Female board representation, corporate innovation and firm performance

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ABSTRACT

We show evidence that female board representation is associated with greater innovative success, and thus enhances firm performance in innovation-intensive industries. Firms with female directors tend to invest more in innovation and obtain more patents and citations for given R&D expenditures. An increase of 10 percentage points in the tenure-weighted fraction of female directors is associated with approximately 6% more patents and 7% more citations. Investigating the underlying mechanisms, the positive association between female board representation and corporate innovation is stronger when product market competition is lower and when managers are more entrenched, consistent with increased monitoring by female directors improving managers' incentives to innovate. Furthermore, we find that female board representation is positively associated with performance only for firms for which innovation and creativity play a particularly important role.

JEL classification: G30, G34, J16, O31, O34

Keywords: Female board representation; Board of directors; Corporate innovation; Firm performance

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1. Introduction

Board gender composition has gained substantial attention over the past decade in light of growing regulatory pressure on firms to address the underrepresentation of women in the boardroom. Some countries such as Norway, France, and Italy have enacted binding gender quotas, whereas others, including the UK and Spain, have taken a "soft" approach to regulation, which provides recommendations that encourage, rather than require, greater female board representation (Smith, 2014). Parallel to and reinforcing these governance reform efforts is a growing body of research examining whether corporate outcomes can be influenced by more women on boards and the potential governance mechanisms that achieve them (e.g., Adams and Ferreira, 2009; Ahern and Dittmar, 2012; Masta and Miller, 2013; Adams and Ragunathan, 2015). The critical insight from this literature is that gender differences in the boardroom matter, especially in relation to monitoring effectiveness, meaning that some firms may benefit from increased representation by female directors.

In this paper, we attempt to investigate and emphasize the impact of female directors by focusing on corporate innovation. More precisely, we investigate the following questions. Does the existing evidence for the influence of women on boards extend to corporate innovation outcomes? Second, given the importance of innovation in driving economic growth, does the effect (if any) of board gender composition on innovation translate into improved corporate performance? If board gender diversity matters for innovation and performance, do firms in innovation-intensive industries benefit more from female board representation than others?

Innovation is a key determinant of firm- and national-level competitiveness (see Porter, 1992, and Solow, 1957, respectively) and innovation productivity is of interest to a large number of stakeholders such as firm managers, employees, and investors (Fang, Tian and Tice, 2014). Yet, agency problems associated with innovation are likely to be severe for at least two reasons. First, risk-averse managers who are concerned about job security may reduce risky investments in innovation in favor of investments in less risky, routine projects (O'Connor and Rafferty, 2012). Second, managers may prefer a quiet life (Bertrand and

Mullainathan, 2003) and dislike the costly efforts associated with innovation projects. Therefore, monitoring has to be intensified to improve the governance of innovation.[1]

The extant literature suggests that female directors enhance the effectiveness of internal governance as a greater representation of women on the board is associated with more effort on monitoring (Adams and Ferreira, 2009), increased public disclosure and stock price informativeness (Gul, Srinidni and Ng, 2011), greater board independence and activism (Adams, Gray and Nowland, 2010; Perrault, 2015), and improved board deliberations of complex issues (Huse and Solberg, 2006). Thus, it is plausible that female directors help mitigate agency problems and could encourage firm innovation by providing effective monitoring. On the other hand, intense monitoring by female directors could also undermine innovation if it promotes managerial myopia and leads managers to reduce long-term investments in innovation (Faleye, Hoitash and Hoitash, 2011; Becker-Blease, 2011). Whether increased monitoring by female directors enhances or impedes corporate innovation therefore requires empirical investigation.[2]

We first examine the relation between female board representation and various measures of corporate innovation. We measure the firm's investment in innovation by the level of research and development (R&D) expenditures and innovation productivity by patent and citation counts. We find that female board representation is positively associated with both R&D expenditures and innovation output. Controlling for R&D expenditure, boards with female directors remain associated with more patents and citations. Specifically, we find

[1] Atanassov (2013), Aghion, Van Reenen and Zingales (2013) and Bernstein (2015) provide supportive evidence demonstrating the importance of strong corporate governance for improving innovation. Managers innovate less when the monitoring provided by takeover threats and investors is reduced.

[2] We acknowledge another strand of the literature that considers risk aversion. Evidence on population gender differences suggests that women are generally more risk averse than men (see the survey by Croson and Gneezy (2009)). However, Adams and Funk (2012) and Adams and Ragunathan (2015) argue that gender differences in the general population may differ from those in the boardroom because of self-selection (women at the top of the corporate ladder may be quite different from those in the general population) or adaptive behavior to the requirement of the job. They provide evidence that female directors are less risk-averse than male directors in their sample. More generally, Nelson (2015) revisits the evidence on gender differences in risk-perception and risk-taking through a different lens and suggests that traditional inferences, supporting higher risk aversion among females, are in fact far more mixed. Thus, if boards with female directors behave in a less conservative manner and engage in more risk-taking activities, we may expect a positive relation between female board representation and firm innovation. However, we do not focus on the risk aversion explanation for two reasons. First, risk aversion is largely unobserved, which limits our ability to test this explanation explicitly. Second, this explanation is hard to reconcile with the findings of our split sample analysis in Sections 5.1 and 5.2, although we are careful to recognize that our analysis does not allow us to completely rule out this alternative explanation.

that an increase of 10 percentage points in the tenure-weighted fraction of female directors is associated with approximately 6% more patents and 7% more citations. The findings are robust to the use of alternative econometric specifications and subsamples.

A potential concern with the interpretation of our baseline results is that the fraction of female directors on the board is likely to be endogenous. Unobservable factors correlated with both board gender composition and corporate innovation could bias the results (the omitted variable concern). Moreover, female directors may self-select better performing firms with high innovation potential (Farrell and Hersch, 2005), or innovative firms may be more responsive to external calls for greater female board representation (the reverse causality concern). We attempt to mitigate these concerns using both propensity score matching and instrumental variable methods. Overall, our positive results continue to hold under these tests.

Our positive relation between female board representation and corporate innovation suggests the presence of effective monitoring that resolves agency problems related to innovation. Therefore, we explore possible mechanisms through which greater monitoring by female directors enhances innovation. There are two important, established theoretical arguments explaining the positive relation between monitoring and corporate innovation. The first is that managers prefer a quiet life (Bertrand and Mullainathan, 2003; Holmström, 1989) and dislike costly efforts associated with innovation projects (e.g., it may require deviating from standard routines). Greater monitoring by female directors could mitigate this agency problem, reducing managers' incentives to shirk and keeping them focused on pursuing innovative and value-creating projects (the quiet life hypothesis).

The second argument is based on the career concern model of Aghion, Van Reenen and Zingales (2013). Risky innovation activities may cost managers their jobs if innovation failures are attributed to poor managerial skill, leading to an aversion to innovate. However, through increased monitoring, which encourages managers to innovate and reveal their talent, boards with female directors acquire more information about managers' abilities before, and independent of, revenue realizations. In turn, this may allow the board to distinguish skillful managers suffering unlucky negative outcomes from poor managers. This insulation for managers from adverse reputational consequences of innovation (the career concern hypothesis) encourages them to innovate in the first place to reveal their ability, initiative and talent.

To distinguish between the quiet life and career concern hypotheses, we conduct tests based on heterogeneity in the relation between female board representation and innovation. The quiet life hypothesis predicts that product market competition and female board representation should be *substitutes* (Aghion, Van Reenen and Zingales, 2013). When competition is low, the manager is not forced to work harder and there is more need for greater monitoring. Similarly, greater monitoring by female directors should be particularly important when managers are more entrenched. In contrast, the career concern hypothesis makes the opposite predictions.[3] Consistent with the quiet life hypothesis, we find that the positive relation between female board representation and innovation is stronger when product market competition is lower and when managers are more entrenched.

Finally, having established the positive association (and potential mechanism) between female board representation and greater innovative success, we examine its relevance for firm performance in industries with different dependency on innovation intensity. We find that women on boards are valuable only for firms in innovation-intensive industries where innovation and creativity play a significant role. This finding is consistent with the view that greater innovative success of firms with female directors translates into better corporate outcomes in innovation-intensive industries.

Our paper contributes to several strands of literature. First, it contributes to the debate over whether and how female representation on the board matters for corporate outcomes. Adams and Ferreira (2009), Ahern and Dittmar (2012), and Masta and Miller (2013) document negative effects of female board representation on firm performance. Using a sample of listed banks, Adams and Ragunathan (2015) find that the presence of women on boards is positively associated with measures of bank performance. Their findings suggest

[3] Specifically, the career concern hypothesis predicts that product market competition and female board representation should be *complements*. In highly competitive environments, corporate outcomes become more uncertain, which increases the reputational risk faced by the manager. Thus, protection against the reputational risk of negative shocks provided by monitoring becomes particularly important. Moreover, this hypothesis predicts that the effect of female board representation should be weaker when managers are more entrenched (and shareholders and the board have less power to restrain managers). See Aghion, Van Reenen and Zingales (2013) for more details.

ambiguity in the evidence on the relation between female representation and performance and imply greater depth in the heterogeneity across industries. Our paper complements this recent work by confirming that female board representation is indeed valuable in certain industries, our contribution demonstrating this value in firms for which innovation and creativity play an important role. Specifically, we find that the top four industries in which female board representation creates value via increasing corporate innovation are pharmaceuticals, computer software, electronic equipment and chemicals.

Second, our paper adds to the growing literature that links firm (or personal) characteristics to innovation. Hirshleifer, Low and Teoh (2012) find that firms run by overconfident CEOs are associated with larger investments in innovation and greater innovation productivity. Tian and Wang (2014) show that IPO firms backed by more failure-tolerant venture capital investors are significantly more innovative. Aghion, Van Reenen and Zingales (2013) document that firms with greater institutional ownership are associated with more innovation. Our results show that firms with greater representation of female directors invest more in innovation and obtain more patents and citations for given R&D expenditures.

Our paper is also related to that of Miller and Triana (2009) who find a positive link between female board representation and firm R&D expenditures. We advance this line of inquiry along two important dimensions. First, we extend beyond the use of R&D expenditures as a proxy for innovation by focusing on a firm's patenting activities. Patenting captures innovation output or productivity, which encompasses how effectively a firm utilizes all of its innovation inputs, both observable and unobservable. R&D expenditures, in contrast, represent only one particular type of observable input to innovation (Aghion, Van Reenen, and Zingales, 2013) and can be subject to several limitations. For instance, Acharya and Subramanian (2009) and Becker-Blease (2011) argue that R&D expenditures are sensitive to accounting norms such as whether it should be capitalized or expensed. Second, we contribute by investigating the role of greater monitoring by female directors in firm innovation. Our findings are consistent with the view that female directors improve firm innovation through effective monitoring.

The rest of the paper is organized as follows. Section 2 describes the sample and measurement of variables. Section 3 discusses the main results and robustness issues. Section 4 addresses identification issues. Section 5 examines the channels through which female directors affect innovation. Section 6 examines whether female board representation enhances firm performance through greater innovation productivity. Section 7 concludes.

2. Data and measures

2.1. Data

We use several databases to construct our sample. Director characteristics, including gender, tenure and other information, are obtained from Riskmetrics, CEO information is collected from ExecuComp, accounting data are from Compustat and stock price information is from CRSP. All accounting variables are winsorized at the 1st and 99th percentiles to reduce the potential impact of outliers.[4] Patent-related data are collected from the 2006 edition of the NBER patent database which is available from 1976 to 2006. The sample includes firms that are at the intersection of these databases. Following the innovation literature, we do not restrict our sample to firms with patents. Firm-year observations with missing data on female board representation measures or any other controls are deleted and financial firms are excluded. The final sample used to examine the relationship between board female representation and one-year-ahead number of patents and citations consists of 1,224 firms from 6,644 firm-year observations over the sample period 1998 to 2006.[5]

2.2. Empirical specification

[4] The results hold without winsorization.

[5] Throughout our empirical analysis, independent variables are lagged one year relative to the dependent variable to help mitigate the endogeneity concern. Hence, our sample of one-year-ahead patents and citations begins in 1998 coinciding with the availability of director gender information (Riskmetrics) in 1997. On the other hand, we end our sample period in 2006 since the NBER patent database is available until 2006. Our sample selection starts with 10,639 firm-year observations for which we have lagged board characteristics data. Excluding financial firms leaves 9,101 firm-years. After merging with the Compustat and Execucomp databases and removing observations with missing control variables, the sample reduces to 7,535 firm-years. Combining with the antitakeover index from Riskmetrics and Bebchuk, Cohen and Ferrell (2009) results in a further loss of data to deliver a final sample of 6,644 firm-year observations. As a robustness check, we re-estimate innovation regressions using the samples at alternative stages of our selection and confirm that sample attrition has little impact on our main findings.

