Do Female Directors Enhance R&D Performance?

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Abstract:
This study examines whether and how female directors enhance innovation performance. Based on a sample of U.S. firms, this study shows that firms with more female directors on boards present a more pronounced positive association between R&D and future firm performance (measured by earnings and operating cash flow), suggesting a positive impact of board gender diversity on R&D performance. We further identify two potential channels through which R&D can contribute to increased firm performance: innovation output (the number of patents and patent citations) and productivity (increased sales revenue). Our results show that a higher number of female directors are associated with higher innovation output (measured by the sensitivity of patents and patent citations to R&D) and higher R&D productivity (measured by the sensitivity of future sales to R&D).

Keywords: Female Directors, R&D, Performance

I. INTRODUCTION

The inclusion of female directors on company boards is an important facet of corporate governance that has attracted significant global attention from both practitioners and researchers. With the increasing awareness of the benefits of engaging female directors (Barber and Odean 2001;Adams and Ferreira 2009; Miller and Triana 2009; Srinidhi et al. 2011; Levi et al. 2013; Terjesen et al. 2015), there has been a significant increase in the number of female directors in the United States and other countries[1]. Nevertheless, the "glass ceiling" may well still exist within the corporate sector. A recent survey shows that the proportion of total U.S. Fortune 500 board seats held by women was 16.9% in 2013 (Catalyst 2013). In innovation-intensive industries, this percentage is only 7.1% (Forbes 2014). This under-representation of women raises concerns regarding its potential adverse impact on innovation and firm performance (Khanna 2013). In this study, we provide empirical evidence based on a large-scale dataset to examine the firm innovation implications of engaging female directors. By doing so, our study explicitly addresses this concern (Khanna 2013) and extends our understanding of the role of female directors in contributing to firm competitiveness.

Innovation is vital at both the firm and country level in terms of creating a competitive advantage. Developed economies around the world are re-shaping themselves as knowledge-based economies and thus recognize innovation as the primary driver of economic growth (Feldman and Link 2001; Kim, Park, and Song 2017). In the capitalist model followed in the U.S., such innovation is driven mostly by value-adding investments in R&D by private corporate enterprises. As a result, the U.S. continues to lead global R&D investment (European Commission 2014).

Despite the widespread belief of a positive relation between R&D investment and firm

[1] For example, a recent survey shows that the proportion of total U.S. Fortune 500 board seats held by women grew from 8.3% in 1993 to 11.1% in 1998, 13.6% in 2003, and 16.9% in 2013 (Catalyst 2013).

performance (Sougiannis 1994; Abrahams and Sidhu 1998; Nguyen et al. 2010), the agency problems inherent in the R&D investment decision process (Jensen 1993) are likely to lower the value of R&D investment. For example, managers have incentives to cut R&D investment to yield more immediate financial benefits when they are about to retire (e.g. Dechow and Sloan 1991; Jensen 1993; Fong 2009). In contrast, it is also possible that R&D investments may represent “perks” because managers might engage in value-destroying R&D projects to benefit themselves (Jensen 1986). These agency problems are further exacerbated in R&D investments due to higher information asymmetry compared with other capital and financial inputs (Aboody and Lev 2000). For example, Pandit, Wasley and Zach (2011) argue that R&D as an innovation input has uncertain outcomes and empirically show that R&D investments may not necessarily lead to tangible outcomes like patents.

Do female directors facilitate better innovation outcomes? Drawing on this literature, we propose two conflicting views. On the one hand, female directors are likely to promote effective governance and increase R&D efficiency in various ways. First, female directors are likely to increase innovation performance by better identifying promising projects. This is because a board with a heterogeneous background is likely to produce a broader range of ideas (Milliken and Vollrath 1991). Second, the presence of female directors on boards could produce a rich information environment for the firm (Gul et al. 2011; Srinidhi et al. 2011; Lai et al. 2016), thereby reducing asymmetric information and R&D-related agency problems (Stein 1988). In addition, a more transparent information environment may enable investors from different backgrounds to evaluate innovative projects, thereby increasing the possibility of being funded and the likelihood of innovation success (Atanassov 2015). Third, the presence of female directors on boards is likely to foster an innovation-encouraging organizational environment within a firm because female directors are more likely to create an atmosphere encouraging cooperation and information exchange that is essential for R&D

success (Jelinek and Adler 1988; Trinidad and Normore 2005). Further, the presence of female directors has positive implications for female managers at lower levels who are engaged in innovative tasks.

However, on the other hand, female directors may negatively affect innovation outcomes because they are typically more conservative and more likely to build up a strict compliance culture that might stifle innovation compared to their male counterparts. For example, a strict compliance culture characterized by excessive monitoring may discourage innovation performance by overly restricting managers from developing innovative products or services (Baysinger et al. 1991; Burkart et al. 1997). Due to these conflicting views, the relationship between female directors and R&D performance is *ex ante* unclear.

To empirically examine the relation between female directors and the performance of R&D, we follow prior literature (Pandit et al. 2011; Tong and Zhang 2014; Atanassov 2013; Abrahams and Sidhu 1998) and examine the effect of engaging female directors on the average firm financial performance measures (including earnings and cash flow) over the following 5 years. Based on a sample of U.S. listed companies for the period of 1998-2013, our findings show that firms with more diverse board exhibit a more significantly positive relationship between R&D investment and future earnings as well as future operating cash flow, suggesting that female directors enhance the performance of a firm's R&D activities. Our results also show that firms with more female directors experience higher *R&D output* (captured by patents and citations generated from R&D) and higher *R&D productivity* (measured by the relationship between R&D and future sales), both of which are expected to contribute to higher R&D-generated firm performance.

Our study may be subject to endogeneity concerns because the results may alternatively be driven by firms displaying high R&D performance opting for boards with more female directors. We address this potential endogeneity problem by estimating the possibility of engaging female directors based on the model in Gul et al. (2011) and using the unexplained female directorship from the first stage analysis in the second-stage regressions. The results remain unchanged, suggesting that our results are not likely to be affected by endogeneity problems.

Our paper contributes to the literature in the following ways. First, we extend corporate governance literature by showing the potential economic benefits that could be brought by female directors. Although prior studies primarily show that female directors are associated with better monitoring performance (Adams and Ferreira 2009; Gul et al. 2011; Srinidhi et al. 2011; Lai et al. 2016), the financial consequences of the inclusion of female directors remain unclear (Adams and Ferreira 2009; Carter et al. 2003; Erhardt et al. 2003). Further, a recent paper (i.e., Chen et al. 2016) finds that female directors are associated with lower risk generated by R&D. However, whether the lower R&D risks eventually contribute to higher R&D-generated performance is unknown yet. This paper aims to answer this question. By demonstrating that gender-diverse boards are associated with higher performance of innovative activities proxied by the sensitivity of R&D investment to future outcomes, our study contributes to this strand of literature, indicating that female directors may provide better monitoring of R&D-intensive companies and thus enhance the performance of R&D investment.

Second, we answer the call of Pandit et al. (2011) for study of R&D in conjunction with innovation output such as patents or citations. Prior studies focus on R&D either in terms of innovation inputs, or patents and citations, which are innovation outputs. Few studies combine both inputs and output in their analysis. To the extent that the conversion from R&D to innovation output is uncertain (Pandit et al. 2011; Hirshleifer et al. 2013), studies examining such relationships could enhance our understanding on how to improve R&D performance. Our study contributes to the literature by showing that engaging female directors could improve a firm's capability to convert innovation inputs to outputs, thus representing a possible channel to improve firm performance. Future studies may consider extending our study by examining how other corporate governance mechanisms increase R&D investment performance.

Finally, our findings also provide important practical implications for industry professionals. The under-representation of female directors on boards in the innovation industry has triggered much debate and controversy. Many people have questioned whether the "glass ceiling" remains especially severe in such industries and therefore results in lower innovation and financial performance (e.g. Khanna 2013). Despite such concerns, few prior studies provide empirical evidence based on a large-scale dataset. Our study contributes to the debate and suggests that under-representation of female directors on boards could hamper firm innovation performance.

The rest of this paper is organized as follows. Section 2 reviews the literature and develops the research hypotheses. Section 3 specifies the research design and Section 4 describes data and presents the empirical analysis. Section 5 concludes.

II. LITERATURE REVIEW AND HYPOTHESIS DEVELOPMENT

Our study is related to the literature on female directors and R&D investment. Previous studies document significant behavioral differences between women and men and find that firms with female directors on their boards exhibit distinct attributes compared to those with all-male directors. Below we briefly review the related literature regarding female directors on boards and develop our hypotheses.

