Do Well-Connected Boards Invest in Productive R&D Activities?

Subramanian R. Iyer
Anderson School of Management
University of New Mexico
Albuquerque, New Mexico 87131
Ph: (505) 277-3207
Email: sriyer@unm.edu

Harikumar Sankaran[†]
College of Business
New Mexico State University
Las Cruces, New Mexico 88003
Ph: (575) 646-3226
Email: sankaran@nmsu.edu

Yan Zhang
College of Business
New Mexico State University
Las Cruces, New Mexico 88003
Ph: (575) 646-7443
Email: yz@nmsu.edu

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[†] Corresponding author: Harikumar Sankaran, College of Business, New Mexico State University, Las Cruces, New Mexico 88003, Ph: (575)646-3226, Email: sankaran@nmsu.edu. We thank the participants at University of New Mexico, Southwestern Finance Association Conference, 2017, and the World Finance Conference, 2017. We especially thank Shofiqur Rahman for his valuable suggestions.

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Abstract

We find that higher board connectivity beyond a threshold is detrimental to shareholders. Our research uses output elasticity of R&D (research quotient (RQ)) as the measure of productivity instead of patents and patent citations. The measure RQ not only serves as a robust estimate of R&D productivity but also provides a measure of an optimal level of R&D expenditures for a given firm-year. We find that as boards become more connected, firms face diminishing marginal RQ, R&D intensity, and market to book value of equity. Analysis of underinvesting firms shows that higher board connectivity has no effect in reducing underinvestment. However increased board connectivity exacerbates overinvestment among overinvesting firms. Our results indicate that greater connectivity causes boards to be busy and the diminished oversight results in greater overinvestment. However, the overinvestment is reduced and R&D expenditures approach first-best if directors hold multiple directorships in similar industries to the focal firm.

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1 Introduction

Well-connected CEOs and directors can access information related to competition, technological developments, initiate opportunities for collaboration, and detect market shifts toward new products thereby improving their ability to exploit innovation opportunities (Faleye, Kovacs, & Venkateswaran, 2014; Chuluun, Prevost, & Upadhyay, 2017; Helmers, Patnam, & Rau, 2017). Greater top management connectivity, however, is not unequivocally valuable to shareholders. Mergers and deals instigated by highly connected CEOs result in more losses to both the bidder and the resulting entity (El-Khatib et al., 2015). Directors serving on many boards tend to be busy and become ineffective monitors, resulting in weaker corporate governance and reduced market valuation (Fich & Shivdasani, 2006; Core, Holthausen, & Larcker, 1999; Kirchmaier & Stathopoulos, 2008). These studies suggest that although more connected directors and CEOs add value, such connections can be detrimental to shareholders if it exceeds a threshold. This research examines whether increases in board level connections beyond a threshold results in sub-optimal R&D investment that adversely affects the market to book value of equity.

We use the output elasticity of R&D (also referred to as Research Quotient or RQ) as a measure of R&D productivity instead of patent numbers or citation based measures.[1] There are

[1] This estimation process and its robustness checks are described in the user manual for the WRDS RQ database, where we obtained the RQ data for our empirics. This 13-page manual describes the theory underpinning RQ, describes the functional form for all variables, as well as the logic behind those functional forms. It then compares estimates for all variables in RQ estimation to those from four other versions of R&D production function estimation, including attempts to control for endogenous choice of inputs.

several reasons for choosing another measure of R&D productivity. Prior studies have gained significant insight into the value of investment in R&D by employing patent and patent citation data as a proxy for R&D output (Hall, Jaffe, and Trajtenberg (2001, 2005)). Unfortunately, studies that use patent data do not capture the vast number of firms engaged in R&D but choose not to patent their inventions. While the R&D activities within such firms have the potential to add value, a patent count of zero assigned to such firms would result in an underestimate of their valuation effect.[2] Knott, and Yang (2015) examine a 26-year panel over 1981 to 2006 find that 63% of firms in their sample are engaged in R&D, but aren't patenting. Cohen, Nelson, and Walsh (2000) find that patents tend to be the least emphasized by firms in most of the manufacturing industries, and secrecy and lead time tend to be emphasized most heavily. Since patents and patent citations accumulate over several years after the R&D investment, it does not provide top management with a benchmark to make resource allocation decisions. RQ holds promise in providing such a benchmark.[3]

The main features of RQ are: a) it measures the productivity of R&D whether or not firms file for patents, (b) it measures the value added by firms that efficiently exploit their set patents even if they are fewer in number, (c) it captures the heterogeneity across firms that differ in their R&D productivity, (d) it is shown to be more strongly associated with current and future firm value as measured in terms of Tobin's q and future risk-adjusted returns than previous patent-based measures, (e) it can be estimated using panel data and is not limited by data

[2] Although citation weighted patents adjust for this problem, Abrams, Akcigit, and Popadak (2013) find a non-monotonic relation between citations and patent value, suggesting that firms are less likely to patent their most valuable innovations.
[3] See Lanjouw & Schankeman (2004) for a discussion on the drop in research productivity, the noise in patent data, and R&D elasticity as a more accurate measure of R&D productivity.

availability, (f) it provides an estimate of the optimal R&D expenditures for a firm in a given year.[4]

A timely estimate of optimal R&D expenditures is a useful benchmark for a firm's board of directors in deciding the R&D budget. This research examines if the presence of more connected board members makes them better at making value enhancing decisions when committing resources towards R&D. The direct and indirect connections between directors (i.e., centrality measures) is computed using the director network data from the Corporate Board Member Magazine Director Database for the period 2000-2014. We then merge the network data with COMPUSTAT and the RQ data from WRDS, to obtain a final sample of 12,975 firm-year observations.

After controlling for known determinants of R&D intensity (R&D expenditure divided by Total Assets), we find a statistically significant concave relation between RQ and board centrality. The positive association between RQ and an increase in the level of board connectivity is consistent with the findings in prior studies that use patent data. However, higher levels of connectivity are associated with diminishing marginal R&D productivity resulting in a concave relation. This non-linearity has not been documented in earlier studies that use patent data as a proxy for R&D output.

Consistent with the decline in marginal RQ, we find a concave relationship between R&D intensity and board centrality. The nonlinearity could be an artifact not attributable to board connectivity if there are other factors related to board connectivity that influence R&D expenditures. The decrease in incremental R&D expenditures associated with better-connected

[4] We also provide a robustness check for the results from RQ by using a new measure recently proposed by Kogan, Papanikolaou, Seru, Stoffman (2017) that captures the private, economic value of innovations that are based on stock market reactions to patent grants.

boards could be due to a spillover effects arising from being near research clusters in universities that serve as a public good. The presence of directors with advanced technical knowledge has been found to provide relevant advice that can potentially result in efficient use of resources that come with better connectivity (Francis, Hasan, and Wu, 2015). It could also be that the director with the maximum connections in a board may prevail on others and override rational objections from others during boardroom deliberations. The interaction between the CEO's connections and the directors' connections can pose a problem in attributing the concavity uniquely to board connectivity. We find that the concave relationship is robust to measures that captures spillovers, monitoring, the influence of powerful board member, and influence of CEOs' network relations. We also run several tests to check for endogeneity and find that the causality runs from board centrality to R&D intensity.[5]

If increases in board connectivity cause R&D to increase, *albeit*, in a concave manner, it is important to verify that board members indeed engage in value enhancing R&D decisions. We address this question by examining the role of board centrality in sub-samples of firms that underinvest or overinvest in R&D. The identification of such sub-samples is made feasible with the estimate of optimal R&D expenditures that results from the estimation process of RQ. We obtained the estimate of optimal R&D expenditures for each firm year in our sample from the WRDS database. Our results indicate that increases in board centrality leaves the extent of underinvestment *unaffected* and *exacerbates* the extent of overinvestment.