To examine how female board representation affects the firm's innovation activities, we estimate the following baseline empirical model:

$$\ln(\mathit{Innovation}_{i,\,t+1}) = \alpha + \beta \times \mathit{Fraction\ of\ female\ directors}_{i,\,t} + \gamma Z_{i,\,t} + \mathit{Industry}_{i} + \mathit{Year}_{t} + \varepsilon_{i,\,t} \qquad (1)$$

The measures of female board representation and *Innovation* are discussed in detail in the following subsections. *Z* is a vector of firm characteristics that affects innovation activities following the existing literature. $\mathit{Industry}_i$ represents industry fixed effects constructed using the Fama and French 49-industry classification and Year_t captures the year fixed effects.

2.2.1. Measuring female board representation

The key independent variable of interest, female board representation, is measured either as the equally weighted or the tenure-weighted fraction of female directors on the board. The equally weighted fraction is calculated as the number of female directors divided by the total number of directors on the board. This measure has been used in the existing board gender composition literature (see for example Levi, Li and Zhang, 2014; Gul, Srinidhi and Ng, 2011; Adams and Ferreira, 2009).

Extending the methodology of this literature, we pay more attention to the tenure-weighted measure of female board representation calculated as the sum of tenures of female directors divided by the sum of tenures of all directors on the board. Essentially, the tenure-weighted measure assigns higher weights to directors with longer tenures. This simple adjustment makes the measure preferable for at least two reasons. First, Schwartz-Ziv and Weisbach (2013) show that directors with longer tenures are more active monitors who are more likely to take some type of action (such as requesting further information or an update, taking an initiative, or voting against other directors). By emphasizing directors who are more experienced and active, our tenure-weighted measure should better capture the impact of female board representation on innovation through internal governance.

The second reason is related to the potential concern of matching between female directors and firms with high innovative potential. Director gender is time-invariant, whereas a firm's innovation prospects vary over time as its strategic resources and competitive environment change. This suggests that the effect of matching between time-invariant director gender and time-varying firm characteristics is likely to be strongest when the director is first appointed (Hirshleifer, Low and Teoh, 2012). Therefore, by underweighting newly appointed directors, the tenure-weighted measure should be less affected by the matching problem, if it exists.

For the above reasons, we report only the regression results using our tenure-weighted measure to keep the tables concise. We confirm that the results are similar when we use the equally weighted measure instead. Appendix B shows our main results using the equally weighted fraction of female directors.

2.2.2. Measuring innovation

We measure firms' resource input into innovation activities by the natural logarithm of R&D expenditures following Aghion, Van Reenen and Zingales (2013). Firm-years with missing R&D information are assigned a zero value. While the input-oriented measure is straightforward, it fails to capture the quality of innovation. Therefore, we apply the output-oriented measures of patent count and citations to capture how effectively a firm has utilized its innovation inputs.

Both patent count and citations are constructed using the 2006 edition of the NBER patent database, which covers over 3 million patent grants and over 23 million citations between 1976 and 2006 (Hall, Jaffe and Trajtenberg, 2001). Patents are included in the database only if they are eventually granted. Therefore, our first measure of innovation output is a firm's number of patent applications filed in a year that are eventually granted. When constructing this measure, we use a patent's application year rather than the grant year because the former is a better indicator of the actual timing of innovation (Griliches, Pakes and Hall, 1988).

Patent count, however, may not be sufficient to capture innovation productivity because patents vary considerably in their technological and economic importance. To assess a patent's importance, we use its citation count as our second measure of innovation output. Citation counts are related to the social and economic value created by the innovation

(Trajtenberg, 1990; Hall, Jaffe and Trajtenberg, 2005). For each firm, the citation-based measure is constructed as the total number of non-self citations ultimately received by the patents applied for in a given year.

The NBER patent database suffers from several imperfections: i) it takes time for an applied patent to be granted and, hence, there is a truncation bias in the number of patents towards the end of the sample period; ii) patents created near the ending year of the sample tend to have fewer citations simply because they have less time to accumulate them; and iii) both patenting and citation intensities vary across industries (Seru, 2014; Hall, Jaffe and Trajtenberg, 2001). To address these concerns, we follow Hall, Jaffe and Trajtenberg (2001) and Seru (2014) and adjust both patent and citation counts.

First, to adjust for the truncation in patent count, we divide the number of patents for each firm by the average patent count of all firms in the same technology class (which is a finer industry classification used by USPTO to assign patents) and year. The adjusted variable is named *Patent*. Second, each patent's non-self citation count is scaled by the mean non-self citation count of all patents in the same technology class and year. The variable *Citation* is the sum of the adjusted citation counts across all patents applied for by a firm in a given year. We use the natural logarithm of one plus *Patent* (*Citation*) for regression purposes because the distribution of patent counts (citations) in the sample is right-skewed.

2.2.3. Control variables

We include several firm characteristics that are related to innovation. First, firm size is measured as the natural logarithm of market capitalization. As argued by previous studies, there may be economies of scale in generating patents due to the fixed costs of maintaining a legal department that deals with Intellectual Property (IP)-related issues (Lerner, 1995; Hall and Ziedonis, 2001), suggesting a positive relation between firm size and patenting activities. Second, Hall and Ziedonis (2001) argue that capital intensity can affect a firm's patenting behavior as it increases the importance of patents in safeguarding against the threat of costly litigation. We define capital intensity as the ratio of net property, plant and equipment to total assets. Third, Adams and Ferreira (2009) report that the majority of female directors act as independent directors. Thus, we control for board independence, defined as the fraction of independent directors on boards, to rule out the possibility that effects of monitoring on innovation may be driven by independent directors rather than female directors. Furthermore, following existing studies (He and Tian, 2013; Tian and Wang, 2014), we also control for other standard determinants of innovation including profitability (ROA), growth opportunities (Tobin's Q) and leverage. Finally, when analyzing patents and citations we also control for R&D expenditures to avoid confounding the effect of female board representation with the effect of innovation input. Detailed variable definitions are provided in Appendix A.

2.2.4. Where does board gender composition variation come from?

The panel data we use include both time-series and cross-sectional variations in the fraction of female directors on the board, innovation measures and other control variables. However, from a statistical point of view, our main source of variation likely comes from the cross section because our sample consists of 1,224 firms, but only 9 years (from 1998 to 2006) due to limited data availability. The disproportionately large number of firms in the cross section compared with the number of years suggests that cross-sectional variation in board gender composition across firms dominates its variation over time.

Moreover, many firms in our sample experienced little temporal changes in board gender composition. On average, the equally weighted fraction of female directors changes by 0.0056 from year to year. Of the 1,224 firms in our sample, there are 401 firms (32.76%) whose fraction of female directors did not change during our sample period and 207 firms (16.91%) who experienced only one change. The lack of within-firm variation works against finding a significant relation between female board representation and innovation in firm fixed effects regressions (Zhou, 2001). For these reasons, we estimate OLS regressions to capture the female-representation-innovation relation. To address endogeneity problems in our analysis, we focus on the instrumental variables approach described in Section 4.2.

3. Female board representation and innovation

3.1. Descriptive statistics

Table 1 provides descriptive statistics for the whole sample, as well as the subsamples of firms with and without female directors. A firm with at least one female director on the board has, on average, about twice as many patents and approximately 1.5 times as many citations as a firm with no female directors. The differences are statistically significant, suggesting that female board representation increases innovation.

Insert Table 1 about here

The mean (median) equally weighted fraction of female directors is 9.3% (10%), and is 6.9% (3.7%) for the tenure-weighted measure. This is close to the 8.5% mean (equally weighted) reported by Adams and Ferreira (2009). With respect to the control variables, firms with female directors are larger and have higher leverage, lower Tobin's q, better performance in terms of ROA, higher fraction of independent directors and more tangible assets than firms without female directors. These results are all comparable to those of Adams and Ferreira (2009).

3.2. Baseline empirical results

Table 2 tests whether firms with higher fractions of female directors devote more resources to innovation activities. The results suggest that, with and without controls, the tenure-weighted measure of female board representation is positively related to R&D expenditures.

Insert Table 2 about here

Table 3 examines the relation between female board representation and innovation productivity, as measured by patent and citation counts. All coefficients on the gender composition variable are positive and statistically significant, suggesting that firms with greater representation of female directors generate more patents and citations. In terms of economic significance, the results in models 1 and 3 suggest that an increase of 10 percentage points in the tenure-weighted fraction of female directors is associated with approximately 6% more patents and 7% more citations.

Importantly, conditioning on R&D spending (in models 2 and 4) slightly reduces the coefficients on our gender composition variable, suggesting that the main effect of female board representation is to improve the effectiveness of innovation activities rather than to increase R&D investments.

Insert Table 3 about here

3.3. Robustness tests

Robustness test results (unreported) confirm that the positive effect of board female representation on innovation persists when (i) Tobit, Poisson and Fama-MacBeth regressions are used, (ii) the sample period is curtailed at 2003 as the patent and citation data for the last three years available in the patent database may be incomplete, (iii) firm-years with female CEOs are excluded to rule out the possibility that the results are driven by female CEOs rather than female directors,[6] (iv) firm-years for Telecom and Utilities, where female directors are more prevalent, are excluded, (v) the alternative citations per patent measure of innovation is used,[7] (vi) additional board composition measures including *Fraction of foreign directors*, *Tenure diversity* and *Age diversity* are controlled for,[8] and (vii) firm-years in industries with below median average citations per patent are excluded to account for the possibility that low citations do not necessarily equate to low impact.

4. Identification

The endogenous nature of corporate boards makes the interpretation of the estimated positive relation between female board representation and innovation difficult. It is hard to distinguish whether our findings are driven by an effect of female directors on innovation or by matching between female directors and firms with high innovation potential. For instance, our estimates may be biased due to either innovative firms being more responsive to external

[6] Matsa and Miller (2011) and Tate and Yang (2015) show that the presence of females as CEOs and their presence as directors are highly correlated.
[7] This is calculated as the natural logarithm of one plus the number of citations per patent.
[8] *Fraction of foreign directors* is defined as the ratio of the number of non-US directors to board size. *Age (Tenure) diversity* is calculated as the standard deviation of director age (tenure) divided by the average age (tenure) of directors on the board.

calls for greater female board representation or female directors self-selecting better performing innovative firms (Farrell and Hersch, 2005). To mitigate this concern, we employ two approaches: propensity score matching mitigates the matching concern based on observable firm characteristics and instrumental variable regressions address reverse causality.

4.1. Propensity score matching estimates

We use propensity score matching to identify a control sample of firms with no female directors on their boards, which exhibit virtually no differences in firm characteristics relative to firms with female directors. We first estimate a logit model where the dependent variable is an indicator for the presence of female directors.[9] Independent variables include firm size, Tobin's q, leverage, capital intensity (*PPE/TA*), return on assets (*ROA*), board independence (*Fraction of independent directors*), R&D expenditures (*R&D/TA*) as well as industry and year effects. We then construct a treatment group and a control group of firms using the nearest-neighbor method based on the predicted probabilities (or propensity score) from the logit regression. Specifically, each firm with female directors on its board (the treatment group) is matched to a firm without female directors (the control group) with the closest propensity score. If a firm in the control group is matched to more than one firm in the treatment group, we retain only the pair for which the difference in the two firms' propensity scores is the smallest.[10] To ensure further that firms in the treatment and control groups are sufficiently indistinguishable, we require that the maximum difference between the propensity score of a treatment firm and its matched control firm does not exceed 0.001 in absolute value. Eventually, we have 1,470 unique pairs of matched observations.

We conduct two diagnostic tests to verify that firms in the treatment and control groups are indistinguishable in terms of observable characteristics. The results are presented in Appendix C. First, we re-estimate the logit model restricted to the matched sample. We find that none of the coefficient estimates are statistically significant, suggesting that there are no

[9] The results are quantitatively similar when we use a probit model in the first step.
[10] As a robustness test we allow control firms to be matched to multiple treatment firms. We find that matching with replacement results in estimates that are of greater economic and statistical significance.

distinguishable trends in innovation outcomes between the matched groups of firms. Second, we examine the difference between observable characteristics of the treatment firms and those of the matched control firms. Again, none of the differences are statistically significant.