Female Directors on Boards

A number of studies have examined the gender difference in social behaviors. Several studies attribute gender differences to gender socialization processes; while women are educated to be caring, selfless and helpful, men are educated to be aggressive and task-oriented (e.g., Eagly and Wood 1999). Such socialization results in a value-orientation discrepancy between men and women. For example, men are typically more concerned with money and advancement, and may break rules to seek success, while women are typically more concerned with harmonious relationships and more often adhere to rules and laws (Bertz et al. 1989). In dealing with ethical issues, females are more sensitive than males (Ameen et al. 1996; Bernardi and Arnold 1997; Cohen et al. 1998; Bear et al. 2010).

Because the corporate board is at the apex of the decision-making control system within a firm (Fama and Jensen 1983) and exerts significant influence on firm performance, gender diversity at board level provides an excellent setting for us to empirically examine how gender differences affect governance performance. Based on the literature, we present three factors that explain how female directors might improve governance.

First, as corporate boards often need to make unstructured decisions in uncertain situations, considering diverse perspectives could reduce uncertainties and partly explain why boards with female directors are likely to result in more informed decisions. Second, female directors are more likely to facilitate close cooperation among board members and their participation on boards could increase board effectiveness. Studies show that female leaders deploy cooperation rather than competition based leadership (Klenke 2003; Trinidad and Normore 2005) and are more likely to adopt an "interactive leadership" style that motivates subordinates through participation and sharing of information and power that make people feel important (Rosener 1990). Such an interactive culture encourages an atmosphere of greater information exchange (Jelinek and Adler 1988). Therefore, a gender-diverse board is likely to promote greater information sharing as well as closer cooperation among directors. Third, female directors are diligent monitors in that they are less likely to belong to old boys' networks and are more adept at effective communication (Hillman et al. 2007; Adams and Ferriera 2009). This suggests that boards with female directors could promote more effective monitoring. Recent studies have shown that boards with female directors are associated with better reporting quality (Srinidhi et al. 2011), more informative stock pricing (Gul et al. 2011), greater auditor effort (Lai et al. 2016), and fewer financial reporting mistakes (Wahid 2018).

Female Directors and R&D Performance

The presence of female directors on a corporate board is likely to enhance its effectiveness as a governing body and increase R&D investment performance in various ways. First, a gender-diverse board is likely to increase R&D investment performance by better identifying promising projects. Previous studies have shown that, compared with a homogenous group, a heterogeneous group is likely to produce a broader range of ideas by incorporating diverse knowledge (Milliken and Vollrath 1991; Ben-Amar et al. 2017). Boards with female directors may better understand the marketplace, customers and other stakeholders, and thus have a greater capacity for identifying and selecting valuable innovative projects. Gender-diverse boards may also bring together a greater variety of ideas and perspectives for solving complex problems encountered during the innovation process. Indeed, diversity is particularly valuable for tasks requiring creative solutions such as the process of innovation (Hoffman and Maier 1961; Van Knnippenbert et al. 2004; Klein and Harrison 2007). We thus expect gender-diverse boards to be more likely to identify more promising projects, leading to better R&D performance.

Second, R&D investment may suffer from severe agency problems due to inherent high information asymmetry and horizon problems (e.g. Dechow and Sloan 1991; Jensen 1993; Fong 2009). Such agency problems can be mitigated with the presence of more female directors on boards because female directors are able to promote a richer information environment and help reduce information asymmetry. Prior studies have shown that firms with female directors are associated with a more transparent information environment (Gul et al. 2011; Srinidhi et al. 2011; Lai et al. 2016; Bobe and Kober 2018) and can also mitigate the under-investment problem resulting from asymmetric information (Stein 1988). As a result, the performance of R&D activities is enhanced with the inclusion of more female directors.

Third, female directors are likely to create an atmosphere encouraging cooperation within a firm (Trinidad and Normore 2005). Further, the presence of women on a board may have positive implications for female managers at lower levels who are engaged in innovation-related tasks. One could expect these managers to have greater motivation and stronger commitment to innovative projects. Hence, a gender-diverse board could result in not only greater information sharing but also closer cooperation among directors and managers, thereby enhancing a board's capacity for monitoring innovative projects.

However, female directors may negatively affect innovation performance because they tend to create a strict compliance culture within a firm. A strict compliance culture characterized by excessive monitoring may discourage innovation outputs by overly restricting managers from developing innovative and creative products and services (Baysinger et al. 1991; Burkart et al. 1997).

The above conflicting viewpoints suggest that the relationship between female directors and R&D performance is an empirical question. We thus state our hypothesis in a null form as follows:

H1. There is no association between female directors and performance of R&D investment.

Female Directors, Innovation Output and R&D Productivity

Next we investigate two potential channels through which female directors may affect the performance of R&D.

First, female directors can improve R&D performance by increasing patents and citations, given that higher innovation outputs have positive implications for firm performance. R&D investment itself is an input into the complex innovation process (Matolcsy and Wyatt 2008). Due to variations in firm capacity and agency costs (e.g. Dechow and Sloan 1991; Jensen 1993; Fong 2009), firms differ in both their ability to convert R&D inputs into tangible outputs (such as patents and other intellectual property) and the quality of the innovative outputs (such as patent citations). To the extent that only high-quality firm-level innovation contributes to increased future earnings through new products and patent licensing or reduced costs through increased efficiency (Pandit et al. 2011), the effect of R&D on firm profitability is contingent on how effectively and efficiently R&D can be converted to patents and citations. Indeed, as a well-established measure of the economic value and quality of patents, patent citation contains useful information about the earnings-enhancing effect of innovation and is found to be positively associated with the future benefits of innovation (e.g., Hall et al. 2005; Gu 2005). Therefore, we examine whether female directors affect the performance of R&D investment by influencing innovation output efficiency (measured by the sensitivity of patents and patent citations to R&D).

The second potential channel through which female directors may improve R&D performance is to increase productivity as captured by sales revenue. Characterized by considerable outcome uncertainty, R&D projects are more prone to failure than other investments. If R&D investments result in new services, product lines, or product modifications that satisfy hitherto unsatisfied customer demands, the firm can increase its market share relative to its less innovative competitors. However, more often than not innovation requires companies to refocus their processes and methods of conducting business. Innovation may necessitate corporate restructuring and decrease revenue if a firm finds it difficult to adapt to such a radical change. As a result, only successful innovative activities enable firms to grab, maintain, and increase market share, leading to increased sales revenue and overall superior performance (Mairesse and Sassenou 1991; Block 2012).

Based on the preceding arguments,, we propose the following two hypotheses:

H2a. There is no association between female directors and R&D outputs (measured by the sensitivity of patents and citations to R&D);

H2b. There is no association between female directors and R&D productivity (measured by the sensitivity of future sales to R&D).

III. RESEARCH DESIGN

Following previous literature (Pandit et al. 2011; Tong and Zhang 2014; Atanassov 2013; Abrahams and Sidhu 1998), we estimate the following regression model to explore the association between female directors and the performance of R&D (H1).

$$\begin{aligned} Performance_{i,t+5} &= \alpha_0 + \alpha_1 \mathrm{RD}_{i,t} + \alpha_2 \mathrm{Female}_{i,t} + \alpha_3 (\mathrm{Female}_{i,t} * \mathrm{RD}_{i,t}) + \alpha_4 \mathrm{Size}_{i,t} \\ &+ \alpha_5 \mathrm{H}HI_{i,t} + \alpha_6 \mathrm{H}HI^2_{i,t} + \alpha_7 \mathrm{Lev}_{i,t} + \alpha_8 \mathrm{Age}_{i,t} + \alpha_9 \mathrm{Independence}_{i,t} + \alpha_{10} \mathrm{Duality}_{i,t} \\ &+ \alpha_{11} \mathrm{M}ultiple_{i,t} + \mathrm{Firm}_{i,t} + \mathrm{Year}_{i,t} + \varepsilon \end{aligned} \tag{1}$$

where i and t denote the firm and the year, respectively. The dependent variable $Performance_{i,t+5}$ is measured by either future earnings ($Earnings_{i,t+5}$) or future operating cash flow ($OCF_{i,t+5}$). Consistent with prior literature (Pandit et al. 2011), we allow five years for R&D to generate payoffs. $Earnings_{i,t+5}$ is calculated as the mean of net income deflated by lagged market value of equity over years $t+1$ through $t+5$. $OCF_{i,t+5}$ is calculated as the mean of cash flows from operations deflated by lagged market value of equity over years $t+1$ through $t+5$.