If increase in board connections beyond a threshold is not effective in ameliorating any distortions in R&D intensity, it should show up in a differential sensitivity between the two sub-samples. Furthermore, if board connections are important from the shareholders' perspective, it

[5] Several studies in this area have confirmed the direction of causality from board centrality to R&D. For example, see Chuluun, Prevost, & Upadhyay (2017), and Helmers, Patnam, & Rau (2017).

ought to be more valuable among firms that underinvest in R&D relative to those that overinvest. We examine this hypothesis by studying the influence of board centrality on both, R&D intensity and one period ahead market to book value of equity in the context of a simultaneous equations framework. Confirming our earlier findings, the results indicate that R&D expenditures are less sensitive to increases in board centrality among underinvesting firms relative to overinvesting firms. Furthermore, we find that the market to book value of equity is positively related to board centrality and is more sensitive among underinvesting firms relative to overinvesting firms. Thus, even though greater board connectivity is valued relatively lower among overinvesting firms, well-connected boards in overinvesting firms tend to invest more in R&D rather than cutting back on such expenditures.

Better connected directors potentially bring valuable information to the focal firm and can provide more effective advice. However, more connections mean less time spent in the focal firm and consequently a less effective monitoring environment. Using the traditional measure offered by Fich and Shivdasani (2006), we find that busy boards indeed exacerbate overinvestment. However, busy boards comprising of directors sitting on firms in similar industries to the focal firm are shown to curtail overinvestment in R&D and are beneficial to shareholders. Our result is consistent with the finding in Dass, Kini, Nanda, Onal, and Wang (2013) that firms engaged in R&D and generate patents and patent citations increase the likelihood of having directors from related industries (DRIs) on the board. The presence of such directors is shown to increase the firm value (Tobin's q) of such firms.

The rest of the paper is laid out as follows. Section 2 presents a brief review of related literature and highlights the need for an alternative measure of research productivity. Section 3 contains a description of the data, variable definitions, and summary statistics. Section 4 contains multiple regressions that examine the relation between board centrality, RQ, and R&D intensity. This section contains the analysis for underinvesting and overinvesting subsamples. Section 5 contains the robustness and endogeneity tests performed in this research. Section 6 examines the relationship between R&D intensity, board centrality, and market to book value of equity in a simultaneous equations framework. Section 7, presents results from the analysis of busy boards to explain the overinvestment phenomenon. Our concluding remarks are presented in Section 8.

2 Related literature

Few researchers have recently studied the influence of CEO and director connections on a firm's innovative activity. Faleye, Kovacs, & Venkateswaran (2014) find that R&D intensity increases with CEO connections. Furthermore, the number of patents received and the probability of receiving patent citations are both positively related to CEO connections. To establish the valuation implications of patents and patent citations, these authors regress firm value (ROA and Tobin's q) on *predicted* R&D, *predicted* patents, and *predicted* patent citations along with appropriate controls and find a positive relation between firm value and the above measures of R&D output.

From a top management perspective, Chuluun, Prevost, & Upadhyay (2017) find that higher board-level connections (i.e., more centrally located board in an interfirm network) induce a higher level of innovative activity based on input measures (R&D intensity) and output measures such as patenting activity. The influence of board centrality is shown to have a distinct effect on a firm's innovative activity that is independent of the influence of CEO connections. From a valuation perspective, these authors hypothesize that R&D activity that results from increased board connections tends to reduce the uncertainty surrounding the investment in intangible assets. They find that the spreads on outstanding bonds decrease as board centrality increases.[6]

Using Indian data, Helmers, Patnam, and Rau (2017) address the endogeneity of board interlocks and R&D activity by an identification strategy that exploits an exogenous change in India's corporate governance framework and patent system. These authors confirm earlier findings and document a positive impact of interlocking on patenting activity. In the context of U.K. firms, Bernini et al. (2014) find that board interlocks are associated with increased patent activity and point toward the use of interlocks as a mechanism by which firms coordinate their patenting activity or transfer technological knowledge. These studies, however, do not examine the valuation effects of board interlocks and innovative activity.

Collectively taken, the above studies suggest that a well connected top management team induces greater investment in R&D resulting in more patents and patent citations that are valued positively by stakeholders in a firm. These studies use of patents per dollar of research and development expenditures as a measure of innovative productivity. However, over a decade ago, Cohen et al (2000) pointed out that except in pharmaceuticals and medical instruments, other industries appropriated rents from their innovations through mechanisms such as lead time (first mover advantage), moving rapidly down the learning curve, the use of complementary sales and service capabilities and secrecy and not patents. These authors suggest that their relative effectiveness does not explain a large amount of patenting as a device for protecting profits due to specific innovations.

The relation between patents and productivity reveals important insights. Boldrin and Levine (2013) document that 59,715 patents were issued in the U.S. in 1983 and this grew to

[6] Since innovative activity and changes in yield spreads are endogenously related, these authors examine changes in yield spreads around patent filing dates and find that spreads decrease as board centrality increases.

244,341 new patents in 2000. Although in less than 30 years, the number of patents quadrupled, the factor productivity has not exhibited a positive trend. The annual growth in total factor productivity was about 1.2% in the 1970s, and less than 1% in the 1990s and until 2009. This observation is consistent with the innovation paradox mentioned in a series of articles in the *Wall Street Journal*.[7]

The study by Bessen (2008) indicates that a litigated patent is worth nearly six times as much as a non-litigated patent. Although there is a positive correlation between citations and patent values, these authors find that citations only explain a small portion of the variance in patent value and hence suggest that citation statistics may be a more meaningful measure of the value of the underlying technology. Cooper, Knott and Yang (2015) examine the relation between patent-based measures and firm value and find that patent-based measures largely capture differences between firms that patent versus those that don't, rather than the differences in innovation.

In this study, we extend earlier research by examining the impact of directors' connections on a firm's investment in R&D and R&D productivity based on a firm's production function. We use this because: (a) it includes those firms that invest in R&D but do not file for patents, (b) the productivity measure is based on a firm's production function have the potential to provide insights into the decline in innovative productivity, and (c) it provides an opportunity to examine the robustness of conclusions drawn from earlier studies that employ patent based output measures. We explain the productivity measure in Section 3.2.3 and provide a robustness check

[7] https://www.wsj.com/articles/the-economys-hidden-problem-were-out-of-big-ideas-1481042066. To quote: "…Economies grow by equipping an expanding workforce with more capital such as equipment, software and buildings, then combining capital and labor more creatively. This last element, called "total factor productivity, captures the contribution of innovation. Its growth peaked in the 1950s at 3.4% a year as prior breakthroughs such as electricity, aviation and antibiotics reached their maximum impact. It has steadily slowed since and averaged a pathetic 0.5% for the current decade."

in Section 5.1 by using a new measure of patent value developed by Kogan, Papanikolaou, Seru, Stoffman (2017).[8]

3 Data, variables, and summary statistics

3.1 Data

We obtain information on companies' boards of directors from the Corporate Board Member Magazine Director Database (hereafter referred to as BoardMag), which contains a listing of directors in companies listed on the NASDAQ OMX Group Inc., NYSE Amex, and NYSE Euronext stock. This database tracks directors who serve on multiple boards, lists inside/outside board members, identifies key boardroom relations, discovers trends in boards and executive officers, and more. We intersect this database with Compustat and use only firms with complete data for a sample period from 2000-2014.