Insert Table 4 about here

Table 4 reports the propensity score matching estimates. The results indicate that firms with female directors generate approximately 7.7% more patents and 6.5% more citations than the matched firms without female directors. Thus, we conclude that matching between female directors and firms, at least based on observable characteristics, does not explain our findings. However, it is important to note that the matching approach does not allow us to account for differences between the treatment and control groups that could arise from unobservable factors.

4.2. Instrumental variable estimates

In addition, we employ the instrumental variables approach to extract the exogenous component of female board representation and use it to explain innovation outcomes. Following Adams and Ferreira (2009), we instrument for female board representation using the fraction of a firm's male directors who sit on other boards that have at least one female director.[11] Adams and Ferreira (2009) and Adams and Ragunathan (2015) argue that male directors with more balanced connections to women may be better able to identify suitable female candidates for directorships, implying a positive relation between the instrument and the fraction of women on the board. On the other hand, it is not obvious why knowing more women and having more balanced connections should be correlated with corporate innovation other than through board gender composition, accounting for various other factors. Therefore, we believe that the instrument used has at least some theoretical justification, although meanwhile we are mindful of the fact that it is never possible to completely rule out violations of the exclusion restriction.

[11] The instrumental variable is constructed on a yearly basis. Its average change is 0.0029 from year to year.

Panel A of Table 5 presents the results of first-stage regressions where the dependent variable is the tenure-weighted fraction of female directors. For brevity, we report only the coefficients on the instrument. Consistent with our prediction, the reported coefficients are positive and significant at the 1% level. In addition, the *p-values* of Cragg-Donald's Wald *F* weak-instrument test statistics are 0.000, rejecting the null hypothesis that the instruments are weak (Cragg and Donald, 1993; Stock and Yogo, 2005).

Insert Table 5 about here

Panel B of Table 5 presents the second-stage regression results where the dependent variables are the number of patents and citations, respectively. The main variables of interest are the predicted values of the fraction of female directors. Their coefficient estimates are positive and significant, confirming our baseline results.

Comparing the IV regression results with the baseline OLS regression results in Table 3, we find that the magnitudes of IV estimates are larger than those of OLS estimates (although the estimates from both approaches are positive and statistically significant), suggesting that OLS regressions bias the estimates downward. This finding suggests that some omitted variables may simultaneously make firms more innovative and female directors less desirable, resulting in the downward bias embedded in the OLS estimates. Once the endogeneity in board gender composition is alleviated using the instrument, the estimates increase, i.e., become more positive, in IV regressions.[12]

A potential concern with the interpretation of the results is that *Fraction of male directors linked to female directors* might capture the connectedness of the board and bias our results. Indeed, well-connected directors with multiple directorships are likely to be those who are better able to perform their monitoring and advising roles as directors, which could be correlated with corporate innovation. To address this concern, we follow Adams and Ferreira (2009) and control for a more direct measure of board connectedness, namely, the

[12] Another possible explanation is that IV estimates may produce an effect that is significantly larger than the true population average treatment effect for legitimate econometric reasons because they uncover a "local average treatment effect" (LATE). See Wei (2017) for more details.

total number of external board seats held by directors. We confirm (unreported) that the results are robust to the inclusion of this additional control.

Another alternative explanation is related to selection, it might be harder for women to get on the board than it is for men. If so, it could be the case that those females that break through the glass ceiling are more qualified than their male counterparts. While director quality is difficult to measure, Adams and Ragunathan (2015) provide supportive evidence that female directors on average have higher educational qualifications than male directors, which we confirm using our data. Continuing this logic, a male director linked with other female directors may also be of higher quality, to the extent that board members have similar levels of qualification within a firm as a result of the firm's choice of hiring practices. In that case, *Fraction of male directors linked to female directors* becomes a proxy for board quality. To mitigate this concern, we control for more direct and standard measures of board quality based on directors' education. Following Adams and Ragunathan (2015), we define *Education* as the highest educational qualification attained by a director. A bachelor's degree is coded as 1, a master's degree as 2, and a PhD as 3.[13] We re-examine the IV regression results after controlling for *Education* and find that our results are not materially affected, suggesting that this alternative explanation does not drive our findings.

5. Quiet life versus career concerns

In this section, we investigate the mechanisms through which greater monitoring enhances innovation, which purport two explanations.[14] The first is that managers prefer a quiet life and thus are reluctant to innovate (Hart, 1983; Bertrand and Mullainathan, 2003). Greater monitoring by female directors mitigates the agency problem, reduces managers' incentives

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[13] As an alternative, we also use other measures of education and find quantitatively similar results. *Board MBA* is the fraction of directors with an MBA degree. *Board Ivy* is the fraction of directors who have attended an Ivy League university. *Board qualification* is the fraction of directors with professional qualifications.

[14] A pre-requisite to this demands evidence that female board representation increases monitoring. In unreported results, we confirm the established findings that female directors tend to have better attendance records than male directors and that male directors are less likely to have attendance problems when there are female directors on the board. Female directors are more likely to sit on monitoring-related committees than male directors. Together, these results suggest that boards with female directors allocate more effort to monitoring. In terms of monitoring outcome, we find that female directors are associated with a higher sensitivity of CEO turnover to stock performance.

to shirk and keeps them focused on pursuing innovative and valuable projects (the quiet life hypothesis).

An alternative explanation is based on the career concern model of Aghion, Van Reenen and Zingales (2013). Absent monitoring, the board infers a manager's ability from the revenue realization, which can be negative for purely stochastic reasons rather than poor managerial ability. However, monitoring and observing managers innovate provides the board with an opportunity to assess the manager's ability independent of and before the revenue realization. Thus, in the presence of female directors who allocate more effort to monitoring and acquiring information about managers' ability through observing them innovate, the manager may have greater incentive to undertake innovative projects to reveal their ability knowing that they are insulated against the reputational risk of random negative revenue shocks (Aghion, Van Reenen and Zingales, 2013).

Both the quiet life and the career concern hypotheses predict that increased monitoring by female directors stimulates innovation. Where the two hypotheses differ is in the interplay between: i) female board representation and product market competition, and ii) female board representation and CEO entrenchment.

5.1. Female board representation and product market competition

Product market competition increases the difficulty of survival and thereby forces the manager to work harder (Hart, 1983). Under the quiet life hypothesis, product market competition and female board representation are *substitutes*. The more competitive a market is, the less managerial slack there should be and the less need there is for greater monitoring by female directors. Thus, the quiet life hypothesis predicts that the impact of female board representation on innovation should be stronger in industries in which competition is low.

In contrast, under the career concern hypothesis, product market competition and female board representation are *complements*. When competition is higher, corporate outcomes become more uncertain, which increases the reputational risk faced by the manager (Aghion, Van Reenen and Zingales, 2013). If female directors stimulate innovation by insulating the manager against the reputational risk from bad revenue realizations, this effect should be stronger in industries with high competition.

Following Ali, Klasa and Yeung (2009), we employ the US census measures of industry concentration that are constructed using data from all public and private firms in an industry.[15] We hand-collect the eight-firm concentration ratio from the *Census of Manufactures* publications.[16] The eight-firm ratio is calculated as the sales of the eight largest firms in a 5-digit NAICS industry divided by the total sales of all firms in that industry.[17] The more concentrated an industry is, the less intense the competition in that industry.

We estimate the innovation regressions separately for firms in low-competition industries and those in high-competition industries. An industry is classified as having *low* competition if its eight-firm concentration ratio is *above* the sample median for that year, and vice versa. Table 6 presents the results where Panels A and B report results for the number of patents and citations, respectively. Using both OLS and IV estimation, we find that the positive effects of female board representation on innovation are more prominent in low-competition industries.

Insert Table 6 about here

5.2. Female board representation and managerial entrenchment

A further implication of the quiet life hypothesis is that the greater monitoring by female directors should be particularly important when managers are entrenched. In such circumstances, female board representation should have a more prominent positive effect on innovation. On the contrary, the career concern hypothesis predicts that the effect of female board representation on innovation should be weaker when managers are more entrenched, or

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[15] Ali, Klasa and Yeung (2009) note that industry concentration measures calculated with Compustat data, which exclude data on private firms, are poor proxies for actual industry concentration and may lead to incorrect conclusions. In contrast, the corresponding US census measures are constructed based on all public and private firms in an industry and hence better capture actual industry concentration. See Ali, Klasa and Yeung (2009) for more details.

[16] The *Census of Manufactures* is published only during years when a US Census takes place. Thus, we hand-collect concentration ratios for the years 1997, 2002 and 2007. Following prior studies, we use the US census data for a given year as a proxy of industry concentration not only for that year but also for the one or two years immediately before and after it (as in Ali, Klasa and Yeung, 2009; Klasa, Ortiz-Molina, Serfling and Srinivasan, 2014; Haushalter, Klasa and Maxwell, 2007). For instance, we use the 2002 *Census of Manufactures* data as a proxy for industry concentration for the period 2000–2004.

[17] We also use four-firm, twenty-firm and fifty-firm concentration ratios and our results still hold.

shareholders and the board have less power to restrain managers (Aghion, Van Reenen and Zingales, 2013). We use the antitakeover index introduced by Bebchuk, Cohen and Ferrell (2009) to capture firms' managerial entrenchment, with higher index values indicating higher degrees of managerial entrenchment.[18] Table 7 reports the innovation regression results separately for firms with a high and low antitakeover index based on the sample median. The results suggest that the positive effect of female board representation on innovation is concentrated on high antitakeover index firms where managers are more entrenched.

Insert Table 7 about here

Overall, the results suggest that the positive effect of female board representation on innovation is more prominent when product market competition is lower and when managers are more entrenched, consistent with the quiet life hypothesis and contrary to the career concern hypothesis. In further unreported robustness analysis, we use CEO tenure as an alternative measure of managerial entrenchment. Entrenchment should increase with tenure because a longer tenure allows CEOs to enhance their internal power (Finkelstein and Hambrick, 1989) and to make manager-specific investments (Shleifer and Vishny, 1989). Moreover, the disciplining power of reputation for CEOs nearing retirement is relatively weak (Murphy, 1986). The quiet life hypothesis predicts that the positive effect of female board representation on corporate innovation should be stronger in firms with high tenure CEOs and our results confirm this.

5.3. Further robustness checks and discussion

We conduct additional analyses to ensure further that differences in director quality and/or other observable characteristics cannot explain our main findings. In Appendix D, we first

[18] The antitakeover index is constructed on the basis of the six provisions that set constitutional limits on shareholder voting power and strengthen the protections against takeovers that managers have. Of the six provisions, four of them set constitutional limits on shareholder voting power. They include: staggered boards, limits to shareholder amendments of the bylaws, supermajority requirements for mergers, and supermajority requirements for charter amendments. Two other provisions that strengthen the protections that managers have on takeovers are poison pills and golden parachute arrangements. Each company is given a score, from 0 to 6, based on the number of these provisions that the company has in the given year. The higher the index value the more entrenched managers are likely to be in a firm. See Bebchuk, Cohen and Ferrell (2009) for more details. The data for the antitakeover index are available only for 1998, 2000, 2002, and 2004 during our sample period. We therefore fill the gaps using the most recent value available at that point in the sample.

compare several observable dimensions of director characteristics between firms with female directors and those without. We find suggestive evidence that firms with female directors tend to have directors with better education and shorter tenure. We then include additional board-level controls for these director characteristics in both the OLS and IV regressions. The additional controls include the fraction of directors with an MBA degree (*Board MBA*), the fraction of directors who have attended an Ivy League university (*Board Ivy*), the fraction of directors with professional qualifications (*Board qualification*) as well as *Average director age* and *Average director tenure*. It is reassuring that, after including these controls, the significantly positive effect of female board representation on corporate innovation remains.

A potential alternative explanation why female board representation is positively associated with innovation is that, in general, heterogeneous groups should produce a broader range of human capital, including ideas and skills, and social capital, such as network resources, promote creativity and ultimately lead to increased innovation, as argued by Miller and Triana (2009).[19] Given that heterogeneity in human and social capital is largely unobserved, it is hard to test explicitly whether this explanation affects our results. However, this interpretation is difficult to reconcile with the findings of our split sample analysis in Sections 5.1 and 5.2.

