. Using a large sample of US firms, this research obtains some interesting results below.

First, we find institutional ownerships positively influence the innovation only appears in the active institutional investors, not in the passive investors. However, the passive investors positively affect innovation once those firms have at least one banker on the board. The

plausible explanation is that a banker on the board benefits firms from professional banking advising, monitoring, and funds support with lower spreads or better non-price loan terms (Francis et al. 2012). Moreover, bankers could foster investment by lending large loans to finance innovative projects.

Second, enacting the Sarbanes–Oxley Act in 2002 facilitates the provision of accurate and transparent information to investors, narrowing the gap between active and passive institutional investors in innovation investment. Our results from the difference-in-differences analysis show that both types of institutional investors benefit from innovation post-SOX Act. However, passive investors gain more benefits from the SOX Act than active investors and become positively affected innovation investment after the event.

Third, a board with a female, a higher presence of auditing committee, or a higher proportion of ethnic minority directors significantly lifts the R&D investment and produces more patents. These findings imply that board diversity is beneficial in fostering innovation. Again, firms with a high percentage of independent directors significantly boost more investment in R& D.

Our findings support the view that institutional investors are not simply attracted to firms with high growth rates but also play a critical role in promoting corporate growth through innovation investment. These institutions are active in enhancing firms' governance mechanisms and innovation effectiveness.

Appendix A: Definition of Variables

Variables name	Variable label	Definition
Innovation measures		
Innovation input	RD_SALE	The ratio of R&D expenditure to total sales
	RD_TA	The ratio of R&D expenditure to total assets
Innovation output	LN(1 + PATENTS)	The logarithm of one plus the total number of patents
Innovative efficiency	IE	The ratio of patents relative to the R&D capitalization
Institutional ownerships		
Total institutional ownership	IO_TOTAL	The percentage of shares owned by total institutional investors divided by total shares outstanding
Active institutional ownership	IO_ACTIVE	The percentage of shares owned by active institutional investors (investment companies, independent investment advisors, and public pension funds) to total shares outstanding

Variables name	Variable label	Definition
Passive institutional ownership	IO_PASSIVE	The percentage of shares owned by passive institutional investors (banks, insurance companies, private pension fund, and others) to total shares outstanding
Board diversity		
Female Appointment	FEMALE	Dummy variable, 1 if at least one director is female; 0 otherwise
Ethnic diversity	ETHNIC_MINORITY	The proportion of the ethnic minority (African-American, Hispanic, and Asian) on the board
Qualification diversity	AUDITING	The proportions of directors who are audit committee members
	BANKING_COMMIT	Dummy variable, 1 if a firm has at least one banker on board providing professional banking services, 0 otherwise
Gender diversity	GENDER	The proportion of females on the board
Board characteristics		
Board independence	BOARD_INDEPEND	The proportion of independent directors on the board
Board size	BOARD_SIZE	Number of directors serving on the board
CEO duality	CEO_DUALITY	Dummy variable, 1 if the CEO also acts as a chairman of the board, 0 otherwise
Firm characteristics		
Firm size	SIZE	The logarithm of the firm's book value of total assets
Firm profitability	PROFITABILITY	Net income/ Total assets
Sales growth rate	GROWTH	$(Sales_{t} - Sale_{t-1})/ Sales_{t-1}$
Cash ratio	CASHRATIO	Total cash divided by total assets
Firm leverage	LEVERAGE	The book value of the firm's debt divided by total assets
Capital expenditure	CAPEX_TA	Capital expenditure divided by total assets
S& P 500 index	SP500_D	SP500_D is set to 1 if the firm is in the S& P 500 index, 0 otherwise
Market capitalization	LNMKVALT	The log of the market value of the firm

Variables name	Variable label		Definition
Industry dummies		INDUSTRY_D	Industry dummies, classified by SIC codes
Event dummies		SOX2002	Dummy variable, 1 if the year was after the Sarbanes–Oxley Act in 2002, 0 otherwise
Accelerated filers		ACCELERATED_FILER	Dummy variable, 1 if is an accelerated filer to comply the Sarbanes–Oxley Act (firm with a market value of equity higher than US$75 million), 0 otherwise

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