3.2 Variables

3.2.1 Centrality measures

We first measure a director's position in the network and then compute the average across all directors within a firm's board. A direct connection (or, link) is established between directors when they serve on the same board. An indirect connection between two directors occurs if a director is connected to another director through a common director. The combination of direct and indirect connections is a richer informational context and subsumes connections involving director interlocks. The whole graph, with both direct and indirect connections was completed using the Stanford Network Analysis Platform (Leskovec & Sosic, 2016) and Networkit (Staudt & Meyerhenke, 2016) software. These connections are the basis for

[8] We thank Tomas Jandik for bringing this to our attention.

computing four commonly uses measures of the centrality for each director in the network (Bonacich, 2007). The network in our sample grew from 66,799 directors and 896,774 links in the year 2000 to 161,487 directors and 3,736,708 links in 2014. Because the type of directors' connections affects the nature of information flow, we use four different centrality measures that are described below. We report the raw measures in Table 1 and use standardized variables [Raw Centrality-Mean Raw Centrality)/Standard Deviation of Raw Centrality)] in regressions.

Betweenness Centrality

A director may serve as a bridge between two distinct networks or groups of directors. In this context, although a director may not directly have access to firm-specific information that he or she serves, he or she still might function as a resource and facilitate making contacts. A director in such a position forms a critical node in the many pathways that connect other directors in the network. Let $d_{st}(i)$ denote the number of shortest paths between directors s and t with director i being an intermediate connection and let d_{st} denote the total number of shortest links that connect directors s and t (including those that involve director i). Then, betweenness centrality is measured by $C_B(i) = \sum_{s \neq t \neq i} \frac{d_{st}(i)}{d_{st}}$, and the scaled measure is given as $C_B^*(i) = \frac{2}{(n-1)(n-2)} C_B(i)$. This measure is approximated by an algorithm described in Geisberger, Sanders, and Schultes (2008).

Closeness Centrality

If a director possesses relatively close ties to a cluster of outside directors, information/ knowledge exchange will be quicker. Let $d(i, j)$ denote the shortest number of steps that connect director i to director j in the network. From director i's perspective, the value $\sum_j d(i, j)$ denotes the total number of (shortest) steps taken to connect with all other directors in the network. The measure of "shortest" captures closeness. The inverse of this measure is denoted by

$C_C(i) = \frac{1}{\sum_j d(i,j)}$ measures closeness, where the higher the value the closely tied director *i* is to other directors in the network. The scaled measure is $C_C^*(i,j) = (n-1)C_C(i)$.

Degree Centrality

Degree centrality measures the number of direct connections a director has with other directors. Let A_{ij} denote a matrix that contains a value of 1 if directors *i* and *j* are connected and 0 otherwise. Let $C_D(i)$ denote the number of nearest neighbors to director *i*. Then, $C_D(i) = \sum_j A_{ij}$ and scaled degree centrality is $C_D^*(i) = \frac{1}{n-1} C_D(i)$, where *n* is the number of directors in the network.

Eigenvector Centrality

Finally, there could be instances in which a director may not be well connected with other directors but may have a connection to a director who is very influential by his/her position in the network. Such a less-than-well-connected director still benefits from his/her contacts. Let v_i denote the importance of director *i*. The value of v_i depends on the value of v_j for director *j* if director *i* is connected to director *j*. If we consider all directors in the network, then v_i is determined by $\sum_j A_{ij} v_j$. To compute v_i, suppose we assign a value of 1 to each director's importance and recursively determine v_i, by the following relation $v_i \leftarrow \sum_j A_{ij}(v_j)$, the values increase in size without bound. To normalize this process, let λ be a normalizing constant such that $v_i = \frac{1}{\lambda} \sum_j A_{ij}(v_j)$. In matrix notation, this is written as $Av = \lambda v$. The constant λ is easily seen as an eigenvalue measure. The eigenvector associated with the largest eigenvalue indicates the measure of each director's importance in the network.

3.2.2 Control variables

Consistent with prior literature, the controls we use include cash holdings (cash and short-term investments scaled by total assets), size (natural log of total assets), firm age (number of years since the firm appeared in COMPUSTAT), leverage (long-term debt plus long-term debt due in one year scaled by total assets), reverse Herfindahl-Hirschman index (RHI), dividends (cash dividends scaled by total assets), ROA Volatility (5-year standard deviation of ROA), Sales Growth (scaled by total assets), Market to book value of equity (MB), and Tangibility (Property, Plant, and Equipment scaled by total assets). We also control for year fixed effect and industry fixed effect. Also, we use a dummy variable, HT, to denote whether a firm belongs to a high-tech industry.[9] All variables are winsorized at .5 and 99.5 percentiles and are described in Appendix A.

3.2.3 R&D intensity and R&D productivity variables

The focus of our study is to examine the influence of board centrality on R&D productivity, R&D intensity and its valuation impact measured by the one-year-ahead market to book value of equity. R&D intensity (denoted as R&D) and is measured as R&D expenditures scaled by total assets and following the conventional approach, we set R&D to zero when it is missing. R&D productivity is more difficult to measure and we propose using a new measure in this paper and present the rationale below.

[9] Knowledge-based business activity tends to occur in high-tech sectors. According to the U.S. Bureau of Labor Studies and the North American Industrial Classification System (NAICS), an industry is considered high tech if employment in technology-oriented occupations accounts for a proportion of that industry's total employment that was at least twice the average for all industries. Because R&D intensity is a dependent variable in our study, we use an exogenous measure to classify firms into high-tech and non-high-tech,

The valuation effects of firms' investment in R&D critically depends on the extent to which the innovations are translated into future cash flows. The prior research uses patents and patent citations as output measures of R&D intensity.[10] These studies use the NBER patent data that was originally constructed by Hall et al. (2001, 2005). There are several concerns with the use of patent data. The period studied is limited due to the patent data being available only until the end of 2006. This data limitation has an implication for studies that examine the influence of board or CEO connectivity on innovation. For instance, our data contains 66,799 directors with a total of 896,774 links in the year 2000. In the year 2006, the number of directors increased to 121,895 and the number of links was 2,478,422. From 2006 to 2013, the number of directors in our database increased by 32.4% to 161,487 and the number of director links increased by 50.7% to 3,736,708. Due to the unavailability of patent data, we are unable to examine whether increased board connectivity of this magnitude results in an increase in innovative activity and consequently higher returns to shareholders.