Furthermore, the benefits generated by female directors due to their greater monitoring and increased group heterogeneity are not mutually exclusive. Differences in networks and backgrounds between male executives and female directors may facilitate board independence and thus effective monitoring. Cognizant of this, we conduct further tests to provide evidence that greater monitoring by female directors matters beyond increased group heterogeneity. First, we separate female directors that are corporate insiders from those who are relatively independent from the firm. We compute *Fraction of female indep. directors* (*Fraction of female exe. directors*) as the number of female independent (executive) directors divided by the total number of directors on the board. We also control for *Fraction of male exe. directors*, defined as the number of male executive directors divided by board size, such

[19] The predicted effect of group heterogeneity on innovation could also be negative if more dissimilar directors create more disagreement and conflict, which could impair innovation efficiency (Milliken and Martins, 1996).

that the holdout, reference group is comprised of male independent directors. Unlike executive directors that are affiliated with the firm, independent directors have no significant relationship with the firm beyond being directors, which enables them to be objective and valuable monitors (Faleye, Hoitash and Hoitash, 2011). Our results (unreported) show that the positive effect of female board representation on innovation is driven by female independent directors, consistent with monitoring mitigating agency issues. Moreover, female independent directors appear to have a significantly larger impact than male independent directors as evident by the positive and significant coefficients on *Fraction of female indep. directors*, suggesting that director independence alone cannot explain our findings.

Second, we distinguish between pre- and post-CEO female directors. A director is pre-CEO (post-CEO) if she is appointed before (after) the current CEO assumes office. We calculate *Fraction of female pre-CEO directors* (*Fraction of female post-CEO directors*) as the number of pre-CEO (post-CEO) female directors divided by the total number of directors on the board. Again, we control for *Fraction of male post-CEO directors* (calculated as the number of post-CEO male directors divided by board size) to make male pre-CEO directors the holdout group. Coles, Daniel and Naveen (2014) and Khanna, Kim and Lu (2015) show that directors appointed after the CEO are more likely to assign their allegiance to the CEO who hired and promoted them to their current position, which reduces monitoring effectiveness. Consistent with the agency view, our unreported results suggest that the positive effect of female board representation on innovation stems from female directors who joined before the current CEO who are relatively more effective at monitoring. In addition, the finding that female pre-CEO directors have a stronger impact than male pre-CEO directors seems to suggest that the observed effects are related to gender.

Third, we classify female directors as busy or non-busy. Following Fich and Shivdasani (2006) a director is defined as busy if she holds three or more directorships, and non-busy otherwise. We calculate *Fraction of female busy directors* (*Fraction of female non-busy directors*) as the number of female busy (non-busy) directors divided by the total number of directors on the board. We control for *Fraction of male busy directors*, with male non-busy directors as the holdout group. Whilst busy directors are inclined to become distracted, resulting in ineffective monitoring (Fich and Shivdasani, 2006; Core, Holthausen and Larcher, 1999), they are also more experienced, better connected, and therefore better positioned to provide advice than are non-busy directors (Field, Lowry and Mkrtchyan, 2013). Our unreported results show that the positive effect of female board representation on innovation is concentrated on female non-busy directors, again consistent with monitoring alleviating agency problems. Further, female non-busy directors have a more prominent impact than male non-busy directors, suggesting that director busyness alone does not drive our results.

In summary, these additional findings considering different aspects of female board representation are difficult to reconcile with the interpretation that female directors increase firm innovation due to the breadth of human and social capital associated with heterogeneous groups. The quiet life hypothesis, instead, is consistent with all of our findings. However, it is important to recognize that our analysis does not allow us to completely rule out alternative interpretations in general. Rather, we argue based on our evidence that the relationship between female board representation and innovation is most consistent with the quiet life hypothesis.

6. Female board representation, innovation and firm performance

Our results suggest that firms with greater representation of female directors invest more in innovation and achieve greater innovative success. More important is an examination of whether this matters sufficiently to affect firm performance. Table 8 reports the results of such investigation. Dependent variables are the average return on assets for the subsequent year, three years and five years for Panel A, and the average Tobin's q for the subsequent year, three years and five years for Panel B. The variable of interest is the tenure-weighted fraction of female directors. Following prior literature (Adams and Ferreira, 2009; Core, Holthausen and Larcher, 1999; Bhaget and Bolton, 2008), we add a rich set of firm and governance controls known to be related to firm performance including *ln(Sales)*, *Leverage*, *PPE/TA*, *R&D/TA*, *No. of business segments*, *Fraction of independent directors*, *Board size* and *Antitakeover index*.[20] Detailed variable definitions are given in the Appendix A. For brevity, we report only the coefficients on the variables of interest. To mitigate the endogeneity of board gender composition in performance regressions, we run IV regressions in addition to OLS regressions using the same instrument as in Table 5.

Insert Table 8 about here

The results in columns (1) and (2) suggest that in general, female directors do not improve firm value as the coefficient estimates on the fraction of female directors are not significant. Next, we investigate the possibility that the value of female board representation depends on the relative importance of innovation activities among firms' corporate strategies. Given that our previous findings suggest that firms with female directors achieve greater innovation, an intuitive implication is that greater innovative success should be more likely to translate into better performance in industries where firm growth is particularly dependent on innovation.

In a report by the Economics and Statistics Administration (ESA) and the US Patent and Trademark Office (USPTO), 75 four-digit NAICS industries (from among 313 in total) are identified as IP-intensive industries.[21] IP-intensive industries are those that produce or use significant amounts of intellectual property, including innovation, creation, and commercial distinctiveness, and rely most intensely on patents, copyrights and trademarks to protect them.[22] By identifying and analyzing IP-intensive industries using data from both private and public firms, the report promotes a better understanding of industries in which innovation and

[20] In further unreported analysis, we repeat the regressions in Table 8 using a range of alternative model specifications. First, we use the firm's market capitalization and total assets as alternative measures of firm size in place of sales. Second, we use the same controls as those in Tables 9 to 11 of Adams and Ferreira (2009) (specifically, *Board size*, *Fraction of independent directors*, *ln(sales)*, *No. of business segments*). Third, we include the same controls as our previous tables (*ln(MVE)*, *Leverage*, *PPE/TA*, *Fraction of independent directors*, *R&D/TA*). All of these tests confirm that our findings are not much affected by these alternative specifications.
[21] Seventy-five IP-intensive industries emerge after combing through the lists of patent, trademark, and copyright intensive industries. Each list consists of a subset of industries that had high scores in various intensity measures regarding patents, trademarks or copyrights, respectively. See ESA and USPTO (2012) for more details.
[22] Patents, trademarks, and copyrights are the primary ways of establishing ownership of inventions and creative ideas, providing a legal foundation to generate tangible benefits from innovation for companies, workers, and consumers. This framework provides the incentives to undertake investments in innovation and therefore is a key force for promoting innovation (ESA and USPTO, 2012).

creativity play a particularly important role (ESA and USPTO, 2012). Hence, we expect the relation between female board representation and firm performance to be positive and significant in IP-intensive industries and insignificant or even negative in non-IP-intensive industries.

We split the sample to test the effect of female board representation on firm performance in IP-intensive and non-IP-intensive industries. The results are reported in columns (3) to (6) of Table 8.[23] Women on boards are particularly valuable in IP-intensive industries as evidenced by the positive and often significant coefficient estimates in columns (3) and (4). The top four industries where female board representation creates value via increasing corporate innovation are pharmaceuticals, computer software, electronic equipment, and chemicals. In contrast, coefficient estimates in columns (5) and (6) suggest that female board representation does not affect, or even undermines, firm performance in non-IP-intensive industries which include, among others, transportation, wholesale, retail, and hotels and restaurants.

7. Conclusion

We find that firms with greater representation of female directors invest more in innovation and achieve greater innovative success, as measured by patent and citation counts, for given R&D expenditures. In other words, the R&D expenditures in firms with female directors are more productive in generating innovation. These findings are robust to the use of alternative measures of board gender composition, econometric specifications and subsamples.

To investigate the potential mechanisms through which female directors affect corporate innovation, we explore the heterogeneity in the innovation effect of female board representation. The positive relation between female board representation and innovation is stronger when product market competition is less intense and when managers are more entrenched, which are consistent with the hypothesis that female directors improve the

[23] We exclude industry effects in all subsample tests in Table 8 to avoid potential inconsistency between the Fama-French 49 industry classification and the NAICS industry classification. As a robustness check, we repeat the subsample analysis with industry effects constructed based on the two-digit NAICS industry classification. The results are not materially changed.

incentives to innovate by increasing oversight over managers. Finally, we find that female representation on the board does not add value on average. However, female directors appear to be valuable for industries in which innovation and creativity are particularly relevant, reinforcing the importance of the role of women on boards for impacting corporate innovation.

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Table 1
Summary statistics

The table presents the means and medians of main variables. *ln(1+R&D)* is the natural logarithm of one plus a firm's R&D expenditures. *ln(1+Patent)* is the natural logarithm of one plus a firm's total number of patents (*Patent*) filed (and eventually granted) in a given year. *ln(1+Citation)* is the natural logarithm of one plus the total number of non-self citations (*Citation*) received on a firm's patents filed (and eventually granted) in a given year. *Fraction of female directors_EW* (*Fraction of female directors_TW*) is the equally weighted (tenure-weighted) measure of the fraction of female directors on the board. *ln(MVE)* is the natural logarithm of market capitalization. *Tobin's Q* is market value of equity plus total assets minus book value of equity, all divided by total assets. *Leverage* is the sum of short-term and long-term debts divided by total assets. *PPE/TA* is net property, plant and equipment divided by total assets. *ROA* is earnings before interest, taxes, depreciation, and amortization divided by total assets. *Fraction of independent directors* is the number of independent directors divided by the total number of directors on the board. *R&D/TA* is R&D expenditures divided by total assets. t-tests (Wilcoxon-Mann-Whitney tests) are conducted to test for differences between the means (medians) for firms with at least one female director on the board and firms without female directors. ***, ** and * indicate significance at the 1%, 5% and 10% levels, respectively.

	Whole Sample N=6,644			Firm-Year Obs. with Female Directors N=4,260			Firm-Year Obs. without Female Directors N=2,384		
Variables	Mean	Median	Stdev	Mean	Median	Stdev	Mean	Median	Stdev
Innovation Measures									
ln(1+R&D)	2.06	0.50	2.34	2.08	0.00	2.49	2.02	1.98	2.04
ln(1+Patent)	0.64	0.00	1.14	0.70	0.00	1.23	0.53***	0.00*	0.94
ln(1+Citation)	0.61	0.00	1.28	0.64	0.00	1.34	0.56**	0.00	1.18
Patent	5.41	0.00	20.74	6.71	0.00	23.48	3.10***	0.00*	14.32
Citation	9.99	0.00	50.91	11.40	0.00	54.92	7.48***	0.00	42.72
Female Board Representation Measures									
Fraction of female directors_EW	0.09	0.10	0.09	0.14	0.13	0.06	0.00***	0.00***	0.00
Fraction of female directors_TW	0.07	0.04	0.09	0.11	0.09	0.09	0.00***	0.00***	0.00
Main Controls									
ln(MVE)	7.60	7.43	1.53	7.98	7.85	1.58	6.93***	6.82***	1.19
Tobin's Q	2.03	1.55	1.37	2.00	1.52	1.38	2.09**	1.62***	1.36
Leverage	0.23	0.24	0.16	0.25	0.26	0.15	0.20***	0.19***	0.17
PPE/TA	0.33	0.27	0.23	0.35	0.30	0.23	0.30***	0.23***	0.23
ROA	0.15	0.14	0.08	0.15	0.14	0.08	0.14***	0.14***	0.09
Fraction of independent directors	0.66	0.67	0.17	0.69	0.71	0.16	0.61***	0.63***	0.18
R&D/TA	0.03	0.00	0.05	0.02	0.00	0.04	0.04***	0.01***	0.06

Table 2

Female board representation and R&D expenditures

Table 2 presents the OLS regression results on the relation between female board representation and R&D expenditures. The dependent variable is the natural logarithm of one plus a firm's R&D expenditures in a given year. Independent variables include: *Fraction of female directors_TW* is the tenure-weighted measure of the fraction of female directors on the board. *ln(MVE)* is the natural logarithm of market capitalization. *Tobin's Q* is market value of equity plus total assets minus book value of equity, all divided by total assets. *Leverage* is the sum of short-term and long-term debts divided by total assets. *PPE/TA* is net property, plant and equipment divided by total assets. *ROA* is earnings before interest, taxes, depreciation, and amortization divided by total assets. *Fraction of independent directors* is the number of independent directors divided by the total number of directors on the board. All independent variables are lagged one year relative to the dependent variable unless otherwise specified. All regressions include industry and year effects. Industry effects are constructed based on the Fama-French 49-industry classification. Statistical significance is based on the heteroskedasticity robust firm-clustered standard errors reported in brackets. ***, ** and * indicate significance at the 1%, 5% and 10% levels, respectively.