$RD_{i,t}$ is research and development expenditure, operationalized by the natural logarithm of one plus R&D expenditure at the end of year t. The coefficient on RD, α_1, measures R&D performance. Since R&D is expected to increase future earnings, we expect α_1 to be significantly positive. Consistent with previous literature (Gul et al. 2011; Srinidhi et al. 2011; Chen et al. 2016), we measure $Female_{i,t}$ as *femalepct* (calculated as the fraction of female directors on the board) and *fdir* (calculated as the number of female directors). The variable of our interest is the interaction term between *Female* and *RD*. A significantly positive (negative) coefficient α_3 suggests that female directors increase (decrease) R&D performance.

To control for factors that may influence future performance, we follow prior studies (Pandit et al. 2011; Tong and Zhang 2014; Atanassov 2013) and include firm size (*Size*, computed as the natural logarithm of total assets), industry concentration (*HHI*, computed as the sum of the squared market shares of the firms in each four-digit SIC industry), nonlinear effects of industry concentration (HHI^2), leverage (*Lev*, the ratio of long-term debt to the total assets) and firm age (*Age*, the number of years since the firm first appeared on *Compustat* or *CRSP*, whichever is earlier).

We also control for other board characteristics in the regression model. These include board independence (*Independence*, computed as the number of independent directors as a percentage of the total number of directors), CEO duality (*Duality*, coded as 1 if the CEO also acts as the chair of the board, 0 otherwise) and multiple directorship (*Multiple*, computed as the average number of outside directorships in other firms held by independent directors). We also control firm and year fixed effects in our model.

To investigate the relationship between female directors and the innovation output of R&D investment (H2a), we follow prior literature (Atanassov 2013) and estimate the following model:

$$\begin{aligned} Output_{i,t+3} = {} & \beta_0 + \beta_1 \mathrm{RD}_{i,t} + \beta_2 \mathrm{Female}_{i,t} + \beta_3 (\mathrm{Female}_{i,t} * \mathrm{RD}_{i,t}) + \beta_4 \mathrm{Size}_{i,t} \\ & + \beta_5 \mathrm{H}HI_{i,t} + \beta_6 \mathrm{H}HI^2_{i,t} + \beta_7 \mathrm{MiLev}_{i,t} + \beta_8 \mathrm{Age}_{i,t} + \beta_9 \mathrm{Pro}fit_{i,t} + \beta_{10} \mathrm{Tang}_{i,t} \\ & + \beta_{11} \mathrm{Independence}_{i,t} + \beta_{12} \mathrm{Duality}_{i,t} + \beta_{13} \mathrm{M}ultiple_{i,t} + \mathrm{Firm}_{i,t} + \mathrm{Year}_{i,t} + \varepsilon \end{aligned} \quad (2)$$

The dependent variable $Output_{i,t+3}$ is measured by either the number of patents ($log(1+Patent)_{i,t+3}$), in which *Patent* is computed as the number of patents for each firm-year divided by the average number of patents for all firms in the same year, or the number of citations ($log(1+Citation)_{i,t+3}$), in which *Citation* is computed as the number of citations for each firm-year divided by the average number of citations for all firms in the same year. Both variables are constructed based on the years in which the patent applications are filed rather than the year in which the applications are granted, because the application year is arguably closer to the time when firms initiate innovation activities. We follow Hall, Jaffe, and Trajtenberg (2001) to correct for potential truncation problems related to both patent and citation data[2]. Both the number of patents and citations are measured three years ahead of the independent variables because it takes time for innovation activities to generate output[3]. Variables that are not detailed above include mean industry leverage (*MiLev*, computed as the mean industry equity divided by total assets), profitability (*Profit*, computed as net income before R&D divided by total assets) and tangible assets (*Tang*, computed as net property plant and equipment divided by assets).

More innovation input will lead to higher levels of innovation output; therefore β_1 is expected to be positive and significant. We also expect to observe a significant and positive β_3 if female directors facilitate the conversion of R&D input into an increased number of patents and patent citations.

To investigate the relationship between female directors and R&D productivity (H2b), we follow prior literature, using the contribution of R&D to the firm's sales revenue to proxy for R&D productivity (Block 2012; Mairesse and Sassenou 1991). We estimate the following

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[2] The data truncation problem arises because on average it takes about two years for a patent application to be granted, and it also takes time for a patent to generate citations. The significant decline in both the number of patents and citations towards the end of the sample period is consistent with these two potential truncation problems.
[3] Following Atanassov (2013), we also measure patents and citations four years later and re-estimate the regression models. The results are unchanged.

model:

$$\text{Log(Sales)}_{i,t} = \chi_0 + \chi_1 \text{RD}_{i,t} + \chi_2 \text{Female}_{i,t} + \chi_3 (\text{Female}_{i,t} * \text{RD}_{i,t}) + \chi_4 \text{Size}_{i,t}$$
$$+ \chi_5 \text{H}HI_{i,t} + \chi_6 \text{H}HI^2_{i,t} + \chi_7 \text{Lev}_{i,t} + \chi_8 \text{Age}_{i,t} + \chi_9 \text{Independence}_{i,t} + \chi_{10} \text{Duality}_{i,t}$$
$$+ \chi_{11} \text{M}ultiple_{i,t} + \text{Firm}_{i,t} + \text{Year}_{i,t} + \varepsilon \qquad (3)$$

The dependent variable is the natural logarithm of sales revenue. The coefficient on the variable *RD* measures R&D productivity. If female directors enhance R&D productivity, we expect χ_3 to be significantly positive.

IV. SAMPLE SELECTION AND EMPIRICAL RESULTS

Data and Sample

We obtain data on female directors and other board characteristics from Institutional Shareholder Services (ISS, previously known as *RiskMetric*)[4]. Financial data are sourced from *Compustat*. Patents and citations data are obtained from the comprehensive patent database compiled by the National Bureau of Economics Research (NBER)[5]. Observations are excluded from our sample if: (1) data needed to calculate the variables are missing; or (2) missing values of assets, sales, book value of equity and market value of equity are reported; or (3) negative values of book value of equity is reported. Our final sample for R&D performance model consists of 10,157 firm-year observations from 1998 to 2008. For the innovation output model and R&D productivity model, the sample sizes are 7,351 and 17,427, respectively.

Summary Statistics and Correlation

Table 1 reports the summary statistics for variables used in all regression models. Panels A, B, and C present the statistics for the variables in the R&D performance model, R&D output model, and R&D productivity model, respectively. In all panels, the median values of *RD* are 0, lower than the mean values. This is due to missing or zero values for

[4] Board multiple directorship data are available only from 1998.

[5] The patent and citations data are available from 1976 to 2006. The details of the data can be found on the webpage: https://sites.google.com/site/patentdataproject/Home/downloads (accessed in August 2017).

R&D expenditures reported in *Computstat*. The statistics is consistent with prior studies and indicate that the distribution of R&D is highly right skewed (Kothari et al. 2002). The mean value of the percentage of female directors is about 10% and the median value of the number of woman board directors is 1. These statistics are similar to those reported in previous studies (Farrell and Hersch 2005; Adams and Ferreira 2009; Gul et al. 2011; Chen et al. 2016). Consistent with prior literature, the mean values of $Earnings_{t+5}$ and OCF_{t+5} are 0.045 and 0.157, respectively. Similar to R&D expenditure, patents and patent citations are also highly right skewed, with median values of 0, lower than the mean values. *Log(sales)*, which proxies for productivity, has a mean value of 7.465 and median value of 7.331. The remaining variables are also consistent with prior studies (e.g., Atanassov 2013; Gu 2005; Pandit et al. 2011; Block 2012).

[Insert Table 1 Around Here]

Univariate correlations of the variables in different models are presented in Table 2. The results show a negative association between female directors (*femalepct*, *fdir*) and R&D, which is consistent with Gul (2008). The results also show that R&D investment is associated with a greater amount of innovation output and larger sales.

[Insert Table 2 Around Here]

Regression Results on Board Gender Diversity and R&D Performance

Table 3 reports the regression results for the relationship between board gender diversity and R&D performance. In columns (1) and (2), we use future earnings to measure future firm performance. In columns (3) and (4) we use future operating cash flow to measure future firm performance. Female directors are measured as either the percentage of female directors (in odd columns) or the number of female directors (in even columns). The results show that the coefficients on *RD* are positive and significant in all specifications, suggesting that R&D investments are associated with higher future performance. The variable of interest, *Female*RD*, has significantly positive coefficients in all columns, which is consistent with female directors increasing the elasticity of R&D spending on future firm performance.

The coefficients on *Size* are significantly negative when the dependent variable is future earnings but are not significant in the future operating cash flow model. The coefficients on *HHI* (HHI^2) are negative and significant, suggesting a nonlinear relationship between industry concentration and future performance. The coefficients on *Lev* are significantly positive, which is consistent with the governance role played by leverage.