Aside from the non-availability of patent-related data beyond 2006, there are several aspects of patenting activity that may affect how patents translate to firm value. Scherer and Harhoff (2010) find that only 10% of patents account for 85% of the economic value. Cohen, Nelson, and Walsh (2000) find that patents tend to be the least emphasized by firms in most of the manufacturing industries, and secrecy and lead time tend to be emphasized most heavily. These authors find that the motives to patent extend beyond directly profiting from a patented innovation through either its commercialization or licensing. Firms commonly patent for different reasons in industries such as chemicals, telecommunications equipment or semiconductors. In the former, firms appear to use their patents commonly to block the

[10] Recent studies that have used number of patents and patent citations as metrics of innovation in the context of board/CEO connectedness include (Chuluun et al., 2017; Faleye et al., 2014; Helmers et al., 2017).

development of substitutes by rivals, and in the latter, firms are much more likely to use patents to force rivals into negotiations. These different uses for patents suggest a disconnect between patent filings and valuation.

From an empirical research standpoint, not all firms that engage in R&D file for patents. While the R&D activities within such firms have the potential to add value, a patent count of zero assigned to such a firm would result in an underestimate of their valuation effect. Cooper, Knott, and Yang (2015) examine a 26-year panel over 1981 to 2006 find that 63% of firms in their sample are doing R&D, but aren't patenting. Given that firms patent for a variety of reasons mentioned above and others don't, may imply that inferences from using patents may be compounded by differences in firms' incentives to patent and not purely innovation activity.

To overcome the above problems with using patent data, an alternate measure should be based on publicly available data for each firm, capture R&D productivity whether or not firms file for patents, measure the value added by firms that efficiently exploit their set patents even if they are fewer in number, and is strongly associated with current and future firm value. In a series of papers, Knott, (2008, 2012), Knott and Vieregger (2015) and Cooper, Knott, and Yang (2015) have offered research quotient (*RQ*) as an alternative firm-level measure of innovation that meets the above criteria. Knott (2008) estimates a random coefficients model based on a firm's final goods production function $Y = K^{\alpha} L^{\beta} R^{\gamma} S^{\delta}$, where Y is output (sales), K is capital, L is labor, R is R&D, and S is spillovers. The term γ is the R&D output elasticity or research quotient, that is estimated for each firm engaged in R&D, regardless of whether the firm files for patents. Research quotient captures the heterogeneity across firms that differ in their R&D productivity. Using the research quotient estimated for each firm, a profit maximization level of R&D expenditures (i.e., optimal R&D or R^*) can be estimated as $R^* = [1/(\gamma K^{\alpha} L^{\beta} S^{\delta})]^{(1/(\gamma-1))}$. The value of R^* is helpful to identify the extent to which R&D investments are distorted from the optimal. Since, our study uses director network data beyond 2006 and examines the influence of board centrality on innovation activity in the context of a larger network, we use research quotient as a metric to measure R&D productivity.

3.3 Summary Statistics

Board Centrality

Table 1 contains descriptive statistics for board centrality measures, R&D measures, and other firm variables. Table 1, Panel A presents the summary statistics for the full sample and Panels B and C contain summary statistics for the underinvestment and overinvestment subsamples. Variable definitions are contained in Appendix A. The intersection of the director network data, COMPUSTAT, and RQ data from WRDS, for the period 2000-2014, resulted in 12,975 firm-year observations. Each of the four centrality measures represents board level centrality and is computed as the average of the centralities of directors on the board. We find that a mean Betweenness of 0.0071% implies that a typical director sits on about one in 14,084 (1/0.0071%) shortest paths between pairs of other directors in the network. A Closeness measure of 23.11% indicates that a typical director is about 4.33 (1/0.2311) degrees of separation from any other randomly chosen director in the network. The Eigenvector measure does not lend itself to an intuitive interpretation. These measures are comparable to those reported in Fogel, Ma, and Morck (2014).

R&D measures

The means of each of the board centralities in the underinvestment is greater than that in the overinvestment sample. Except for Betweenness centrality, the rest of the differences in centrality measures are statistically significant at the 1% level. On average, boards in the underinvestment sample are better connected than the overinvestment sample. Yet, these firms underinvest in R&D. Conversely, the boards in the overinvesting firms can potentially benefit from better connections to facilitate a more optimal resource allocation.

The average R&D intensity of 2.05% of total assets ($223.31m) in the underinvestment sample is significantly lower than the 10.12% of total assets ($619.95m) in the overinvestment sample. The underinvestment sample has a significantly higher RQ and R* (11.44% and 5.04% of total assets, respectively) compared to 10.42% and 3.66% of total assets, respectively for the overinvestment sample. Despite a higher level of board centrality and a higher RQ in the underinvestment sample, the R&D investment in underinvestment is significantly lower than the optimal R&D. The lower RQ and R* in the overinvestment sample suggests that these firms ought to cut back on R&D and avoid negative NPV investment.

Other Firm Variables

The difference in firm characteristics provides further insight. Although the average market to book value in the overinvestment sample is higher than that in the underinvestment sample, it is not significantly different from each other. The high-tech dummy indicates that 70.62% (23.37%) of the firms in the overinvestment (underinvestment) sample are classified as high-tech firms. In comparison to the firms in the underinvestment sample, the firms in the overinvestment sample are younger, have lower leverage, pay lower dividends, and operate in highly competitive industries. These characteristics suggest that firms in the overinvestment sample are disposed to investing in R&D to keep up with competition.

Board Characteristics

A comparison of the board level characteristics presented in Table 2 indicates that the average board size, the number of directorships, and membership in governance committees (audit, compensation, and governance) is statistically larger in the underinvestment sample than the overinvestment sample. The average values, however, are not very different. The overinvestment sample has significantly higher number of directors who hold advanced degrees. This is consistent with the observation that firms in the overinvestment sample have a large fraction of high-tech firms.

Overall, relative to the overinvestment sample, the underinvestment sample is characterized by firms that are relatively older, have higher leverage, pay more dividends, operate in less competitive industries, and have bigger boards with better governance. Despite a higher average board centrality, underinvestment firms have more room to invest in R&D to reach the first-best level. Next, we examine the relationship between RQ, R&D and board centrality in a multivariate regression.

4 Multivariate Analysis of Board Centrality, RQ, and R&D intensity

4.1 Board Centrality and RQ

The relation between board centrality and *RQ* is estimated for the overall sample and the two subsamples using equation (1). Since *RQ* is related to R&D activities, we use the control variables that influence R&D and firm, industry and year fixed effects and standard errors are clustered at the firm-level.

$$\begin{aligned} RQ_{i,t} = {} & \delta_0 + \delta_1 Centrality_{i,t} + \delta_2 Centrality_{i,t}^2 + \delta_4 MB_{i,t} + \delta_5 HT_{i,t} + \delta_6 Cash_{i,t} \\ & + \delta_7 Size_{i,t} + \delta_8 Firmage_{i,t} + \delta_9 Leverage_{i,t} + \delta_{10} RHI_{i,t} + \delta_{11} Dividends_{i,t} \\ & + Firm\ Fixed\ Effects + Industry\ Fixed\ Effects + Year\ Fixed\ Efects \\ & + u_{i,t} \end{aligned} \quad (1)$$

The results are reported in Table 3.