	ln(1+R&D)	
Independent Variables	1	2
Intercept	2.691**	-1.192
	(1.164)	(0.888)
Fraction of female directors_TW	3.686***	1.022**
	(0.614)	(0.420)
ln(MVE)	–	0.579***
		(0.039)
Tobin's Q	–	0.002
		(0.035)
Leverage	–	-0.106
		(0.269)
PPE/TA	–	-1.248***
		(0.293)
ROA	–	-1.498***
		(0.486)
Fraction of independent directors	–	0.736***
		(0.207)
Industry effects	Yes	Yes
Year effects	Yes	Yes
No. of obs.	6,644	6,644
Adj. R^2	0.598	0.720

Table 3

Female board representation and innovation productivity

Table 3 presents the OLS regression results on the relation between female board representation and innovation productivity. Dependent variables include: *ln(1+Patent)* is the natural logarithm of one plus a firm's total number of patents filed (and eventually granted) in a given year. *ln(1+Citation)* is the natural logarithm of one plus the total number of non-self citations received on a firm's patents filed (and eventually granted) in a given year. Independent variables include: *Fraction of female directors_TW* is the tenure-weighted measure of the fraction of female directors on the board. *ln(MVE)* is the natural logarithm of market capitalization. *Tobin's Q* is market value of equity plus total assets minus book value of equity, all divided by total assets. *Leverage* is the sum of short-term and long-term debts divided by total assets. *PPE/TA* is net property, plant and equipment divided by total assets. *ROA* is earnings before interest, taxes, depreciation, and amortization divided by total assets. *Fraction of independent directors* is the number of independent directors divided by the total number of directors on the board. *R&D/TA* is R&D expenditures divided by total assets. All independent variables are lagged one year relative to the dependent variable unless otherwise specified. All regressions include industry and year effects. Industry effects are constructed based on the Fama-French 49-industry classification. Statistical significance is based on the heteroskedasticity robust firm-clustered standard errors reported in brackets. ***, ** and * indicate significance at the 1%, 5% and 10% levels, respectively.

	ln(1+Patent)		*ln(1+Citation)*	
Independent Variables	1	2	3	4
Intercept	-1.726***	-1.964***	-0.921***	-1.129***
	(0.350)	(0.334)	(0.200)	(0.196)
Fraction of female directors_TW	0.601***	0.582**	0.663***	0.624***
	(0.228)	(0.227)	(0.211)	(0.211)
ln(MVE)	0.329***	0.338***	0.294***	0.307***
	(0.025)	(0.025)	(0.024)	(0.024)
Tobin's Q	-0.004	-0.043**	0.026	-0.027
	(0.020)	(0.020)	(0.023)	(0.024)
Leverage	0.017	0.112	-0.026	0.090
	(0.147)	(0.144)	(0.156)	(0.151)
PPE/TA	-0.194	-0.188	-0.323*	-0.288*
	(0.185)	(0.181)	(0.179)	(0.172)
ROA	-0.334	0.135	-0.208	0.410
	(0.244)	(0.242)	(0.276)	(0.280)
Fraction of independent directors	0.416***	0.367***	0.331**	0.258*
	(0.127)	(0.123)	(0.140)	(0.136)
R&D/TA	–	4.274***	–	5.706***
		(0.663)		(0.747)
Industry effects	Yes	Yes	Yes	Yes
Year effects	Yes	Yes	Yes	Yes
No. of obs.	6,644	6,644	6,644	6,644
Adj. R^2	0.490	0.503	0.439	0.457

Table 4

Female board representation and corporate innovation: Propensity score matching

Table 4 reports the average treatment effect estimates. *ln(1+Patent)* is the natural logarithm of one plus a firm's total number of patents filed (and eventually granted) in a given year. *ln(1+Citation)* is the natural logarithm of one plus the total number of non-self citations received on a firm's patents filed (and eventually granted) in a given year. ***, ** and * indicate significance at the 1%, 5% and 10% levels, respectively.

Variables	Firm-Year Obs. with Female Dirs. N=1,470	Firm-Year Obs. without Female Dirs. N=1,470	Difference	t-statistics
ln(1+Patent)	0.610	0.533	0.077**	2.050
ln(1+Citation)	0.608	0.543	0.065*	1.750

Table 5

Female board representation and corporate innovation: Instrumental variables

Table 5 presents estimates of instrumental variables methods using two-stage least square (2SLS) panel regressions. Panel A presents the first-stage regression results in which the dependent variable is the tenure-weighted fraction of female directors. The instrumental variable is *Fraction of male directors linked to female directors*, defined as the fraction of male directors on the board who sit on other boards on which there is at least one female director. The results for other controls are suppressed for brevity. Panel B reports the second-stage regression results. The dependent variables are: *ln(1+Patent)* is the natural logarithm of one plus a firm's total number of patents filed (and eventually granted) in a given year. *ln(1+Citation)* is the natural logarithm of one plus the total number of non-self citations received on a firm's patents filed (and eventually granted) in a given year. All other control variables are the same as those in the baseline models. Industry and year effects are included. Industry effects are constructed based on the Fama-French 49-industry classification. Statistical significance is based on the heteroskedasticity robust firm-clustered standard errors reported in brackets. ***, ** and * indicate significance at the 1%, 5% and 10% levels, respectively.

Panel A. First-Stage Regressions

Independent Variables	*Fraction of female directors_TW*
Fraction of male directors linked to female directors	0.073***
	(0.010)
Control Variables	Yes
Industry effects	Yes
Year effects	Yes
No. of obs.	6,644
CD Wald F-statistics	223.800***
Adj. R^2	0.284

Panel B. Second-Stage Regressions

Independent Variables	*ln(1+Patent)* 1	*ln(1+Citation)* 2
Intercept	-1.327***	-0.665**
	(0.473)	(0.309)
Fraction of female directors_TW	4.833***	3.678**
	(1.452)	(1.515)
ln(MVE)	0.282***	0.267***
	(0.031)	(0.032)
Tobin's Q	-0.012	-0.004
	(0.024)	(0.027)
Leverage	0.026	0.019
	(0.154)	(0.159)
PPE/TA	-0.112	-0.200
	(0.191)	(0.182)
ROA	-0.105	0.213
	(0.277)	(0.300)
Fraction of independent directors	-0.048	-0.041
	(0.183)	(0.198)
R&D/TA	4.160***	5.577***
	(0.723)	(0.774)
Industry effects	Yes	Yes
Year effects	Yes	Yes
No. of obs.	6,644	6,644
Adj. R^2	0.422	0.424

Table 6

Female board representation and product market competition

Table 6 presents OLS and IV regression results separately for firms in low-competition industries and those in high-competition industries. An industry is classified as having *low* competition if its eight-firm concentration ratio is *above* the sample median for that year, and vice versa. The eight-firm ratio is calculated as the sales of the eight largest firms in a 5-digit NAICS industry divided by the total sales of all firms in that industry. The dependent variable for Panel A is the natural logarithm of one plus a firm's total number of patents filed (and eventually granted) in a given year. The dependent variable for Panel B is the natural logarithm of one plus the total number of non-self citations received on a firm's patents filed (and eventually granted) in a given year. The variable of interest is *Fraction of female directors_TW*, defined as the tenure-weighted measure of the fraction of female directors on the board. Other control variables are the same as those in the baseline models. For brevity, only the coefficient estimates on the variable of interest are presented. For IV regressions, the instrumental variable used is *Fraction of male directors linked to female directors*, defined as the fraction of male directors on the board who sit on other boards on which there is at least one female director. All regressions include industry and year effects. Industry effects are constructed based on the Fama-French 49-industry classification. Statistical significance is based on the heteroskedasticity robust firm-clustered standard errors reported in brackets. ***, ** and * indicate significance at the 1%, 5% and 10% levels, respectively.

	Low competition (N=3,856)		High competitioin (N=2,788)	
	OLS	IV	OLS	IV
	1	2	3	4
Panel A: Dependent is ln(1+Patent)				
Fraction of female directors_TW	0.812***	7.099***	0.256	2.839
	(0.284)	(2.395)	(0.357)	(1.776)
Panel B: Dependent is ln(1+Citations)				
Fraction of female directors_TW	0.802***	4.844**	0.162	1.619
	(0.281)	(2.211)	(0.327)	(1.996)

Table 7

Female board representation and CEO entrenchment

Table 7 presents OLS and IV regression results separately for firms with different levels of managerial entrenchment. We measure managerial entrenchment by the antitakeover index introduced by Bebchuk, Cohen and Ferrell (2009) and it is constructed based on six provisions. A firm is in the high antitakeover index (more entrenched) group if its antitakeover index is above the sample median, and vice versa. The dependent variable for Panel A is the natural logarithm of one plus a firm's total number of patents filed (and eventually granted) in a given year. The dependent variable for Panel B is the natural logarithm of one plus the total number of non-self citations received on a firm's patents filed (and eventually granted) in a given year. The variable of interest is *Fraction of female directors_TW*, defined as the tenure-weighted measure of the fraction of female directors on the board. Other control variables are the same as those in the baseline models. For brevity, only the coefficient estimates on the variable of interest are presented. For IV regressions, the instrumental variable used is *Fraction of male directors linked to female directors*, defined as the fraction of male directors on the board who sit on other boards on which there is at least one female director. All regressions include industry and year effects. Industry effects are constructed based on the Fama-French 49-industry classification. Statistical significance is based on the heteroskedasticity robust firm-clustered standard errors reported in brackets. ***, ** and * indicate significance at the 1%, 5% and 10% levels, respectively.

	High antitakeover index (N=3,329)		Low antitakeover index (N=3,315)	
	OLS	IV	OLS	IV
	1	2	3	4
Panel A: Dependent is ln(1+Patent)				
Fraction of female directors_TW	0.583**	5.901***	0.022	4.025
	(0.244)	(1.688)	(0.401)	(2.939)
Panel B: Dependent is ln(1+Citations)				
Fraction of female directors_TW	0.570**	5.499***	-0.234	-0.073
	(0.242)	(1.841)	(0.373)	(3.075)

Table 8
Female board representation, corporate innovation and firm performance

Table 8 presents the OLS and IV regressions results on the relation between female board representation and subsequent firm performance. Dependent variables are the average return on assets for the subsequent year, three years and five years for Panel A, and the average Tobin's q for the subsequent year, three years and five years for Panel B. The variable of interest is *Fraction of female directors_TW*, defined as the tenure-weighted measure of the fraction of female directors on the board. Other control variables include *ln(Sales), Leverage*, *PPE/TA, R&D/TA, No. of business segments*, *Fraction of independent directors*, *Board size* and *Antitakeover index*. Detailed variable definitions are provided in Appendix A. For brevity, only the coefficient estimates on the variable of interest are presented. For IV regressions, the instrumental variable used is *Fraction of male directors linked to female directors*, defined as the fraction of male directors on the board who sit on other boards on which there is at least one female director. An industry is classified as *IP-Intensive* if it is one of the 75 IP-intensive industries identified by the Economics and Statistics Administration (ESA) and the U.S. Patent and Trademark Office (USPTO), and *Non-IP-Intensive* otherwise. IP-intensive industries are those that are particularly dependent on patent, copyright, or trademark protection. All regressions include year effects. Industry effects are constructed based on the Fama-French 49-industry classification. Statistical significance is based on the heteroskedasticity robust firm-clustered standard errors reported in brackets. ***, ** and * indicate significance at the 1%, 5% and 10% levels, respectively.