[Insert Table 3 Around Here]

Regression Results on Board Gender Diversity and Innovation Output of R&D Investment

In Table 4, we present the results on the impact of female directors on the two measures of innovation output, namely patents and patent citations. The dependent variables are patents in columns (1) to (4) and patent citations in columns (5) to (8). Female directors are measured as the percentage of female directors in columns (1), (2), (5) and (6) and as the number of female directors in other columns. In all models the coefficients on *RD* are positive and significant, which suggests that higher inputs in the innovation process lead to higher outputs. The coefficients on *Female* are significantly positive. More interestingly, the coefficients on the interaction terms between *Female* and *RD* are also significantly positive. These results are consistent with the notion that an increased number of female directors on boards is associated with not only higher innovation outputs but also a stronger capacity to convert innovation inputs to outputs. Overall, the findings reject our second hypothesis (H2a) by suggesting that board gender diversity enhances higher R&D-generated outputs.

The coefficients on the control variables are largely consistent with previous findings in the literature (e.g., Atanassov 2013). *Size* has positive and significant coefficients, indicating that larger firms have more patents and more citations. Industry concentration and mean industry leverage have no significant impact on innovation. More mature and profitable firms have higher innovation outputs, as evidenced by the positive coefficients on *Age* and *Profit*. The coefficients on *Tang* are positive in the first four columns, suggesting that more tangible assets have more patents. In terms of board characteristics, both board independence and the separation of CEO and chairman positions have a positive impact while board multiple directorship does not exert a significant impact on innovation outputs.

[Insert Table 4 Around Here]

Regression Results on Board Gender Diversity and R&D Productivity

Table 5 reports results regarding the relationship between board gender diversity and R&D-generated sales. The dependent variables are *Log(Sales)* in all columns. Again female directors are measured as the percentage of female directors (in odd columns) and as the number of female directors (in even columns). In columns (3) and (4), we use lag values of *Female* as we expect a lagged effect on sales revenue. The results show positive and significant coefficients on *RD*, indicating that firms with more R&D investment are associated with a higher level of productivity. The coefficients on *Female*RD* are significantly positive in three out of four regressions, suggesting that board gender diversity strengthens the positive impact of R&D on firm productivity. The results reject our second hypothesis (H2b) and support the notion that board gender diversity increases R&D performance by enhancing firm productivity.

The coefficients on the control variables are consistent with prior studies (e.g., Block 2012). Firms that are larger, more mature, and less geared are associated with higher productivity. Industry concentration has a positive impact, suggesting that companies operating in a concentrated industry might benefit from monopoly power and therefore earn higher revenues (Mueller 1977; Eaton and Lipsey 1981). However, such a relationship is not linear, which is supported by the significantly negative coefficients on HHI^2. Finally, firms with directors sitting on multiple boards also display higher productivity.

[Insert Table 5 Around Here]

Analysis of Endogeneity

Although the findings thus far support our hypotheses, our study may be subject to endogeneity concerns. One potential endogeneity concern is omitted correlated variable. That is, certain firm characteristics lead to both greater representation of women board directors and higher R&D performance/output/productivity. Another concern arises from reverse causality in that it is plausible that firms with better R&D performance/output/productivity tend to appoint more female directors on boards. In order to assuage these endogenous problems, we following prior studies (Hillman et al. 2007; Gul et al. 2011； Chen et al. 2016) and estimate a prediction model for the representation of female directors to generate unexplained female directorship. We then test how the unexplained female directorship affects our dependent variables.

The prediction model is presented below:

$$\begin{aligned}&\mathrm{Female}_{i,t} = \mathrm{d}_0 + \mathrm{d}_1 ROA_{i,t} + \mathrm{d}_2 Tobq_{i,t} + \mathrm{d}_3 \mathrm{Re}t_{i,t} + \mathrm{d}_4 Vwretd_{i,t} + \mathrm{d}_5 Growth_{i,t} + \\&\mathrm{d}_6 \mathrm{Risk}_{i,t} + \mathrm{d}_7 \mathrm{DT}_{i,t} + \mathrm{d}_8 Size_{i,t} + \mathrm{d}_9 Age_{i,t} + \mathrm{d}_{10} \mathrm{F}emaleCEO_{i,t} + \mathrm{d}_{11} \mathrm{F}emaleChair_{i,t} \\&+ \mathrm{Firm}_{i,t} + \mathrm{Year}_{i,t} + \varepsilon \qquad (4)\end{aligned}$$

The first set of control variables are accounting performance (*ROA*) and market performance variables including Tobin's Q (*Tobq)*, annual stock returns (*Ret)*, and annual value-weighted stock returns (*Vwretd*). The reason why we control performance variables in the prediction model is that Adams and Ferreira (2009) suggest that firm performance is an important determinant of board gender diversity. We then control for sales growth (*Growth)*, firm risk (*Risk*, calculated as standard deviation in daily returns over a fiscal year), and firm complexity measure (*DT*) because firms with higher growth, greater risks and higher complexity are characterized by increased information asymmetry and therefore have higher demand for greater representation of woman directors on board to provide more rigorous monitoring. Firm size (*Size*) is controlled because larger firms are normally associated with more diverse boards. *Age* is also controlled because firms with longer history might have higher female representation. Because firms managed by female executives tend to appoint female directors on boards, we also include two dummy variables to control for this effect. One is *Female CEO* that equals 1 if the CEO is female and 0 otherwise and the other is *Female Chair* that equals 1 if the chair of the board is female and 0 otherwise. ε, the residual of the predication mode, captures the unexplained female directorships.

[Insert Table 6 Around Here]

Table 6, Panel A reports the regression results of equation (4). The dependent variables in odd columns are *femalepct* and those in even columns are *fdir*. The presented results are generally consistent with our argument above. Panel B shows the regression results of equation (1) where the independent variable *Female* is replaced by unexplained female directorship (i.e., *Residual* from the predication model). The results show that the coefficients on *Residual*RD* are positive and significant in three out of four specifications, which is consistent with our main analysis. Panel C presents the regression results of equation (2) where the independent variable *Female* is replaced by unexplained female directorship. The results remain qualitatively unchanged. Specifically, the coefficients on *Residual* are significantly positive in four columns. The interaction term *Residual*RD* has significantly positive coefficients in all specifications. Panel D shows the relationship between unexplained female directorship and R&D productivity. Similar to the above findings, the coefficients on *Residual*RD* are positive and significant in both columns. Taken together, the results are consistent with our main findings reported in Tables 3, 4 and 5.

V. CONCLUDING REMARKS

In this study, we examine whether and how female directors enhance innovation performance. We examine this empirical question using a large sample of U.S. firms. Using R&D to proxy for innovation input, we find that greater representation of women board directors are associated with a stronger relation between R&D and future firm performance proxied by earnings or operating cash flow, suggesting a positive impact of board gender diversity on innovation performance.

There are two potential channels through which R&D may contribute to increased firm performance (Pandit et al. 2011; Block 2012). One is the number of patents and patent citations generated by R&D investment and the other is the increased sales revenue brought by R&D (Trajtenberg 1990). Accordingly, we further explore these channels by examining whether female directors increase R&D investment outputs and R&D productivity. Our results show that more female directors are associated with both higher R&D innovation output (measured by the sensitivity of patents and citations to R&D) and greater R&D productivity (proxied by the sensitivity of future sales to R&D). Our results are robust to endogeneity tests.

The employment of female directors has long been regarded as a way to improve corporate governance and firm management. However, there are still concerns about the role of female directors in innovation activities (Khanna 2013). Very few studies examine the role of female directors in managerial decision-making related to innovation. By documenting a positive relationship between female directors and R&D performance as well as the potential drivers underlying the relationship, this paper contributes to this gap in the literature and sheds light on the influence of gender within corporate innovation.