[Insert Table 3 here]

The control variables enter the regression in a predictable manner. RQ is more sensitive for firms in the high-tech industries (HT), for younger firms, firms with lower leverage, firms with higher levels of cash and those that pay fewer dividends. The results for the overall sample indicates a statistically significant concave relation between *RQ* and three of the four centrality measures. We do not find Eigenvector centrality to be related to *RQ*. Firms in the overinvestment sample appear to be the main driver of the relationship between board centrality and RQ. The coefficient on Betweenness and Eigenvalue centrality is statistically significant at the 5% level in the overinvestment sample but not significant in the underinvestment sample. The lower of RQ to centrality is consistent with the descriptive statistics in Table 1, Panel B, where, on average, firms that underinvest have a lower RQ, and fewer high-tech firms that operate in less competitive industries. The Closeness and Degree centrality is significant at the 1% level in the overinvestment sample but has a lower level of significance (10% and 5%, respectively) in the underinvestment sample. Although, overall R&D productivity is found to be positively related to board connectedness in the overinvestment sample, we find a statistically significant concave relation board centrality and RQ. In other words, we observe a decline in marginal R&D productivity as boards of overinvesting firms increase their connectivity beyond a threshold.

The use RQ instead of patents or patent citations as a measure of R&D productivity facilitates the analysis of the impact of board centrality on R&D measures for underinvesting and overinvesting firms. *Prima facie*, one would expect underinvesting firms to increase R&D intensity and overinvesting firms to cut-back on R&D expenditures, especially when directors are better connected and are more aware of industry trends. In the next section, we examine the relationship between board centrality and R&D intensity and whether board centrality reduces the distortions from optimal R&D.

4.2 Board Centrality, R&D Intensity, and Distortion from Optimal R&D Intensity

We use the equation (2) to test the relation between R&D expenditures and board centrality:

$$R\&D_{i,t} = \gamma_0 + \gamma_1 Centrality_{i,t} + \gamma_2 Centrality_{i,t}^2 + \gamma_4 MB_{i,t} + \gamma_5 HT_{i,t} + \gamma_6 Cash_{i,t} + \gamma_7 Size_{i,t} + \gamma_8 Firmage_{i,t} + \gamma_9 Leverage_{i,t} + \gamma_{10} RHI_{i,t} + \gamma_{11} Dividends_{i,t} + Firm\ Fixed\ Effects + Industry\ Fixed\ Effects + Year\ Fixed\ Efects + u_{i,t} \quad (2)$$

The coefficients γ_1 and γ_2 measure the increase in R&D for one standard deviation change in a centrality measure. Considering that increased board connectivity (i.e., centrality) serves as a conduit for information exchange, we expect $\gamma_1 > 0$. The coefficient γ_2 captures the presence of a nonlinear effect of centrality on R&D expenditures. The remaining variables in regression equation (2) are known determinants of R&D expenditures. We use firm, industry and year fixed effects and standard errors are clustered at the firm-level.

Table 4 contains the results of equation (2). The regression models are highly significant

[Insert Table 4 here]

with an R^2 of approximately 35%. All the control variables (except Firm Age) enter the regression at a high level of statistical significance with the predicted signs. We find the coefficient of Cash to be significant and positive. This is consistent with the availability of internal sources of funds to help fund R&D projects, especially when a firm faces friction in the capital markets. Also, cash reserves tend to smooth R&D expenditures and serve to dampen volatility in R&D spending (Brown, Martinsson, & Petersen, 2012; Brown & Petersen, 2011). The positive coefficient on RHI is consistent with the notion that to remain competitive, firms need to innovate and invest in R&D continually. Consistent with prior literature, the negative coefficients on Size, and Dividends, and Leverage indicates that smaller firms that pay fewer dividends and take on less leverage tend to spend more on R&D.

We find that R&D intensity is a concave function of board centrality. The coefficients $\beta_1 > 0$ and $\beta_2 < 0$, are statistically significant at the 1% level for each centrality measures in the overall sample and the two subsamples. In particular, for the overall sample, R&D increases by 1.02% for a one standard deviation increase in Betweenness centrality but is dampened due to the negative sign on β_2. While, the sign and significance of β_1 have been documented in the previous literature (Chuluun et al., 2017; Faleye et al., 2014), one would expect the sensitivity of R&D intensity to board centrality to be higher (lower) in the underinvestment (overinvestment) sample to reduce any potential distortion. We observe an opposite pattern. The coefficient β_1 for Betweenness is 0.0047 (0.0108) in the underinvestment (overinvestment) sample. We observe a similar pattern for Closeness and Degree centralities but not Eigenvalue centrality. The stronger concavity (β_2) among overinvesting firms is reassuring, in that, better-connected boards tend to slow down the investment in R&D. To our knowledge, the finding that higher levels of centrality are associated with a marginal decrease in R&D intensity has not been reported in the literature.

To determine the presence of distortion in R&D intensity requires an estimate of the optimal R&D intensity for each firm-year. As mentioned in Section 3.2.3, given a firm's final goods production function $Y = K^{\alpha} L^{\beta} R^{\gamma} S^{\delta}$, where Y is output (sales), K is capital, L is labor, R is R&D, and S is spillovers a profit maximization level of R&D expenditures, the optimal R&D is $R^* = [1/(\gamma K^{\alpha} L^{\beta} S^{\delta})]^{(1/(\gamma-1))}$. The optimal R&D expenditures for each firm-year in our sample were obtained from the WRDS database. A deviation of actual R&D intensity from optimal R&D intensity will result in a distortion in R&D investment. Let actual R&D intensity minus optimal R&D intensity be denoted as *RNDDIFF*. A firm underinvests if RNDDIFF < 0 and overinvests if

RNDDIFF > 0. Using equation (3), we test the relation between board centrality and absolute RNDDIFF for subsamples based on underinvesting and overinvesting firms:

$$ABS(RNDDIFF)_{i,t} = \theta_0 + \theta_1 Centrality_{i,t} + \theta_2 Centrality_{i,t}^2 + \theta_4 MB_{i,t} + \theta_5 HT_{i,t} + \theta_6 Cash_{i,t} + \theta_7 Size_{i,t} + \theta_8 Firmage_{i,t} + \theta_9 Leverage_{i,t} + \theta_{10} RHI_{i,t} + \theta_{11} Dividends_{i,t} + Firm\ Fixed\ Effects + Industry\ Fixed\ Effects + Year\ Fixed\ Efects + u_{i,t} \tag{3}$$

The results are reported in Table 5. We find a positive and statistically significant coefficient (at the 1% level) on each of the four board centrality measures for the subsample of firms that overinvest. This result implies that increase in board centrality exacerbates the overinvestment in R&D. The negative coefficient on the squared centrality term indicates a significant concave relation between overinvestment and board centrality. The coefficients on board centrality in the underinvestment subsample are not statistically significant. Taken collectively, we infer that well-connected boards increase investment in R&D to the point of value destruction due to the exacerbation of overinvestment. The absence of a statistically significant relationship between board centrality and Abs(RNDDIFF) among underinvesting firms suggests that even though better-connected boards increase investment in R&D, they do not help reduce the underinvestment.

5 Robustness and Endogeneity Tests

5.1 Robustness: Board Centrality and RQ

As mentioned earlier, prior research has used patent count and patent citations as output measures of R&D. While these measures are suggestive of research output, the value of each patent that is granted to a firm is more relevant from a firm valuation viewpoint. Based on the estimation method described in section 3.2.3, it is reasonable to expect a firm's R&D

productivity (RQ) in year t to be associated with the value of patents filed by a firm in years (t+1), (t+2) or possibly (t+3).[11]

Recently, Kogan, Papanikolaou, Seru, Stoffman (2017), propose a new measure of the private, economic value of innovations that are based on stock market reactions to patent filings. These authors use the patent data available from Google Patents for all utility patents issued by the USPTO between 1/1/1926 to 11/2/2010 and combine this data with the returns data from CRSP to estimate the value of each patent grant.[12] The patent data contains the patent number, filing date, issue (grant) date, the publication date of the patent, the estimated value of the patent in nominal dollars, number of cites, and the technology class the patent belongs. We merged their dataset with our sample to examine the relation between board centrality and value of patent filings.