		Full Sample		IP-Intensive Industries		Non-IP-Intensive Industries	
		OLS	IV	OLS	IV	OLS	IV
		1	2	3	4	5	6
Panel A. Average ROA for Subsequent Year							
One Year	Fraction of female directors_TW	0.015	0.001	0.072**	0.122	-0.048*	-0.289
		(0.021)	(0.142)	(0.031)	(0.159)	(0.025)	(0.231)
Three Years	Fraction of female directors_TW	0.017	0.095	0.078***	0.242*	-0.055**	-0.197
		(0.021)	(0.144)	(0.030)	(0.136)	(0.027)	(0.258)
Five Years	Fraction of female directors_TW	0.018	0.196	0.091***	0.290**	-0.067**	-0.098
		(0.021)	(0.143)	(0.029)	(0.145)	(0.027)	(0.257)
Panel B. Average Tobin's Q for Subsequent Year							
One Year	Fraction of female directors_TW	0.064	1.392	1.023**	2.966	-0.272	2.729
		(0.327)	(1.999)	(0.468)	(2.447)	(0.336)	(2.623)
Three Years	Fraction of female directors_TW	0.168	2.387	1.065**	4.565*	-0.182	2.527
		(0.313)	(2.144)	(0.449)	(2.549)	(0.336)	(2.818)
Five Years	Fraction of female directors_TW	0.154	2.988	1.042**	4.947**	-0.301	2.122
		(0.297)	(2.070)	(0.443)	(2.428)	(0.307)	(2.826)

APPENDIX A

Variable definition

Variables	Descriptions	Source
Innovation Measures		
ln(1+R&D)	Natural logarithm of one plus firm *i*'s R&D expenditures in a given year.	Compustat
ln(1+Patent)	Natural logarithm of one plus the total number of patents filed by firm *i* (and eventually granted) in a given year.	NBER Patent Database
ln(1+Citation)	Natural logarithm of one plus the total number of non-self citations received on firm *i*'s patents filed (and eventually granted) in a given year.	NBER Patent Database
Female Board Representation Measures and Instruments		
Fraction of female directors_EW	The number of female directors on the board divided by board size.	IRRC
Fraction of female directors_TW	The sum of tenures of female directors divided by the sum of tenures of all directors on a board.	IRRC
Fraction of female indep. directors	The number of female independent directors divided by the total number of independent directors on the board.	IRRC
Fraction of female exe. directors	The number of female executive directors divided by the total number of executive directors on the board.	IRRC
Fraction of female post-CEO directors	The number of post-CEO (i.e., joined after the current CEO) female directors divided by the total number of post-CEO directors on the board.	IRRC
Fraction of female pre-CEO directors	The number of pre-CEO (i.e., joined before the current CEO) female directors divided by the total number of pre-CEO directors on the board.	IRRC
Fraction of female busy directors	The number of female busy directors divided by the total number of busy directors on the board. A director is defined as busy if she holds three or more directorships, and non-busy otherwise.	IRRC
Fraction of female non-busy directors	The number of female non-busy directors divided by the total number of non-busy directors on the board.	IRRC
Fraction of male directors linked to female directors	The fraction of male directors on the board who sit on other boards on which there are at least one female director, following Adams and Ferreira (2009).	IRRC
Female-to-male participation ratio	A state-level variable calculated as the female labor force participation rate divided by the male labor force participation rate. The participation rate is defined as the labor force as a percentage of the civilian non-institutional population of each specified group.	US Economic Census

Control variables		
Leverage	The sum of short-term and long-term debts divided by total assets.	Compustat
R&D/TA	R&D expenditures divided by total assets.	Compustat
Tobin's Q	Market value of equity plus total assets minus book value of equity, all divided by total assets. Market value of equity is calculated by multiplying the year-end closing price by the number of shares outstanding.	Compustat
ROA	Earnings before interest, taxes, depreciation, and amortization divided by total assets.	Compustat
PPE/TA	Net property, plant and equipment divided by total assets.	Compustat
ln(MVE)	Natural logarithm of market capitalization where capitalization is defined as the product of stock price and number of shares outstanding.	Compustat
ln(Total Assets)	Natural logarithm of total assets in 2009 dollars.	Compustat
ln(Sales)	Natural logarithm of sales in 2009 dollars.	Compustat
Board size	Total number of directors on the board.	IRRC
Fraction of independent directors	The number of independent directors divided by board size.	IRRC
Board MBA	The fraction of directors with an MBA degree	IRRC
Board Ivy	The fraction of directors who have attended an Ivy League university.	IRRC
Board qualification	The fraction of directors with professional qualifications.	IRRC
Average director age	The average age of all directors on the board.	IRRC
Average director tenure	The average tenure of all directors on the board.	IRRC
No. of business segments	The number of business segments.	Compustat
Antitakeover index	The governance index introduced by Bebchuk, Cohen and Ferrell (2009). It is based on six provisions: staggered boards, limits to shareholder bylaw amendments, poison pills, golden parachutes, and supermajority requirements for mergers and charter amendments. Each firm is given a score, from 0 to 6, based on the number of these provisions that the company has in the given year.	Riskmetrics; Bebchuk, Cohen and Ferrell (2009)
Four-Firm Concentration Ratio	The fraction of a 5-digit NAICS industry's sales accounted for by its largest four firms.	US Economic Consensus
Eight-Firm Concentration Ratio	The fraction of a 5-digit NAICS industry's sales accounted for by its largest eight firms.	US Economic Consensus
IP-Intensive Industry	A dummy variable equal to 1 if a firm is in one of the 75 IP-intensive industries, and 0 otherwise. The classification of the 75 IP intensive industries is provided by the US Economics and Statistics Administration (ESA) and US Patent and Trademark Office (USPTO) in 2012. See ESA and USPTO (2012) for more details.	ESA and USPTO (2012)

APPENDIX B

Main results using the equally weighted fraction of female directors

The table presents the OLS and IV regression results on the relation between female board representation and innovation productivity using the equally weighted fraction of female directors. The dependent variables include: *ln(1+Patent)* is the natural logarithm of one plus a firm's total number of patents filed (and eventually granted) in a given year. *ln(1+Citation)* is the natural logarithm of one plus the total number of non-self citations received on a firm's patents filed (and eventually granted) in a given year. Independent variables include: *Fraction of female directors_EW* is the equally weighted measure of the fraction of female directors on the board. *ln(MVE)* is the natural logarithm of market capitalization. *Tobin's Q* is market value of equity plus total assets minus book value of equity, all divided by total assets. *Leverage* is the sum of short-term and long-term debts divided by total assets. *PPE/TA* is net property, plant and equipment divided by total assets. *ROA* is earnings before interest, taxes, depreciation, and amortization divided by total assets. *Fraction of independent directors* is the number of independent directors divided by the total number of directors on the board. *R&D/TA* is R&D expenditures divided by total assets. All independent variables are lagged one year relative to the dependent variable unless otherwise specified. All regressions include industry and year effects. Industry effects are constructed based on the Fama-French 49-industry classification. Statistical significance is based on the heteroskedasticity robust firm-clustered standard errors reported in brackets. ***, ** and * indicate significance at the 1%, 5% and 10% levels, respectively.

	ln(1+Patent)		*ln(1+Citation)*	
	OLS	IV	OLS	IV
Independent Variables	1	2	3	4
Intercept	-2.013***	-1.505***	-1.189***	-0.878***
	(0.334)	(0.402)	(0.198)	(0.253)
Fraction of female directors_EW	0.389*	5.565***	0.424*	4.238**
	(0.224)	(1.696)	(0.226)	(1.761)
ln(MVE)	0.341***	0.265***	0.309***	0.255***
	(0.025)	(0.036)	(0.025)	(0.036)
Tobin's Q	-0.045**	-0.010	-0.028	-0.003
	(0.021)	(0.024)	(0.024)	(0.027)
Leverage	0.118	0.040	0.097	0.031
	(0.145)	(0.157)	(0.151)	(0.160)
PPE/TA	-0.194	-0.134	-0.297*	-0.213
	(0.181)	(0.198)	(0.173)	(0.185)
ROA	0.145	-0.161	0.422	0.167
	(0.243)	(0.285)	(0.280)	(0.305)
Fraction of independent directors	0.384***	-0.143	0.276**	-0.112
	(0.126)	(0.207)	(0.138)	(0.222)
R&D/TA	4.291***	4.315***	5.729***	5.700***
	(0.663)	(0.741)	(0.747)	(0.783)
Industry effects	Yes	Yes	Yes	Yes
Year effects	Yes	Yes	Yes	Yes
No. of obs.	6,644	6,644	6,644	6,644
Adj. R^2	0.502	0.388	0.457	0.408

APPENDIX C

Diagnostic test results for the propensity score matching estimation

The table reports the diagnostic test results for the propensity score matching estimates shown in Table 4. Panel A reports parameter estimates from the logit model used to estimate the propensity scores. The dependent variable is an indicator for the presence of female directors in a firm for a given year. Independent variables include: *ln(MVE)* is the natural logarithm of market capitalization. *Tobin's Q* is market value of equity plus total assets minus book value of equity, all divided by total assets. *Leverage* is the sum of short-term and long-term debts divided by total assets. *PPE/TA* is net property, plant and equipment divided by total assets. *ROA* is earnings before interest, taxes, depreciation, and amortization divided by total assets. *Fraction of independent directors* is the number of independent directors divided by the total number of directors on the board. *R&D/TA* is R&D expenditures divided by total assets. All independent variables are lagged one year relative to the dependent variable unless otherwise specified. All regressions include industry and year effects. Industry effects are constructed based on the Fama-French 49-industry classification. Statistical significance is based on the heteroskedasticity robust firm-clustered standard errors reported in brackets. Panel B reports the univariate comparisons of firm characteristics between firms with and without female directors and the corresponding t-statistics. ***, ** and * indicate significance at the 1%, 5% and 10% levels, respectively.

Panel A. Prematch Propensity Score Regression and Postmatch Diagnostic Regression

	Dependent Variable: *Dummy equals 1 if female directors are on the board and 0 otherwise*	
	Prematch	Postmatch
Independent Variables	1	2
Intercept	-6.448***	-0.127
	(1.468)	(1.501)
ln(MVE)	0.708***	-0.019
	(0.052)	(0.061)
Tobin’s Q	-0.368***	-0.004
	(0.053)	(0.062)
Leverage	0.340	0.028
	(0.408)	(0.433)
PPE/TA	-0.031	-0.209
	(0.470)	(0.479)
ROA	2.176**	0.097
	(0.851)	(0.849)
Fraction of independent directors	2.812***	-0.223
	(0.368)	(0.392)
R&D/TA	0.507	0.615
	(1.747)	(1.831)
Industry effects	Yes	Yes
Year effects	Yes	Yes
No. of obs.	6,619	2,940
Pseudo R^2	0.237	0.005

Panel B. Differences in Firm Characteristics

Variables	Firm-Year Obs. with Female Dirs. N=1,470	Firm-Year Obs. without Female Dirs. N=1,470	Difference	t-statistics
ln(MVE)	7.093	7.112	-0.018	-0.398
Tobin’s Q	1.993	2.005	-0.012	-0.235
Leverage	0.214	0.211	0.003	0.425
PPE/TA	0.304	0.308	-0.005	-0.561
ROA	0.146	0.146	0.000	0.050
Fraction of independent directors	0.638	0.640	-0.002	-0.293
R&D/TA	0.032	0.032	0.000	0.058

APPENDIX D

Main results with additional board-level controls for director characteristics

This table re-examines OLS and IV regression results after controlling for additional director characteristics. Panel A presents the summary statistics for the additional director characteristics. *Board MBA* is the fraction of directors with an MBA degree. *Board Ivy* is the fraction of directors who have attended an Ivy League university. *Board qualification* is the fraction of directors with professional qualifications. *Average director age* is the average age of all directors on the board. *Average director tenure* is the average tenure of all directors on the board. t-tests (Wilcoxon-Mann-Whitney tests) are conducted to test for differences between the means (medians) for firms with at least one female director on the board and firms without female directors. Panel B shows the OLS and IV regression results with additional board-level controls for director characteristics. The instrumental variable used is *Fraction of male directors linked to female directors*, defined as the fraction of male directors on the board who sit on other boards on which there is at least one female director. Dependent variables include: *ln(1+Patent)* is the natural logarithm of one plus a firm's total number of patents (*Patent*) filed (and eventually granted) in a given year. *ln(1+Citation)* is the natural logarithm of one plus the total number of non-self citations (*Citation*) received on a firm's patents filed (and eventually granted) in a given year. The variable of interest is *Fraction of female directors_TW*, defined as the tenure-weighted measure of the fraction of female directors on the board. All other control variables are defined in Appendix A. Industry effects are constructed based on the Fama-French 49-industry classification. Statistical significance is based on the heteroskedasticity robust firm-clustered standard errors reported in brackets. ***, ** and * indicate significance at the 1%, 5% and 10% levels, respectively.