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Table 1 Descriptive Statistics

Variable	No.	Mean	Std.	Median	25^{th}	75^{th}
Panel A. R&D Performance Model (1998-2008)						
$Earnings_{t+5}$	10,157	0.045	0.092	0.063	0.037	0.085
OCF_{t+5}	10,157	0.157	0.108	0.135	0.095	0.189
RD	10,157	1.805	2.280	0.000	0.000	3.610
femalepct	10,157	0.094	0.088	0.100	0.000	0.143
Fdir	10,157	0.949	0.918	1.000	0.000	1.000
Size	10,157	7.656	1.590	7.482	6.506	8.657
HHI	10,157	0.242	0.192	0.186	0.102	0.314
HHI^2	10,157	0.096	0.162	0.035	0.010	0.099
Lev	10,157	0.226	0.177	0.218	0.064	0.345
Age	10,157	24.923	19.290	18.929	9.923	34.107
Independence	10,157	0.669	0.171	0.700	0.563	0.800
Duality	10,157	0.713	0.453	1.000	0.000	1.000
Multiple	10,157	0.952	0.709	0.857	0.400	1.375
Panel B. R&D Output Model (1998-2003)						
$Log(1+Patent)_{t+3}$	7,351	0.407	0.823	0.000	0.000	0.384
$Log(1+Citation)_{t+3}$	7,351	0.364	0.834	0.000	0.000	0.207
RD	7,351	1.715	2.195	0.000	0.000	3.467
femalepct	7,351	0.084	0.084	0.091	0.000	0.133
Fdir	7,351	0.863	0.886	1.000	0.000	1.000
Size	7,351	7.536	1.621	7.316	6.335	8.577
HHI	7,351	0.225	0.180	0.177	0.090	0.299
HHI^2	7,351	0.083	0.139	0.031	0.008	0.090
MiLev	7,351	0.234	0.117	0.228	0.137	0.316
Age	7,351	23.244	18.677	17.595	8.510	31.104
Profit	7,351	0.057	0.108	0.052	0.016	0.104
Tang	7,351	0.284	0.229	0.226	0.102	0.420
Independence	7,351	0.631	0.183	0.667	0.500	0.778
Duality	7,351	0.819	0.385	1.000	1.000	1.000
Multiple	7,351	0.965	0.771	0.833	0.333	1.429
Panel C. R&D Productivity Model (1999-2013)						
Log(Sales)	17,427	7.465	1.489	7.331	6.413	8.436
RD	17,427	1.716	2.275	0.000	0.000	3.564
femalepct	17,427	0.106	0.093	0.111	0.000	0.167
Fdir	17,427	1.066	0.967	1.000	0.000	2.000
Size	17,427	7.847	1.642	7.668	6.627	8.912
HHI	17,427	0.244	0.202	0.186	0.097	0.321
HHI^2	17,427	0.100	0.173	0.035	0.009	0.103
Lev	17,427	0.224	0.177	0.212	0.066	0.340
Age	17,427	25.784	18.925	19.929	11.595	35.107
Independence	17,427	0.717	0.157	0.750	0.625	0.846
Duality	17,427	0.592	0.492	1.000	0.000	1.000
Multiple	17,427	0.917	0.639	0.833	0.429	1.333

This table provides the descriptive statistics of all variables used in the main regression models. Panels A, B, and C show the statistics for the variables in the R&D performance model, R&D output model and R&D productivity model, respectively. All variables other than dummy variables are winsorized at the bottom and top 1% levels. $Earnings_{t+5}$ is calculated as the mean of net income deflated by lagged market value of equity over years *t+1* through *t+5*. OCF_{t+5} is calculated as the mean of cash flows from operations deflated by lagged market value of equity over years *t+1* through *t+5*. *RD* is research and development expenditure, computed as the natural logarithm of one plus R&D expenditure at the end of year *t*. *femalepct* is female directors as a percentage of all directors on the board. *fdir* is the number of female directors on the board. *Size* is firm size, computed as the natural logarithm of total assets. *HHI* is industry concentration, computed as the sum of the squared market shares of the firms in each four-digit SIC industry. *Lev* is leverage, computed as the ratio of long-term debt to the total assets. *Age* is firm age, computed as the number of years since the firm first appeared on the *Compustat* or *CRSP*, whichever is earlier. *Independence* is board independence, computed as the number of independent directors as a percentage of the total number of directors. *Duality* is a dummy variable coded as 1 if the CEO also acted as the chair of the board. *Multiple* is multiple directorships, computed as the average number of outside directorships in other firms held by independent directors. *Patent* is computed as the number of patents for each firm-year divided by the mean number of patents for the same year. *Citation* is computed as the number of citations for each firm year divided by the mean number of citations for the same year. *MiLev* is mean industry leverage, computed as the mean industry equity divided by total assets. *Profit* is profitability, computed as net income before R&D divided by total assets. *Tang* is tangible assets, computed as net property plant and equipment divided by assets. *Sales* is the sales revenue in year *t*.

Table 2 Correlation

This table presents the Pearson (above the diagonal) and Spearman rank (below the diagonal) correlation coefficients of the variables used in the regressions in this paper. Panel A includes the variables used in the R&D performance model; Panel B includes the variables used in the R&D output model; and Panel C includes the variables used in the R&D productivity model. Bold text in all panels indicates significance at the 0.05 level or better (two-tailed). See Table 1 for variable definitions.

Panel A. R&D Performance Model

Variable	$Earnings_{t+5}$	OCF_{t+5}	*Log(1+RD)*	*femalepct*	*fdir*	*Size*	*HHI*	HHI^2	*Lev*	*Age*	*Independence*	*Duality*	*Multiple*
$Earnings_{t+5}$	1.000	0.009	**0.089**	**0.080**	**0.090**	**0.048**	0.007	0.001	**-0.040**	**0.114**	**0.027**	0.018	**0.036**
OCF_{t+5}	**0.318**	1.000	**-0.048**	**0.065**	**0.075**	**0.094**	**-0.065**	**-0.055**	**0.212**	**0.034**	0.013	-0.007	0.008
Log(1+RD)	**0.082**	**-0.039**	1.000	0.018	**0.022**	**0.095**	**0.087**	**0.077**	**-0.136**	**0.133**	**0.157**	**0.050**	**0.208**
femalepct	**0.108**	**0.079**	-0.009	1.000	**0.943**	**0.310**	**0.044**	**0.042**	**0.068**	**0.243**	**0.243**	**0.040**	**0.185**
fdir	**0.126**	**0.094**	-0.017	**0.951**	1.000	**0.439**	**0.044**	**0.047**	**0.109**	**0.310**	**0.239**	**0.067**	**0.233**
Size	**0.102**	**0.135**	0.013	**0.312**	**0.439**	1.000	-0.018	0.012	**0.248**	**0.388**	**0.180**	**0.115**	**0.376**
HHI	0.018	**-0.092**	**0.100**	**0.038**	**0.035**	**-0.074**	1.000	**0.943**	-0.004	**0.099**	**0.036**	**0.024**	**0.080**
HHI^2	0.018	**-0.092**	**0.100**	**0.038**	**0.035**	**-0.074**	**1.000**	1.000	**0.024**	**0.106**	**0.045**	**0.024**	**0.062**
Lev	**0.032**	**0.245**	**-0.150**	**0.084**	**0.131**	**0.294**	**-0.040**	**-0.040**	1.000	**0.148**	0.005	**0.089**	**0.104**
Age	**0.153**	**0.086**	**0.048**	**0.224**	**0.306**	**0.357**	**0.054**	**0.054**	**0.168**	1.000	**0.252**	**0.102**	**0.200**
Independence	**0.061**	**0.076**	**0.150**	**0.252**	**0.256**	**0.194**	0.016	0.016	**0.049**	**0.232**	1.000	-0.013	**0.165**
Duality	**0.023**	0.006	**0.044**	**0.049**	**0.075**	**0.112**	0.016	0.016	**0.099**	**0.067**	-0.013	1.000	**0.121**
Multiple	**0.058**	**0.022**	**0.200**	**0.199**	**0.259**	**0.372**	**0.098**	**0.098**	**0.111**	**0.153**	**0.211**	**0.114**	1.000