We assume that a firm can potentially file for patents for up to three years after the board decides on R&D expenditures in year t. Hence, we compare board centrality in year t with the value of all patents filed in years (t+1), (t+2), and (t+3). As in Kogan, Papanikolaou, Seru, Stoffman (2017), we scaled the value of each patent granted to a firm in year t by the total assets in year t. The regression model is given in equation (3) and the results are reported in Table 5.

$$\begin{aligned} PV(t+k,t+j)_{i,t} &= \beta_0 + \beta_1 Centrality_{i,t} + \beta_2 Centrality_{i,t}^2 + \beta_3 R\&D_{i,t} + \beta_4 HT_{i,t} + \beta_5 Cash_{i,t} \\ &+ \beta_6 Size_{i,t} + \beta_7 Firmage_{i,t} + \beta_8 Leverage_{i,t} + \beta_9 RHI_{i,t} + \beta_{10} Dividends_{i,t} \\ &+ Firm\ Fixed\ Effects + Industry\ Fixed\ Effects + Year\ Fixed\ Efects \\ &+ u_{i,t} \end{aligned} \quad (4)$$

[11] Note that although several patents may be filed in year t+1, they may be granted over several years during the post filing period.
[12] The dataset used by Kogan, Papanikolaou, Seru, Stoffman (2017) is available at https://iu.app.box.com/v/patents.

PV(t+k, t+j)$_{i,t}$ is the sum of the present values of all patents pertaining to the filing years *t+k* to *t+j*, by firm i, evaluated at time t. For example, for *k=1* and *j=1*, *PV(t+1, t+1)*$_{i,t}$ is the present value of all patents filed by firm *i*, at time (t+1), evaluated at time t. *PV(t+1, t+2)*$_{i,t}$ is the sum of the values of all patents pertaining to the filing years *(t+1)* and *(t+2)*. Also, we include the *R&D* at time *t* as an independent variable in equation 4.

Summary statistics (not reported) for the variable *PV(t+k, t+j)* indicate that the mean *PV(t+1, t+2), PV(t+2, t+3)* and *PV(t+1, t+3)* are 12.91%, 10.70%, and 17.94% of total assets, respectively, compared to an R&D intensity of 4.07% of total assets at time t.[13] The measure RQ is concave in Closeness and Degree centrality among underinvesting firms. The results for the overinvestment sample indicate that the value of patents for each of the segment of filing periods we consider are related to board Betweenness, Closeness, and Degree centrality in a *concave*

[Insert Table 6 here]

manner. This result is similar to the concavity observed using RQ and reported in Table 3. In contrast, even though RQ is concave in Eigenvalue centrality, the value of patent filings is negatively related to Eigenvalue centrality. The results in Table 6 suggest a more significant role for Betweenness centrality. Overall, we find that value of patent filings and RQ are robust measures of R&D productivity and exhibit a similar relationship with board centrality.

5.2 Robustness: Board Centrality and R&D Intensity

The concavity in R&D intensity may not be associated with better-connected boards but could be due to other factors such as (a) spillover effects arising from the firm being near research clusters in universities that serve as a public good, (b) the presence of directors with

[13] Unfortunately the data does not allow us to associate the value of each patent with the R&D dollars spent. Hence, the comparison with R&D at time t may only be suggestive.

advanced technical knowledge (Francis, Hasan, Park, & Wu, 2015), (c) the influence of a powerful director and not the board, (d) the interaction between the CEO's connections and the directors' connections can pose a problem in attributing the concavity uniquely to board connectivity (Fracassi & Tate, 2012).

To isolate the influence of spillovers, we constructed two variables: (a) a measure of advanced degrees held by directors, and (b) the proximity of research universities from a firm's headquarters. Although these variables had the predicted sign, the concave relation between board centrality and R&D intensity is found to be significant and robust. To remove the influence of the most powerful director (a director with the highest centrality measure) and the influence of CEO's network, we followed (El-Khatib, Fogel, & Jandik, 2015) and created the relevant orthogonalized variables and included them in the regressions. The concave relation between board centrality and R&D intensity maintained its' sign and significance. The concavity in R&D intensity could be due to poor governance. We examined several governance-related variables such as Intense[14], fraction of outsiders on the board, and board size. All the above variables entered the regression with expected signs but the concave relation between board centrality and R&D expenditures continue to be statistically significant and robust.[15]

5.3 Endogeneity: Board Centrality and R&D Intensity

Our results indicate that a firm's R&D increases as their boards become better connected. However, the causality may run in the opposite direction. To enhance their reputations, directors may pursue positions on boards in firms that have higher R&D budgets. Under such a scenario,

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[14] We follow the methodology in (El-Khatib et al., 2015) and include the variable Intense, defined as boards with most of independent board members who have two or more memberships in auditing, compensation, and nomination committees.

[15] We did not include the results of the above tests for the sake of brevity. These are available upon request.

director connectivity may be endogenously linked to R&D (e.g. Adams, Hermalin, and Weisbach 2010). Also, our findings could be influenced by an omitted variable correlated with our connectivity measure that also affects R&D expenses. We check for the reverse causality and the omitted variable bias in numerous ways.

First, as is popular in the literature, we lag the independent variables and estimate equation (2). This method is not without critics.[16] One of the conditions for this method to control for simultaneity bias is that the independent variable should be a stationary process. We test our measures of board centralities to determine if they are stationary using the Fisher's test in panel data and find that they are stationary. We proceed to estimate equation (2) with lagged values of the standardized board centralities and find that the results are unchanged up to two lags.

Second, we use the instrumental variables approach. We use equation (2), but we drop the squared centrality term. A Hausman test reveals that we cannot reject the null hypothesis of endogeneity. Hence, as in Omer, Shelley, and Tice (2014), we proceed to use median industry centralities as our instruments for board centralities. We use the industry median centrality as an instrumental variable because it is expected to be correlated to the board's centrality but uncorrelated with the error term. The median centrality of the industry could determine the hiring of well-connected directors for firms in certain industries, but the median centrality of the industries should not be related to firm-level idiosyncrasies. Our second instrument is the sum of the directorships held by every board member. The first stage regressions reveal that our instruments have significant explanatory power. In the second stage, we find that board centralities are positively associated with R&D.

[16] See (Bellemare, Masaki, & Pepinsky, 2017).