Panel A. Summary statistics for director characteristics

	Whole Sample				Firm-Year Obs. with Female Directors				Firm-Year Obs. without Female Directors			
Variables	N	Mean	Median	Stdev	N	Mean	Median	Stdev	N	Mean	Median	Stdev
Board MBA	4,034	0.202	0.188	0.132	2,728	0.219	0.214	0.132	1,306	0.165***	0.154***	0.124
Board Ivy	4,034	0.129	0.111	0.110	2,728	0.144	0.133	0.108	1,306	0.098***	0.083***	0.105
Board qualification	4,034	0.016	0.000	0.037	2,728	0.016	0.000	0.035	1,306	0.016	0.000	0.041
Average director age	6,644	59.149	59.429	3.810	4,260	59.180	59.429	3.315	2,384	59.092	59.429	4.563
Average director tenure	6,105	9.753	9.214	3.911	3,885	9.398	9.091	3.430	2,220	10.373***	9.667***	4.570

Panel B: OLS and IV regression results with additional controls for director characteristics

	ln(1+Patent)		*ln(1+Citations)*	
	OLS	IV	OLS	IV
	(1)	(2)	(3)	(4)
Intercept	-1.954***	-3.426***	-0.012	-2.778***
	(0.482)	(0.517)	(0.434)	(0.472)
Fraction of female directors_TW	0.515*	4.655***	0.490**	2.708*
	(0.267)	(1.755)	(0.225)	(1.612)
ln(MVE)	0.312***	0.253***	0.231***	0.202***
	(0.028)	(0.037)	(0.023)	(0.034)
Tobin's Q	-0.029	-0.002	0.007	0.024
	(0.024)	(0.028)	(0.025)	(0.027)
Leverage	0.100	0.038	-0.007	-0.079
	(0.166)	(0.176)	(0.155)	(0.159)
PPE/TA	-0.179	-0.154	-0.117	0.008
	(0.207)	(0.223)	(0.168)	(0.178)
ROA	-0.272	-0.393	-0.398	-0.554*
	(0.295)	(0.334)	(0.299)	(0.308)
Fraction of independent directors	0.313**	-0.171	0.136	-0.137
	(0.145)	(0.243)	(0.138)	(0.229)
R&D/TA	3.456***	3.356***	3.305***	3.011***
	(0.729)	(0.844)	(0.694)	(0.734)
Board MBA	0.129	-0.007	-0.017	-0.114
	(0.170)	(0.190)	(0.153)	(0.158)
Board Ivy	0.085	-0.213	0.139	-0.068
	(0.217)	(0.267)	(0.197)	(0.230)
Board qualification	0.293	0.043	0.321	0.251
	(0.547)	(0.604)	(0.466)	(0.501)
Average director age	0.010	0.016**	0.011*	0.011*
	(0.007)	(0.008)	(0.006)	(0.007)
Average director tenure	0.006	0.011	0.004	0.009
	(0.006)	(0.007)	(0.006)	(0.006)
Industry effects	Yes	Yes	Yes	Yes
Year effects	Yes	Yes	Yes	Yes
Obs.	4,034	4,034	4,034	4,034
Adj. R2	0.504	0.423	0.445	0.423

Supporting Documentation
NOT FOR PUBLICATION
Results Available From the Author on Request

ROBUSTNESS TEST

Section 3.3: Robustness tests of the baseline results

The table examines the robustness of our findings on the relation between female board representation and corporate innovation to alternative econometric specifications and the use of different subsamples. The dependent variables are: *ln(1+Patent)* is the natural logarithm of one plus a firm's total number of patents filed (and eventually granted) in a given year. *ln(1+Citation)* is the natural logarithm of one plus the total number of non-self citations received on a firm's patents filed (and eventually granted) in a given year. The main independent variables of interest are the equally weighted and tenure-weighted measures of the fraction of female directors. For brevity, we report only the coefficient estimates on the key variables of interest. Other controls are included as in the baseline models in Table 3 (we control for R&D expenditures in all regressions). All regressions include industry and year effects. Industry effects are constructed based on the Fama-French 49-industry classification. Statistical significance is based on the heteroskedasticity robust firm-clustered standard errors reported in brackets. ***, ** and * indicate significance at the 1%, 5% and 10% levels, respectively.

	Dependent Variable	
Independent Variables	*ln(1+Patent)*	*ln(1+Citation)*
Tobit Regressions		
Fraction of female directors_EW	0.524	0.967
	(0.520)	(0.754)
Fraction of female directors_TW	1.076**	1.660**
	(0.545)	(0.709)
Poisson Regressions		
Fraction of female directors_EW	-1.178	-1.791
	(1.014)	(1.115)
Fraction of female directors_TW	1.164*	1.138*
	(0.654)	(0.662)
Fama and MacBeth Regressions		
Fraction of female directors_EW	0.453*	0.427
	(0.199)	(0.242)
Fraction of female directors_TW	0.592*	0.534
	(0.286)	(0.305)
Sample Period Ends in 2003 (N=4,260)		
Fraction of female directors_EW	0.601**	0.630*
	(0.299)	(0.333)
Fraction of female directors_TW	0.979***	0.999***
	(0.302)	(0.318)
Excluding Female CEOs (N=6,553)		
Fraction of female directors_EW	0.438*	0.476**
	(0.234)	(0.241)
Fraction of female directors_TW	0.645***	0.707***
	(0.238)	(0.222)
Excluding the Utilities and Telecoms Industries (N=5,915)		
Fraction of female directors_EW	0.339	0.419*
	(0.241)	(0.242)
Fraction of female directors_TW	0.503*	0.549**
	(0.260)	(0.240)
Controlling for the fraction of foreign directors, age and tenure diversity		
Fraction of female directors_EW	0.376*	0.372*
	(0.220)	(0.216)
Fraction of female directors_TW	0.573**	0.577***
	(0.233)	(0.214)

Excluding industries with below median average citations per patent (N=3,285)		
Fraction of female directors_EW	0.462	0.374
	(0.393)	(0.429)
Fraction of female directors_TW	1.029**	0.827*
	(0.441)	(0.456)

ROBUSTNESS TEST

Section 3.3: Robustness tests with citations per patent

The table presents OLS regression results in which the dependent variable is citations per patent. Independent variables include: *Fraction of Female Directors_EW* (*Fraction of Female Directors_TW*) is the equally weighted (tenure-weighted) measure of the fraction of female directors on the board. *ln(MVE)* is the natural logarithm of market capitalization. *Tobin's Q* is market value of equity plus total assets minus book value of equity, all divided by total assets. *Leverage* is the sum of short-term and long-term debts divided by total assets. *PPE/TA* is net property, plant and equipment divided by total assets. *ROA* is earnings before interest, taxes, depreciation, and amortization divided by total assets. *Fraction of independent directors* is the number of independent directors divided by the total number of directors on the board. *R&D/TA* is R&D expenditures divided by total assets. All independent variables are lagged one year relative to the dependent variable unless otherwise specified. All regressions include industry and year effects. Industry effects are constructed based on the Fama-French 49-industry classification. Statistical significance is based on the heteroskedasticity robust firm-clustered standard errors reported in brackets. ***, ** and * indicate significance at the 1%, 5% and 10% levels, respectively.

	Dependent Variable: *ln(1+Citation/Patent)*			
Independent Variables	1	2	3	4
Intercept	0.311***	0.150***	0.037	-0.093
	(0.061)	(0.055)	(0.113)	(0.085)
Fraction of female directors_EW	0.134*	0.136*	–	–
	(0.080)	(0.077)		
Fraction of female directors_TW	–	–	0.149**	0.139**
			(0.067)	(0.065)
ln(MVE)	0.046***	0.052***	0.049***	0.054***
	(0.006)	(0.006)	(0.006)	(0.005)
Tobin's Q	0.013	-0.012	0.010	-0.011
	(0.008)	(0.009)	(0.008)	(0.009)
Leverage	-0.075	-0.001	-0.076	-0.024
	(0.060)	(0.056)	(0.060)	(0.056)
PPE/TA	-0.167***	-0.093**	-0.061	-0.057
	(0.046)	(0.043)	(0.054)	(0.052)
ROA	-0.041	0.243**	-0.049	0.207*
	(0.116)	(0.115)	(0.117)	(0.116)
Fraction of independent directors	0.049	0.027	0.052	0.026
	(0.050)	(0.048)	(0.050)	(0.048)
R&D/TA	–	2.225***	–	2.329***
		(0.280)		(0.288)
Industry effects	Yes	Yes	Yes	Yes
Year effects	Yes	Yes	Yes	Yes
No. of obs.	6,644	6,644	6,644	6,644
Adj. R^2	0.382	0.403	0.386	0.406

FOOTNOTE 10

Propensity score matching estimator with replacement

The table presents the average treatment effect estimates from propensity score matching with replacement. The logit model used to estimate the propensity scores is the same as in Panel A of Table 4. *ln(1+Patent)* is the natural logarithm of one plus a firm's total number of patents filed (and eventually granted) in a given year. *ln(1+Citation)* is the natural logarithm of one plus the total number of non-self citations received on a firm's patents filed (and eventually granted) in a given year. ***, ** and * indicate significance at the 1%, 5% and 10% levels, respectively.

	Firm-Year Obs. with Female Dirs. N=3,832	Firm-Year Obs. without Female Dirs. N=2,229	Difference	t-stat
ln(1+Patent)	0.671	0.458	0.213***	4.04
ln(1+Citation)	0.622	0.438	0.184***	2.92

ROBUSTNESS TEST

Section 4.2: Instrumental variable estimation with external board seats as an additional control

This table presents the robustness test results with external board seats as an additional control in 2SLS regressions. Panel A presents the first-stage regression results in which the dependent variables are the equally weighted and tenure-weighted fraction of female directors. The instrumental variable is *Fraction of male directors linked to female directors*, defined as the fraction of male directors on the board who sit on other boards on which there is at least one female director. The results for other controls are suppressed for brevity. Panel B reports the second-stage regression results. The dependent variables are: *ln(1+Patent)* is the natural logarithm of one plus a firm's total number of patents filed (and eventually granted) in a given year. *ln(1+Citation)* is the natural logarithm of one plus the total number of non-self citations received on a firm's patents filed (and eventually granted) in a given year. *No. external board seats* is the total number of external board seats by directors. All other control variables are the same as those in the baseline models. Industry effects are constructed based on the Fama-French 49-industry classification. Statistical significance is based on the heteroskedasticity robust firm-clustered standard errors reported in brackets. ***, ** and * indicate significance at the 1%, 5% and 10% levels, respectively.

Panel A. First-Stage Regressions

	Dependent Variables	
Independent Variables	*Fraction of female directors_EW*	*Fraction of female directors_TW*
Fraction of male directors linked to female directors, z_1	0.056***	0.059***
	(0.011)	(0.012)
Other Control Variables	Yes	Yes
Industry effects	Yes	Yes
Year effects	Yes	Yes
No. of obs.	6,629	6,629
CD Wald F-statistics	89.720***	93.740***
Adj. R^2	0.273	0.285

Panel B. Second-Stage Regressions

	Dependent Variables			
	ln(1+Patent)	*ln(1+Citation)*	*ln(1+Patent)*	*ln(1+Citation)*
Independent Variables	1	2	3	4
Intercept	-1.504***	-1.031***	-1.323***	-0.794**
	(0.393)	(0.242)	(0.483)	(0.319)
Fraction of female directors_EW	5.122**	4.185*		
	(2.183)	(2.248)		
Fraction of female directors_TW			4.894**	3.939*
			(2.048)	(2.080)
ln(MVE)	0.268***	0.255***	0.283***	0.267***
	(0.036)	(0.037)	(0.032)	(0.032)
Tobin's Q	-0.012	-0.003	-0.012	-0.003
	(0.024)	(0.027)	(0.024)	(0.027)
Leverage	0.027	0.002	0.010	-0.012
	(0.154)	(0.159)	(0.154)	(0.160)
PPE/TA	-0.127	-0.093	-0.102	-0.082
	(0.197)	(0.182)	(0.194)	(0.181)
ROA	-0.152	0.166	-0.127	0.191
	(0.299)	(0.326)	(0.295)	(0.320)
Fraction of independent directors	-0.119	-0.114	-0.056	-0.061
	(0.225)	(0.238)	(0.203)	(0.214)
R&D/TA	4.269***	5.854***	4.127***	5.714***
	(0.729)	(0.785)	(0.726)	(0.783)
No. external board seats	0.002	0.002	-0.000	0.000
	(0.006)	(0.006)	(0.006)	(0.006)
Industry effects	Yes	Yes	Yes	Yes
Year effects	Yes	Yes	Yes	Yes
No. of obs.	6,629	6,629	6,629	6,629
Adj. R^2	0.408	0.407	0.421	0.417

ROBUSTNESS TEST

Section 4.2: IV regressions with additional controls for directors' education

This table shows the second stage IV regression results after controlling for directors' education. The instrumental variable used is *Fraction of male directors linked to female directors*, defined as the fraction of male directors on the board who sit on other boards on which there is at least one female director. Dependent variables include: *ln(1+Patent)* is the natural logarithm of one plus a firm's total number of patents (*Patent*) filed (and eventually granted) in a given year. *ln(1+Citation)* is the natural logarithm of one plus the total number of non-self citations (*Citation*) received on a firm's patents filed (and eventually granted) in a given year. Independent variables include: *Fraction of female directors_EW* (*Fraction of female directors_TW*) is the equally weighted (tenure-weighted) measure of the fraction of female directors on the board. *Board education* is the average *Education* of directors on the board. *Board MBA* is the fraction of directors with an MBA degree. *Board Ivy* is the fraction of directors who have attended an Ivy League university (i.e., Brown University, Columbia University, Cornell University, Dartmouth College, Harvard University, Princeton University, University of Pennsylvania, and Yale University). *Board qualification* is the fraction of directors with professional qualifications. *No. external board seats* is the total number of external board seats by directors. All other control variables are the same as those in the baseline models. Industry effects are constructed based on the Fama-French 49-industry classification. Statistical significance is based on the heteroskedasticity robust firm-clustered standard errors reported in brackets. ***, ** and * indicate significance at the 1%, 5% and 10% levels, respectively.