Panel B. R&D Output Model

Variable	*Log(1+Patent)*$_{t+3}$	*Log(1+Citation)*$_{t+3}$	*RD*	*femalepct*	*fdir*	*Size*	*HHI*	*HHI*^{2}	*MiLev*	*Age*	*Profit*	*Tang*	*Independence*	*Duality*	*Multiple*
Log(1+Patent)$_{t+3}$	1.000	**0.944**	**0.724**	**0.062**	**0.083**	**0.236**	**0.095**	**0.086**	**-0.156**	**0.205**	**0.178**	**-0.095**	**0.144**	**0.066**	**0.239**
Log(1+Citation)$_{t+3}$	**0.893**	1.000	**0.665**	**0.037**	**0.051**	**0.210**	**0.054**	**0.047**	**-0.181**	**0.145**	**0.161**	**-0.108**	**0.111**	**0.052**	**0.208**
RD	**0.732**	**0.668**	1.000	-0.004	-0.017	**0.042**	**0.112**	**0.095**	**-0.282**	**0.106**	**0.237**	**-0.199**	**0.150**	**0.040**	**0.213**
femalepct	0.016	-0.004	**-0.032**	1.000	**0.930**	**0.282**	**0.028**	**0.035**	**0.096**	**0.244**	**0.048**	**0.034**	**0.223**	**0.105**	**0.205**
fdir	0.010	-0.006	**-0.056**	**0.948**	1.000	**0.435**	0.010	**0.029**	**0.126**	**0.314**	**0.024**	**0.038**	**0.227**	**0.130**	**0.249**
Size	**0.062**	**0.066**	**-0.030**	**0.297**	**0.429**	1.000	**-0.072**	-0.017	**0.154**	**0.382**	**-0.089**	-0.016	**0.170**	**0.189**	**0.361**
HHI	**0.147**	**0.111**	**0.130**	0.010	-0.015	**-0.135**	1.000	**0.944**	**0.050**	**0.090**	**0.026**	**-0.047**	0.013	0.015	**0.085**
HHI^2	**0.147**	**0.111**	**0.130**	0.010	-0.015	**-0.135**	**1.000**	1.000	**0.056**	**0.104**	0.016	**-0.034**	**0.035**	**0.033**	**0.060**
MiLev	**-0.190**	**-0.194**	**-0.285**	**0.100**	**0.131**	**0.172**	**0.036**	**0.036**	1.000	**0.224**	**-0.146**	**0.515**	-0.001	**0.045**	**0.035**
Age	**0.077**	**0.052**	-0.004	**0.238**	**0.322**	**0.353**	**0.033**	**0.033**	**0.220**	1.000	**0.034**	**0.183**	**0.255**	**0.137**	**0.213**
Profit	**0.281**	**0.279**	**0.350**	0.016	**-0.025**	**-0.226**	**0.107**	**0.107**	**-0.210**	**-0.025**	1.000	**-0.052**	-0.000	**-0.025**	-0.008
Tang	**-0.052**	**-0.059**	**-0.117**	**0.045**	**0.046**	**-0.032**	**0.040**	**0.040**	**0.528**	**0.186**	0.006	1.000	0.020	**0.029**	-0.008
Independence	**0.152**	**0.108**	**0.142**	**0.232**	**0.241**	**0.177**	**-0.028**	**-0.028**	0.020	**0.234**	**-0.035**	**0.026**	1.000	**0.137**	**0.174**
Duality	**0.038**	**0.035**	**0.028**	**0.116**	**0.140**	**0.191**	-0.014	-0.014	**0.045**	**0.122**	**-0.041**	**0.027**	**0.139**	1.000	**0.133**
Multiple	**0.226**	**0.216**	**0.210**	**0.215**	**0.263**	**0.342**	**0.116**	**0.116**	**0.033**	**0.157**	0.010	**0.036**	**0.215**	**0.136**	1.000

Panel C. R&D Productivity Model

Variable	*Log(Sales)*	*RD*	*femalepct*	*fdir*	*Size*	*HHI*	*HHI*^{2}	*Lev*	*Age*	*Independence*	*Duality*	*Multiple*
Log(Sales)	1.000	**0.100**	**0.352**	**0.458**	**0.820**	**0.117**	**0.101**	**0.164**	**0.411**	**0.192**	**0.103**	**0.415**
RD	0.009	1.000	0.003	0.001	**0.031**	**0.108**	**0.086**	**-0.135**	**0.134**	**0.134**	0.014	**0.213**
femalepct	**0.350**	**-0.025**	1.000	**0.943**	**0.299**	**0.038**	**0.034**	**0.073**	**0.230**	**0.244**	0.003	**0.163**
fdir	**0.457**	**-0.043**	**0.949**	1.000	**0.438**	**0.022**	**0.029**	**0.100**	**0.298**	**0.248**	**0.030**	**0.203**
Size	**0.804**	**-0.054**	**0.303**	**0.440**	1.000	**-0.092**	**-0.041**	**0.234**	**0.358**	**0.199**	**0.096**	**0.317**
HHI	**0.115**	**0.140**	**0.031**	0.007	**-0.156**	1.000	**0.941**	-0.005	**0.098**	**0.042**	-0.011	**0.090**
HHI^2	**0.115**	**0.140**	**0.031**	0.007	**-0.156**	**1.000**	1.000	**0.022**	**0.107**	**0.052**	-0.006	**0.068**
Lev	**0.214**	**-0.148**	**0.095**	**0.130**	**0.288**	**-0.036**	**-0.036**	1.000	**0.120**	**0.016**	**0.074**	**0.118**
Age	**0.362**	**0.050**	**0.210**	**0.288**	**0.335**	**0.041**	**0.041**	**0.140**	1.000	**0.239**	**0.072**	**0.190**
Independence	**0.214**	**0.127**	**0.265**	**0.273**	**0.217**	**0.027**	**0.027**	**0.059**	**0.229**	1.000	**-0.087**	**0.169**
Duality	**0.101**	0.008	**0.003**	**0.031**	**0.087**	**-0.019**	**-0.019**	**0.086**	**0.041**	**-0.076**	1.000	**0.080**
Multiple	**0.421**	**0.202**	**0.180**	**0.224**	**0.309**	**0.119**	**0.119**	**0.128**	**0.141**	**0.220**	**0.062**	1.000

Table 3 Female Directors and R&D Performance

Variables	Dependent Variable: $Earnings_{t+5}$ (1) percentage	(2) number	Dependent Variable: OCF_{t+5} (3) percentage	(4) number
RD	0.011***	0.011***	0.003*	0.003*
	[0.000]	[0.000]	[0.058]	[0.058]
Female	0.008	0.002	-0.015	-0.001
	[0.562]	[0.203]	[0.289]	[0.673]
Female*RD	***0.020****	***0.002****	***0.010***	***0.001**
	[0.000]	***[0.000]***	***[0.029]***	***[0.066]***
Size	-0.036***	-0.037***	0.004	0.004
	[0.000]	[0.000]	[0.156]	[0.157]
HHI	-0.121***	-0.123***	-0.126***	-0.127***
	[0.000]	[0.000]	[0.000]	[0.000]
HHI^2	0.108***	0.109***	0.079***	0.080***
	[0.005]	[0.005]	[0.004]	[0.003]
Lev	0.090***	0.090***	0.112***	0.112***
	[0.000]	[0.000]	[0.000]	[0.000]
Age	0.001**	0.001**	-0.000	-0.000
	[0.021]	[0.020]	[0.697]	[0.717]
Independence	-0.019***	-0.020***	-0.000	-0.001
	[0.005]	[0.005]	[0.961]	[0.880]
Duality	0.000	-0.000	-0.004**	-0.004**
	[0.988]	[0.972]	[0.026]	[0.023]
Multiple	0.001	0.001	0.002	0.002
	[0.469]	[0.456]	[0.325]	[0.327]
Constant	0.261***	0.263***	-0.031	-0.030
	[0.000]	[0.000]	[0.148]	[0.160]
Observations	10,157	10,157	10,157	10,157
Adjusted R^2	0.686	0.686	0.770	0.770

This table presents results regarding the relationship between board gender diversity and R&D performance. The dependent variables are $Earnings_{t+5}$ in columns (1) and (2), and OCF_{t+5} in columns (3) and (4). *Female* is measured as *femalepct* in columns (1) and (3) and as *fdir* in columns (2) and (4). All variables follow the definitions in Table 1. The firm (and year) fixed effects are included, but not reported. Robust P-values are reported in parentheses. *, **, *** denote statistically significant results at the 1%, 5%, and 10% level or better, respectively (two tailed).