Third, we perform a correlation test between two-period, forward-looking board centralities and lagged R&D. We do this to verify whether directors self-select into firms with higher R&D. We find that the correlations are in fact negative and not statistically significant. Finally, we estimate equation (2) with lagged standardized board centralities for those firms without a change in board composition and find that our results are unchanged. [17] Overall, endogeneity does not seem to influence our results.[18]

6 Valuation Effects of Board Centrality and R&D Intensity

6.1 SEM Regression

Consistent with prior literature, we established that *R&D intensity* is positively related to board centrality across each of the four board centrality measures. Several studies find a positive association between increases in R&D expenditures and share-price response.[19] Larcker, So, and Wang (2013) find evidence that more central boards earn superior risk-adjusted returns especially among high growth opportunity firms. The benefits of greater innovation resulting from better-connected boards accrue to bondholders, as well. Chuluun, Prevost, and Upadhyay (2017) find that innovation has a positive (negative) marginal effect on corporate yield spreads when firms have lower (higher) connectedness. Because, the above studies point towards an

[17] One could argue that board size could remain the same even when board members leave. For example, two new directors could replace two departing directors. In this case, the board centralities could be different from the previous year. We surmise that such situations are very rare.
[18] Results of endogeneity tests are available upon request.
[19] See (Sougiannis, 1994) for valuation of R&D expenditures conveyed by accounting earnings; Chambers, Jennings, and Thompson (2002) for excess returns to R&D intensive firms; (Eberhart, Maxwell, & Siddique, 2004) for short-run undervaluation of R&D expenditures; (Chan, Lakonishok, & Sougiannis, 2001; Szewczyk, Tsetsekos, & Zantout, 1996) for stock price reaction to increases in R&D expenditures.

endogenous relation between board centrality, R&D, and market to book value of equity, we use a simultaneous equation model (SEM) framework.[20]

The SEM structure comprises of equations (5) and (6) and includes measures of board centrality, firm-level control variables that are common to the determination of R&D and market to book value, other control variables known to affect the market to book value (Maury and Pajuste 2005), firm, industry, and year fixed effects, and robust clustering of standard errors. The variables in equation (5) are contemporaneous and market to book value of equity is lagged one period ahead in equation (6).

$$\begin{aligned} R\&D_{i,t} = {} & \gamma_0 + \gamma_1 Centrality_{i,t} + \gamma_2 Centrality_{i,t}^2 + \gamma_4 MB_{i,t} + \gamma_5 HT_{i,t} + \gamma_6 Cash_{i,t} \\ & + \gamma_7 Size_{i,t} + \gamma_8 Firmage_{i,t} + \gamma_9 Leverage_{i,t} + \gamma_{10} RHI_{i,t} + \gamma_{11} Dividends_{i,t} \\ & + Firm\ Fixed\ Effects + Industry\ Fixed\ Effects + Year\ Fixed\ Efects \\ & + u_{i,t} \end{aligned} \tag{5}$$

$$\begin{aligned} MB_{i,t+1} = {} & \beta_0 + \beta_1 Centrality_{i,t} + \beta_2 Centrality_{i,t}^2 + \beta_3 HT_{i,t} + \beta_4 Size_{i,t} \\ & + \beta_5 Leverage_{i,t} + \beta_6 Dividend_{i,t} + \beta_7 R\&D_{i,t} + \beta_8 Tangibility_{i,t} \\ & + \beta_9 ROA\ Volatility_{i,t} + \beta_{10} Sales\ Growth_{i,t} + Firm\ Fixed\ Effects \\ & + Industry\ Fixed\ Effects + Year\ Fixed\ Efects + u_{i,t} \end{aligned} \tag{6}$$

The above system of equations contains either observed or estimable variables that are related to an interdependent framework. There are no latent variables in the above SEM framework. The test variables are β_1, β_2, γ_1, and γ_2. The predicted signs for the control variables in equation (5) are the same as in equation (2). The results of the estimation of equations (5) and (6) are reported in Table 7.

[Insert Table 7 here]

[20] Griliches (1998) mentions that variables of interest tend to move together over time and space. R&D investments are affected by past profits, in turn, affecting future value. Because it is hard to untangle the separate effects, it forces one to formulate simultaneous equations models and turn to more complex estimation techniques.

Consider the results of equation (5). We find that the concave relation between R&D and board centrality persists across all centrality measures for the full sample, the underinvestment and overinvestment sample. Additionally, compared to the results reported in Table 4, we find that the magnitude of the coefficients on centrality measures and their statistical significance remains the same in the SEM framework. The control variables enter the regression predictably. Now, consider the results for equation (6). As board centrality increases, we find that market to book value of equity increases but at a decreasing rate, resulting in a concave relation. This result holds across all measures of centrality and is statistically significant at the 1% level. Although the coefficient on the primary centrality term (γ_1) is positive and consistent with Larcker, So, and Wang (2013), we find that as a board becomes better connected, it adds less value. Also, the coefficient on R&D is positive and significant at the 1% level, confirming the endogenous relationship between board centrality, R&D, and market to book value of equity.

6.2 SEM: Analysis of Overinvestment and Underinvestment

To illustrate the relation between RQ, Board centrality, R&D, and market to book value of equity, consider equations (5) and (6) in the SEM framework. Let MB_{t+1} denote market to book value of equity at t+1, R denote R&D, and C denotes a standardized centrality measure. Based on the SEM regressions, we can write $MB_{t+1} = K_1 + \beta_1 C + \beta_2 C^2 + \beta_7 R$, and $R = K_2 + \gamma_1 C + \gamma_2 C^2$, where K_1 and K_2 capture the effect of other variables in regressions (5) and (6). Based on the regression in Table 3, we can write $RQ = K_3 + \delta_1 C + \delta_2 C^2$, where K_3 is the value of other variables in regression (1). The first-order and second-order conditions imply that the optimal (standardized) centrality that maximizes RQ is $C_{RQ} = \frac{\delta_1}{-2\delta_2}$ and the optimal (standardized) centrality that maximizes M_{t+1} is $C_M = \frac{(\beta_1+\beta_7\gamma_1)}{-2(\beta_2+\beta_7\gamma_2)}$. Consider the overinvestment sample and Betweenness centrality. We know $\gamma_1 = 0.0103$, and $\gamma_2 = -0.0010$ (from Panel C, Table 7), $\beta_1 = 0.1977$, $\beta_2 = -0.0268$, and $\beta_7 = 10.1631$ (from Panel C, Table 7), $\delta_1 = 0.0028$ and $\delta_2 = -0.0003$ (from Table 3). Substituting these values yields C_M = 4.09 and C_{RQ} = 4.67. To convert these to raw measures, we know from Table 1, Panel C that the Mean and Standard Deviation of (Raw) Betweenness is 0.0070% and 0.0070%, respectively. Given that Standardized Betweenness = (Raw Betweenness – Mean)/Standard Deviation, we get the values of, and $(Raw)C_M = 0.035\%$. Based on these calculations, note that the market to book value of equity and RQ reach a maximum at approximately the same level of Betweenness centrality (a difference of only 285 shortest paths given that the mean is 14,285 shortest paths), thus confirming that the investors price the concave relation between RQ, Centrality, R&D, and market to book value of equity.[21] We performed similar calculations for all measures of centrality, for both subsamples, and found that market to book value peaks for a centrality level that is less than the maximum value in our sample. In summary, we find that research productivity and consequently market to book value of equity deteriorate as boards become better connected. The next section examines whether increases in board connectivity beyond a threshold results in the exacerbation of R&D overinvestment due to boards becoming busy.

7 Busy Board and Overinvestment

Our results indicate that increases in board centrality result in diminishing marginal R&D productivity and tend to exacerbate overinvestment in R&D. The overinvestment in R&D is reflected in a concave relation between market to book value of equity and board centrality, implying that board connectivity beyond a threshold is detrimental to shareholders. Since a

[21] The maximum value of raw Betweenness in our sample is 0.1068%, indicating that there are firms in our sample with board connections that far exceed the optimum level of centrality.

higher level of board connectivity is a result of directors sitting on many boards, we examine the relationship between busy boards and overinvestment in R&D.