	Dependent Variables							
	ln(1+Patent)	ln(1+Citation)	ln(1+Patent)	ln(1+Citation)	ln(1+Patent)	ln(1+Citation)	ln(1+Patent)	ln(1+Citation)
	1	2	3	4	5	6	7	8
Intercept	-1.867***	-1.143**	-2.208***	-1.267***	-1.973***	-1.215***	-2.279***	-1.308***
	(0.705)	(0.453)	(0.458)	(0.365)	(0.623)	(0.378)	(0.427)	(0.318)
Fraction of female directors_EW	7.199*	6.535*			6.534*	6.345*		
	(4.241)	(3.863)			(3.892)	(3.573)		
Fraction of female directors_TW			4.467**	4.168**			4.159**	4.090**
			(2.185)	(2.072)			(2.104)	(2.014)
Board education	-0.252	-0.213	-0.130	-0.111				
	(0.210)	(0.181)	(0.130)	(0.119)				
Board MBA					-0.332	-0.390	-0.137	-0.204
					(0.271)	(0.255)	(0.193)	(0.189)
Board Ivy					-0.352	-0.319	-0.153	-0.131
					(0.371)	(0.338)	(0.269)	(0.248)
Board qualification					-0.161	-0.015	0.111	0.181
					(0.724)	(0.631)	(0.602)	(0.533)
ln(MVE)	0.224***	0.154***	0.256***	0.180***	0.223***	0.149***	0.254***	0.177***
	(0.058)	(0.049)	(0.039)	(0.035)	(0.055)	(0.049)	(0.039)	(0.035)

Tobin's Q	0.012	0.033	-0.001	0.023	0.012	0.035	-0.002	0.024
	(0.034)	(0.031)	(0.028)	(0.028)	(0.033)	(0.031)	(0.028)	(0.028)
Leverage	-0.029	-0.440*	-0.014	-0.394**	0.006	-0.410**	0.002	-0.382**
	(0.198)	(0.230)	(0.178)	(0.197)	(0.186)	(0.208)	(0.172)	(0.186)
PPE/TA	-0.119	-0.357**	-0.122	-0.392***	-0.128	-0.374**	-0.126	-0.399***
	(0.238)	(0.155)	(0.222)	(0.141)	(0.234)	(0.153)	(0.221)	(0.140)
ROA	-0.663	-0.486	-0.473	-0.347	-0.552	-0.399	-0.413	-0.298
	(0.442)	(0.367)	(0.350)	(0.329)	(0.387)	(0.356)	(0.332)	(0.331)
Fraction of independent directors	-0.347	-0.577	-0.214	-0.463	-0.334	-0.593	-0.207	-0.471
	(0.407)	(0.389)	(0.293)	(0.295)	(0.379)	(0.377)	(0.281)	(0.287)
R&D/TA	3.705***	4.457***	3.393***	4.116***	3.259***	4.106***	3.169***	3.943***
	(0.989)	(0.994)	(0.843)	(0.847)	(0.923)	(0.885)	(0.834)	(0.805)
No. external board seats	0.002	0.003	0.004	0.004	0.002	0.003	0.003	0.004
	(0.008)	(0.007)	(0.006)	(0.006)	(0.008)	(0.007)	(0.006)	(0.006)
Industry effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Year effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
No. of obs.	4031	4031	4031	4031	4031	4031	4031	4031
Adj. R^2	0.291	0.230	0.426	0.349	0.328	0.241	0.437	0.352

ROBUSTNESS TEST

Section 5.3: Alternative female board representation measures
independent vs. executive female directors

This table presents the OLS regression results with alternative measures of female board representation. The dependent variables are *ln(1+R&D)*, *ln(1+Patent)* and *ln(1+Citation)*. Independent variables include: *Fraction of female indep. directors* (*Fraction of female exe. directors*) is calculated as the number of female independent (executive) directors divided by the total number of directors on the board. *Fraction of male exe. directors* is calculated as the number of male executive directors divided by the total number of directors on the board. *ln(MVE)* is the natural logarithm of market capitalization. *Tobin's Q* is market value of equity plus total assets minus book value of equity, all divided by total assets. *Leverage* is the sum of short-term and long-term debts divided by total assets. *PPE/TA* is net property, plant and equipment divided by total assets. *ROA* is earnings before interest, taxes, depreciation, and amortization divided by total assets. *R&D/TA* is R&D expenditures divided by total assets. All independent variables are lagged one year relative to the dependent variable unless otherwise specified. All regressions include industry and year effects. Industry effects are constructed based on the Fama-French 49-industry classification. Statistical significance is based on the heteroskedasticity robust firm-clustered standard errors reported in brackets. ***, ** and * indicate significance at the 1%, 5% and 10% levels, respectively.

	ln(1+R&D)	*ln(1+Patent)*	*ln(1+Citation)*
Independent Variables	1	2	3
Intercept	-2.325**	-1.670***	-0.910***
	(0.978)	(0.332)	(0.194)
Fraction of female indep. directors	1.330***	0.618**	0.621**
	(0.455)	(0.241)	(0.247)
Fraction of female exe. directors	-1.933	-0.879	-0.889*
	(1.248)	(0.558)	(0.524)
Fraction of male exe. directors	-0.698**	-0.466***	-0.345*
	(0.309)	(0.171)	(0.191)
ln(MVE)	0.575***	0.337***	0.306***
	(0.039)	(0.025)	(0.025)
Tobin's Q	0.002	-0.043**	-0.027
	(0.035)	(0.021)	(0.024)
Leverage	-0.137	0.090	0.072
	(0.271)	(0.144)	(0.151)
PPE/TA	-1.287***	-0.209	-0.308*
	(0.292)	(0.181)	(0.172)
ROA	-1.473***	0.150	0.427
	(0.488)	(0.245)	(0.282)
R&D/TA		4.250***	5.678***
		(0.666)	(0.749)
Industry effects	Yes	Yes	Yes
Year effects	Yes	Yes	Yes
No. of obs.	6,644	6,644	6,644
Adj. R^2	0.720	0.502	0.457

ROBUSTNESS TEST

Section 5.3: Alternative female board representation measures
pre- vs. post-CEO female directors

This table presents the OLS regression results with alternative measures of female board representation. The dependent variables are *ln(1+R&D)*, *ln(1+Patent)* and *ln(1+Citation)*. Independent variables include: *Fraction of female pre-CEO directors* (*Fraction of female post-CEO directors*) is calculated as the number of pre-CEO (post-CEO) female directors divided by the total number of directors on the board. *Fraction of male post-CEO directors* is calculated as the number of post-CEO male directors divided by the total number of directors on the board. *ln(MVE)* is the natural logarithm of market capitalization. *Tobin's Q* is market value of equity plus total assets minus book value of equity, all divided by total assets. *Leverage* is the sum of short-term and long-term debts divided by total assets. *PPE/TA* is net property, plant and equipment divided by total assets. *ROA* is earnings before interest, taxes, depreciation, and amortization divided by total assets. *Fraction of independent directors* is the number of independent directors divided by the total number of directors on the board. *R&D/TA* is R&D expenditures divided by total assets. All independent variables are lagged one year relative to the dependent variable unless otherwise specified. All regressions include industry and year effects. Industry effects are constructed based on the Fama-French 49-industry classification. Statistical significance is based on the heteroskedasticity robust firm-clustered standard errors reported in brackets. ***, ** and * indicate significance at the 1%, 5% and 10% levels, respectively.

Independent Variables	*ln(1+R&D)* 1	*ln(1+Patent)* 2	*ln(1+Citation)* 3
Intercept	-1.077	-1.692***	-1.179***
	(0.795)	(0.196)	(0.187)
Fraction of female post-CEO directors	0.188	0.143	0.336
	(0.508)	(0.268)	(0.269)
Fraction of female pre-CEO directors	0.903	0.739**	0.448*
	(0.579)	(0.315)	(0.262)
Fraction of male post-CEO directors	-0.040	-0.024	-0.017
	(0.112)	(0.066)	(0.071)
ln(MVE)	0.576***	0.329***	0.294***
	(0.040)	(0.026)	(0.024)
Tobin's Q	0.013	-0.044**	-0.018
	(0.035)	(0.020)	(0.023)
Leverage	-0.048	0.165	0.057
	(0.273)	(0.148)	(0.148)
PPE/TA	-1.307***	-0.307*	-0.199
	(0.295)	(0.178)	(0.163)
ROA	-1.683***	0.032	0.020
	(0.497)	(0.253)	(0.275)
Fraction of independent directors	0.727***	0.410***	0.244*
	(0.217)	(0.130)	(0.133)
R&D/TA		4.537***	5.149***
		(0.667)	(0.715)
Industry effects	Yes	Yes	Yes
Year effects	Yes	Yes	Yes
No. of obs.	6,060	6,060	6,060
Adj. R^2	0.779	0.473	0.434

ROBUSTNESS TEST

Section 5.3: Alternative female board representation measures
busy vs. non-busy female directors

This table presents the OLS regression results with alternative measures of female board representation. The dependent variables are *ln(1+R&D)*, *ln(1+Patent)* and *ln(1+Citation)*. Independent variables include: *Fraction of female busy directors* (*Fraction of female non-busy directors*) is calculated as the number of female busy (non-busy) directors divided by the total number of directors on the board. *Fraction of male busy directors* is calculated as the number of male busy directors divided by the total number of directors on the board. A director is defined as busy if he or she holds three or more directorships, and non-busy otherwise. *ln(MVE)* is the natural logarithm of market capitalization. *Tobin's Q* is market value of equity plus total assets minus book value of equity, all divided by total assets. *Leverage* is the sum of short-term and long-term debts divided by total assets. *PPE/TA* is net property, plant and equipment divided by total assets. *ROA* is earnings before interest, taxes, depreciation, and amortization divided by total assets. *Fraction of independent directors* is the number of independent directors divided by the total number of directors on the board. *R&D/TA* is R&D expenditures divided by total assets. All independent variables are lagged one year relative to the dependent variable unless otherwise specified. All regressions include industry and year effects. Industry effects are constructed based on the Fama-French 49-industry classification. Statistical significance is based on the heteroskedasticity robust firm-clustered standard errors reported in brackets. ***, ** and * indicate significance at the 1%, 5% and 10% levels, respectively.

Independent Variables	*ln(1+R&D)* 1	*ln(1+Patent)* 2	*ln(1+Citation)* 3
Intercept	-1.628***	-1.580***	-1.105***
	(0.336)	(0.212)	(0.208)
Fraction of female busy directors	1.932	0.125	-0.000
	(1.188)	(0.683)	(0.599)
Fraction of female non-busy directors	0.804*	0.566**	0.495**
	(0.463)	(0.226)	(0.231)
Fraction of male busy directors	0.062	0.479	0.425
	(0.345)	(0.305)	(0.312)
ln(MVE)	0.567***	0.326***	0.299***
	(0.042)	(0.026)	(0.025)
Tobin's Q	0.003	-0.044**	-0.025
	(0.036)	(0.021)	(0.024)
Leverage	0.179	0.204	0.092
	(0.285)	(0.147)	(0.151)
PPE/TA	-1.943***	-0.410**	-0.291*
	(0.317)	(0.179)	(0.173)
ROA	-1.240**	0.327	0.468*
	(0.510)	(0.252)	(0.281)
Fraction of independent directors	0.919***	0.371***	0.233*
	(0.221)	(0.128)	(0.139)
R&D/TA		4.717***	5.734***
		(0.671)	(0.746)
Industry effects	Yes	Yes	Yes
Year effects	Yes	Yes	Yes
No. of obs.	6,644	6,644	6,644
Adj. R^2	0.686	0.490	0.458