Table 4 Female Directors and Innovative Outputs

Variables	Dependent Variable: *Log(1+Patent)*$_{t+3}$ (1) percentage	(2) percentage	(3) number	(4) number	Dependent Variable: *Log(1+Citation)*$_{t+3}$ (5) percentage	(6) percentage	(7) number	(8) number
RD	0.263***	0.251***	0.263***	0.242***	0.248***	0.237***	0.248***	0.230***
	[0.000]	[0.000]	[0.000]	[0.000]	[0.000]	[0.000]	[0.000]	[0.000]
Female	***0.238****	***0.285****	***0.024****	***0.040****	***0.269****	***0.313****	***0.022***	***0.036****
	[0.004]	***[0.001]***	***[0.003]***	***[0.000]***	***[0.003]***	***[0.001]***	***[0.013]***	***[0.000]***
Female*RD		***0.410****		***0.053****		***0.381****		***0.048****
		[0.000]		***[0.000]***		***[0.000]***		***[0.000]***
Size	0.139***	0.139***	0.137***	0.137***	0.139***	0.138***	0.138***	0.137***
	[0.000]	[0.000]	[0.000]	[0.000]	[0.000]	[0.000]	[0.000]	[0.000]
HHI	-0.100	-0.101	-0.100	-0.109	0.157	0.157	0.157	0.149
	[0.765]	[0.762]	[0.764]	[0.739]	[0.678]	[0.679]	[0.678]	[0.690]
HHI^2	0.114	0.123	0.114	0.126	-0.177	-0.169	-0.178	-0.168
	[0.731]	[0.710]	[0.731]	[0.699]	[0.642]	[0.656]	[0.640]	[0.654]
MiLev	0.209	0.200	0.206	0.195	0.138	0.130	0.133	0.124
	[0.165]	[0.181]	[0.173]	[0.194]	[0.421]	[0.447]	[0.436]	[0.469]
Age	0.002***	0.002***	0.002***	0.001**	0.001**	0.001*	0.001**	0.000
	[0.000]	[0.000]	[0.000]	[0.022]	[0.026]	[0.094]	[0.027]	[0.483]
Profit	0.201***	0.178**	0.201***	0.168**	0.218**	0.196**	0.219**	0.190**
	[0.009]	[0.016]	[0.009]	[0.022]	[0.014]	[0.023]	[0.014]	[0.028]
Tang	0.209***	0.203***	0.206***	0.193***	0.093	0.089	0.092	0.080
	[0.000]	[0.001]	[0.000]	[0.001]	[0.160]	[0.186]	[0.168]	[0.235]
Independence	0.061*	0.067*	0.063*	0.066*	0.017	0.023	0.023	0.025
	[0.093]	[0.062]	[0.082]	[0.063]	[0.661]	[0.560]	[0.557]	[0.507]
Duality	-0.029**	-0.030**	-0.029*	-0.030**	-0.031*	-0.032*	-0.030*	-0.031*
	[0.050]	[0.041]	[0.051]	[0.040]	[0.066]	[0.057]	[0.072]	[0.060]
Multiple	-0.007	-0.003	-0.007	0.001	-0.014	-0.010	-0.014	-0.007
	[0.480]	[0.780]	[0.470]	[0.898]	[0.189]	[0.342]	[0.194]	[0.547]
Constant	-1.239***	-1.177***	-1.226***	-1.142***	-1.186***	-1.104***	-1.180***	-1.082***
	[0.000]	[0.000]	[0.000]	[0.000]	[0.000]	[0.000]	[0.000]	[0.000]
Observations	7,351	7,351	7,351	7,351	7,351	7,351	7,351	7,351
Adjusted R^2	0.680	0.687	0.680	0.693	0.618	0.624	0.618	0.628

This table presents results regarding the relationship between board gender diversity and innovation output. The dependent variables are *Log(1+Patent)*$_{t+3}$ in columns (1) to (4), and *Log(1+Citation)*$_{t+3}$ in columns (5) to (8). *Female* is measured as *femalepct* in columns (1), (2), (5), and (6) and as *fdir* in all other columns. All variables follow the definitions in Table 1. The firm (and year) fixed effects are included, but not reported. Robust P-values are reported in parentheses. *, **, *** denote statistically significant results at the 1%, 5%, and 10% level or better, respectively (two tailed).

Table 5 Female Directors and R&D Productivity

Variables	(1) percentage$_{(t)}$	(2) number$_{(t)}$	(3) Percentage$_{(t-1)}$	(4) Number$_{(t-1)}$
	Dependent Variable: *Log(Sales)*			
RD	0.042***	0.043***	0.043***	0.043***
	[0.000]	[0.000]	[0.000]	[0.000]
Female	0.002	0.004	0.009	0.003
	[0.950]	[0.206]	[0.788]	[0.313]
Female*RD	***0.045****	***0.004***	***0.027**	***0.002***
	[0.003]	***[0.017]***	***[0.069]***	***[0.127]***
Size	0.729***	0.728***	0.729***	0.729***
	[0.000]	[0.000]	[0.000]	[0.000]
HHI	0.140*	0.136*	0.137*	0.135*
	[0.081]	[0.089]	[0.086]	[0.092]
HHI^2	-0.136*	-0.133*	-0.134*	-0.132*
	[0.056]	[0.061]	[0.058]	[0.063]
lev	-0.350***	-0.350***	-0.349***	-0.349***
	[0.000]	[0.000]	[0.000]	[0.000]
Age	0.003**	0.003**	0.003**	0.003**
	[0.031]	[0.029]	[0.030]	[0.029]
Independence	0.023	0.021	0.023	0.022
	[0.281]	[0.321]	[0.272]	[0.287]
Duality	0.005	0.005	0.005	0.005
	[0.384]	[0.399]	[0.384]	[0.397]
Multiple	0.015***	0.015***	0.015***	0.015***
	[0.006]	[0.006]	[0.006]	[0.006]
Constant	-5.737***	-5.732***	-5.739***	-5.736***
	[0.000]	[0.000]	[0.000]	[0.000]
Observations	17,427	17,427	17,427	17,427
Adjusted R^2	0.984	0.984	0.984	0.984

This table presents results regarding the relationship between board gender diversity and R&D productivity. The dependent variable is *Log(Sales)*. *Female* is measured as *femalepct* in columns (1) and (3) and as *fdir* in columns (2) and (4). *Female* is reported as lag values in columns (3) and (4). All variables follow the definitions in Table 1. The firm (and year) fixed effects are included, but not reported. Robust P-values are reported in parentheses. *, **, *** denote statistically significant results at the 1%, 5%, and 10% level or better, respectively (two tailed).

Table 6 Addressing Endogeneity

Panel A: Female directorship prediction model

	Dependent Variable: Female Directorship					
	For R&D Performance		For R&D Output		For R&D Productivity	
	(1)	(2)	(3)	(4)	(5)	(6)
VARIABLES	percentage	number	percentage	number	percentage	number
ROA	0.001	0.037	-0.000	0.011	0.003	0.017
	[0.929]	[0.673]	[0.970]	[0.896]	[0.727]	[0.788]
Tobq	-0.000	0.002	0.000	0.005	-0.002**	-0.021***
	[0.946]	[0.789]	[0.683]	[0.525]	[0.036]	[0.006]
Ret	-0.000	-0.009	-0.001	-0.010	0.001	0.017
	[0.819]	[0.452]	[0.468]	[0.368]	[0.266]	[0.125]
Vwretd	-0.003	-0.053	-0.011	-0.072	-0.006	-0.067
	[0.723]	[0.488]	[0.174]	[0.317]	[0.274]	[0.200]
Growth	-0.000	-0.015	0.000	-0.001	-0.005**	-0.042**
	[0.900]	[0.534]	[0.857]	[0.976]	[0.043]	[0.050]
Risk	-0.002**	-0.026**	-0.002*	-0.022*	-0.000	-0.008
	[0.049]	[0.016]	[0.061]	[0.061]	[0.821]	[0.359]
DT	0.005**	0.057***	0.006***	0.060***	0.003**	0.035**
	[0.010]	[0.004]	[0.002]	[0.001]	[0.042]	[0.028]
Size	-0.001	0.056***	0.002	0.053**	0.000	0.054***
	[0.661]	[0.006]	[0.408]	[0.029]	[0.883]	[0.001]
Age	0.000	0.001	0.000	0.000	-0.000	-0.003
	[0.617]	[0.596]	[0.941]	[0.887]	[0.289]	[0.161]
Female CEO	0.032***	0.286***	0.039***	0.366***	0.030***	0.282***
	[0.000]	[0.000]	[0.000]	[0.000]	[0.000]	[0.000]
Female Chair	0.013***	0.148***	0.021***	0.229***	0.002	0.022
	[0.002]	[0.000]	[0.000]	[0.000]	[0.665]	[0.558]
Constant	0.060***	0.131	0.018	-0.048	0.064***	0.290**
	[0.001]	[0.403]	[0.382]	[0.798]	[0.000]	[0.025]
Observations	8,019	8,019	6,011	6,011	14,247	14,247
Adjusted R-squared	0.755	0.785	0.795	0.816	0.749	0.771

Panel A presents the regression results of the female directorship prediction model. The dependent variables for columns (1), (3), and (5) are *femalecpt* and the dependent variables for columns (2), (3), and (4) are *fdir*. The residuals of column (1) and (2) are used for the R&D performance model in Panel B; the residuals of column (3) and (4) are used for the R&D output model in Panel C; and the residuals of columns (5) and (6) are used for the R&D productivity model in Panel D. *ROA* is net income before R&D expenditures (adjusted for the tax saving of R&D expenditures) scaled by total assets. *Tobq* is Tobin's Q, calculated as the ratio of total assets minus book value of equity plus market value to total assets. *Ret* is annual stock return during the fiscal year. *Vwretd* is value-weighted annual market return during the fiscal year. *Growth* is the annual growth rate of sales. *Risk* is standard deviation in daily returns over the fiscal year (standardized to mean of 0 and standard deviation of 1). *DT* is computed as $\sum_{i=1}(P_i*\ln(1/P_i))$ where P_i is the share of the i^{th} industry segment in the total sales of the firm. Industries are classified according to the four-digit SIC code in which the firm operates. *Female CEO* is a dummy variable coded as 1 if the CEO is female and 0 otherwise. *Female Chair* is a dummy variable coded as 1 if the chair of the board is female and 0 otherwise. The remaining variables follow the definitions in Table 1. The firm (and year) fixed effects are included, but not reported. Robust P-values are reported in parentheses. *, **, *** denote statistically significant results at the 1%, 5%, and 10% level or better, respectively (two tailed).

Panel B: Association between unexplained female directorship and R&D Performance

Variables	Dependent Variable: $Earnings_{t+5}$ (1) percentage	(2) number	Dependent Variable: OCF_{t+5} (3) percentage	(4) number
RD	0.009***	0.009***	0.005***	0.005***
	[0.000]	[0.000]	[0.002]	[0.001]
Residual	0.001	0.001	-0.025*	-0.002
	[0.938]	[0.375]	[0.089]	[0.125]
Residual *RD	***0.011****	***0.001****	***0.009****	***0.001***
	[0.035]	***[0.097]***	***[0.062]***	***[0.325]***
Size	-0.033***	-0.034***	0.001	0.002
	[0.000]	[0.000]	[0.594]	[0.559]
HHI	-0.096***	-0.097***	-0.113***	-0.114***
	[0.005]	[0.004]	[0.000]	[0.000]
HHI^2	0.073*	0.074*	0.049*	0.050*
	[0.072]	[0.068]	[0.093]	[0.086]
Lev	0.092***	0.092***	0.131***	0.131***
	[0.000]	[0.000]	[0.000]	[0.000]
Age	0.000	0.000	0.000	0.000
	[0.172]	[0.170]	[0.790]	[0.776]
Independence	-0.004	-0.005	0.002	0.002
	[0.553]	[0.504]	[0.764]	[0.814]
Duality	-0.000	-0.000	-0.002	-0.002
	[0.994]	[0.998]	[0.287]	[0.278]
Multiple	0.000	0.001	-0.000	-0.000
	[0.772]	[0.755]	[0.861]	[0.860]
Constant	0.228***	0.229***	-0.019	-0.020
	[0.000]	[0.000]	[0.372]	[0.361]
Observations	8,019	8,019	8,019	8,019
Adjusted R^2	0.686	0.686	0.782	0.782

Panel B presents the association between unexplained female directorship and R&D performance. The dependent variables are $Earnings_{t+5}$ in columns (1) and (2) and OCF_{t+5} in columns (3) and (4). *Residual* is the unexplained component of female directorships, measured as the residual values obtained from model (4). Specifically, in columns (1) and (3) we use *femalecpt* as the dependent variable in model (4). In columns (2) and (4) we use *fdir* as the dependent variable in model (4). All variables follow the definitions in Table 1. The firm (and year) fixed effects are included, but not reported. Robust P-values are reported in parentheses. *, **, *** denote statistically significant results at the 1%, 5%, and 10% level or better, respectively (two tailed).

Panel C: Association between unexplained female directorship and Innovation Output

Variables	Dependent Variable: *Log(1+Patent)*$_{t+3}$				Dependent Variable: *Log(1+Citation)*$_{t+3}$			
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
	percentage	percentage	number	number	percentage	percentage	number	number
RD	0.257***	0.257***	0.257***	0.256***	0.242***	0.242***	0.242***	0.241***
	[0.000]	[0.000]	[0.000]	[0.000]	[0.000]	[0.000]	[0.000]	[0.000]
Residual	***0.123***	***0.141***	**0.025****	***0.030******	***0.158***	***0.178***	***0.022****	***0.026*****
	[0.175]	***[0.151]***	**[0.012]**	***[0.008]***	***[0.121]***	***[0.106]***	***[0.050]***	***[0.039]***
Residual *RD		**0.126***		**0.021*****		**0.147****		**0.019****
		[0.054]		**[0.003]**		**[0.048]**		**[0.023]**
Size	0.142***	0.142***	0.142***	0.142***	0.143***	0.144***	0.144***	0.144***
	[0.000]	[0.000]	[0.000]	[0.000]	[0.000]	[0.000]	[0.000]	[0.000]
HHI	0.130	0.129	0.127	0.121	0.315	0.313	0.316	0.311
	[0.698]	[0.703]	[0.704]	[0.718]	[0.411]	[0.415]	[0.409]	[0.417]
HHI^2	-0.103	-0.097	-0.099	-0.091	-0.311	-0.304	-0.311	-0.304
	[0.756]	[0.769]	[0.763]	[0.783]	[0.416]	[0.427]	[0.416]	[0.427]
MiLev	0.021	0.029	0.022	0.038	-0.073	-0.064	-0.074	-0.060
	[0.890]	[0.846]	[0.882]	[0.799]	[0.664]	[0.706]	[0.662]	[0.723]
Age	0.002***	0.002***	0.002***	0.002***	0.002***	0.002***	0.002***	0.002***
	[0.000]	[0.000]	[0.000]	[0.000]	[0.006]	[0.006]	[0.006]	[0.007]
Profit	0.174**	0.175**	0.175**	0.177**	0.176*	0.176*	0.176*	0.177*
	[0.027]	[0.025]	[0.026]	[0.023]	[0.058]	[0.056]	[0.058]	[0.055]
Tang	0.177***	0.181***	0.174***	0.181***	0.067	0.072	0.065	0.071
	[0.003]	[0.002]	[0.003]	[0.002]	[0.316]	[0.286]	[0.332]	[0.292]
Independence	0.052	0.052	0.046	0.043	0.004	0.004	0.003	-0.000
	[0.178]	[0.178]	[0.226]	[0.262]	[0.929]	[0.930]	[0.950]	[0.992]
Duality	-0.028*	-0.029*	-0.028*	-0.030*	-0.034*	-0.036**	-0.034*	-0.036**
	[0.071]	[0.062]	[0.069]	[0.058]	[0.054]	[0.047]	[0.054]	[0.047]
Multiple	-0.011	-0.011	-0.012	-0.010	-0.020*	-0.020*	-0.021*	-0.020*
	[0.283]	[0.303]	[0.269]	[0.326]	[0.074]	[0.082]	[0.071]	[0.088]
Constant	-1.240***	-1.162***	-1.238***	-1.162***	-1.179***	-1.093***	-1.178***	-1.094***
	[0.000]	[0.000]	[0.000]	[0.000]	[0.000]	[0.000]	[0.000]	[0.000]
Observations	6,011	6,011	6,011	6,011	6,011	6,011	6,011	6,011
Adjusted R^2	0.688	0.689	0.688	0.690	0.625	0.626	0.625	0.626

Panel C presents the association between unexplained female directorship and R&D output. The dependent variables are *Log(1+Patent)*$_{t+3}$ in columns (1) to (4), and *Log(1+Citation)*$_{t+3}$ in columns (5) to (8). *Residual* is the unexplained component of female directorships, measured as the residual values obtained from model (4). Specifically, in columns (1), (2), (5), and (6) we use *femalecpt* as the dependent variable in model (4). In columns (3), (4), (7), and (8) we use *fdir* as the dependent variable in model (4). All variables follow the definitions in Table 1. The firm (and year) fixed effects are included, but not reported. Robust P-values are reported in parentheses. *, **, *** denote statistically significant results at the 1%, 5%, and 10% level or better, respectively (two tailed).

Panel D: Association between unexplained female directorship and R&D Productivity

Variables	Dependent Variable: *Log(SALES)* (1) percentage	(2) number
RD	0.047***	0.047***
	[0.000]	[0.000]
Residual	0.054	0.010***
	[0.154]	[0.008]
Residual *RD	0.052***	0.005***
	[0.001]	[0.004]
Size	0.713***	0.714***
	[0.000]	[0.000]
HHI	0.068	0.064
	[0.451]	[0.473]
HHI^2	-0.116	-0.113
	[0.142]	[0.153]
Lev	-0.347***	-0.348***
	[0.000]	[0.000]
Age	0.003***	0.003***
	[0.004]	[0.004]
Independence	0.036	0.034
	[0.124]	[0.144]
Duality	0.006	0.006
	[0.324]	[0.320]
Multiple	0.021***	0.021***
	[0.000]	[0.000]
Constant	-5.479***	-5.484***
	[0.000]	[0.000]
Observations	14,247	14,247
Adj R^2	0.984	0.984

Panel D presents the association between unexplained female directorship and R&D productivity. The dependent variable is *Log(Sales)*. *Residual* is the unexplained component of female directorships, measured as the residual values obtained from model (4). Specifically, in column (1) we use *femalecpt* as the dependent variable in model (4). In column (2) we use *fdir* as the dependent variable in model (4). All variables follow the definitions in Table 1. The firm (and year) fixed effects are included, but not reported. Robust P-values are reported in parentheses. *, **, *** denote statistically significant results at the 1%, 5%, and 10% level or better, respectively (two tailed).