The literature is divided on whether or not a busy director is beneficial to shareholders. Fich and Shivdasani (2006) find that firms where directors have multiple board seats tend to have lower market to book ratios and are less likely to fire a CEO in response to poor performance. Ferris, Jagannathan, and Pritchard (2003) find that the past performance of the firms on which a director serves is positively associated with the number of board seats that they hold and that firms appointing a new director with multiple board seats experience positive announcement returns. Some authors have attempted to resolve these contradictory results by examining S&P 500 versus non-S&P 500 firms (Cashman, Gillan, and Jun, 2012), newly public firms (Field, Lowry, Mkrtchyan, 2013), or different estimation methods (Cashman, Gillan, and Jun, 2012). These authors find that busy directors are detrimental (beneficial) to shareholders in S&P 500 (non- S&P 500 or newly public) firms and the inclusion of firm fixed-effects to account of unobservable firm-level variables renders such directors as being beneficial.

We report the descriptive characteristics for five firm variables in our overinvestment sample and those presented in Cashman, Gillan, and Jun (2012) for S&P 500 and non-S&P 500 in Table 8, Panel A. The market to book value in our sample is 2.37, greater than both the values S&P 500 and non-S&P 500 firms. Our sample is closer to the non-S&P 500 firms in terms of

[Insert Table 8 here]

Assets, Firm Age, and percent of outside directors. The median board size for firms in our sample is closer to the value in the S&P 500 sample. Based on these firm characteristics, we are unable to classify the firms in our sample as either S&P 500 or non-S&P 500 type firms, and consequently cannot *a priori* rely on prior studies to hypothesize whether or not busy directors provide a valuable role to curtail overinvestment. We do include fixed-firm effects and examine whether busy boards are beneficial to shareholders.

Our first test is based on the approach in Fich and Shivdasani (2006) but include all directors on the board holding greater than or equal to three directorships and denote this variable as Busy.[22] We include all directors to account for potential lack of monitoring exerted by inside directors, who presumably know more about the unique characteristics of the R&D processes within their firm than outside directors. We define the variable Busy as the fraction of a board with directors holding 3 or more directorships. The results are reported in Table 8, Panel B. The variable Busy is statistically significant at the 1% level and exacerbates the overinvestment in three of the four regressions. We find that degree centrality captures the busyness of the board and renders the Busy variable as not being significant. This makes sense because degree centrality simple measures the number of connections held by a director and does not qualify the nature of these connections. The interaction term for betweenness centrality indicates a (weak) positive role for a busy board as it tends to ameliorate the overinvestment.

Our second test for busyness attempts to capture the extent to which directors hold multiple directorships within proximity of a specific industry and how this influences the overinvestment in R&D. Considering the context of our research, we hypothesize that directors can bring specialized expertise and provide better advice if they are exposed to the recent technical developments within the same industry, thereby reducing the extent of overinvestment

[22] Cashman, Gillan, and Jun (2012) find that the empirical relations with the alternative measures of busy directors are qualitatively similar to those of the traditional measures, and they have similar explanatory power.

in R&D.[23] Conversely, if directors hold multiple directorships in disparate industries, they will unlikely possess the expert knowledge to guide the top management away from overinvesting in R&D. [24] Let Ind_Busy (j) denote the extent of firm j's board directorships are held in industries different from firm j. We construct this variable in the following manner. Consider director i, sitting on firm j, and holding a directorship in firm k, where k = 1, …, n_i, and i=1, .., m_j. A director sitting on the board of another firm in the same industry as firm j would have a high degree of industry focus relative to a directorship held in a very different industry. We use the difference in the SIC codes as measure of the level of industry focus and compute a variable $DIST_i$ (j, k) = Absolute |SIC (j) – SIC (k)| for a director i in firm j who sits on a firm belonging to industry k. Next, we compute the average $DIST_i$ (j, k) over all the directorships held by director i. We then divide the average $DIST_i$ (j, k) by director centrality to compute a busyness variable for director i in firm j and then average across all directors in firm j to obtain the variable Ind_Busy (j). A higher (lower) value of the variable Ind_Busy(j) indicates that on average, the directors on firm j sits on boards from industries that are different from (closer to) the industry to which firm j belongs. The regression results using Ind_Busy is reported in Table 8, Panel C.

We find that Ind_Busy is positively related to the extent of overinvestment and is statistically significant at the 1% level in three of the four models. This result indicates that boards with directors sitting on firms in industries that are very different from the focal firm tend not to bring in expertise to the focal firm's board and are not effective in providing valuable advice to reduce overinvestment. The observation in Table 8, Panel B indicates that directors

[23] See Dass, Kini, Nanda, Onal, and Wang, J. (2013) for an extensive discussion about the role of directors from related industries that help bridge the information gap in R&D intensive firms.

[24] Note, that the definition of industry proximity is not the same as closeness centrality because the latter is only sensitive to a director's position in a network regardless of the industry.

sitting on boards of firms distinctly different from the focal firm is detrimental to the shareholders. Conversely, directors who potentially sit on many boards but are clustered closer to the focal firm's industry reduce overinvestment and are beneficial to shareholders.

8 Conclusion

Corporate boards and CEOs are responsible for providing vision, defining the strategic course for a firm, performing an advisory and monitoring role, deciding on resource allocation, encouraging innovation to remain competitive, and performing their fiduciary role by making value increasing decisions. Several papers find that directors on boards who are well-connected in a network of directors, serve as a conduit of valuable information that induces more innovation, leading to higher market to book value of equity.

In this research, we use the output elasticity of research and development as a measure of productivity and find that increases in board connectivity results in diminishing marginal research productivity, R&D expenditures, and market to book value of equity. Although higher levels of board connectivity increases R&D expenditures, it is not nearly enough to reduce the extent of underinvestment among firms that exhibit an investment in R&D that less than optimum. We also observe that higher levels of board connectivity induce further increases in R&D among firms that already invest more in R&D than they ought to. As board centrality increases beyond a threshold, these distortions in R&D investment are found to result in diminishing marginal market to book value of equity. An examination of board busyness indicates that having better-connected directors on a board, *per se*, is not valuable to shareholders. However, value loss due to overinvestment is mitigated if the directors hold multiple directorships within the same industry as the focal firm.

Appendix A

Centrality Measures:

Betweenness Centrality	: the number of shortest paths from all vertices to all others that pass through that node.
Closeness Centrality	: the reciprocal of the sum of the distances from every other node Degree
Centrality	: the number of edges of a node scaled by the total number of nodes (N) in the network
Eigenvector Centrality	: the importance of the person connected to. (see text for full description)

R&D Related Measures

R&D	: Research and Development Expense (XRD) divided by total assets (AT)
RQ	: Research Quotient calculated as in Cooper, Knott, and Yang (2015). Available through WRDS
R*	: Optimal R&D estimated by Knott and Vieregger (2015). Available through WRDS
R&D-R*	: Actual R&D minus optimal R*
Under Inv. Dummy	: Equals 1, if (R&D-R*) > =0
Over Inv. Dummy	: Equals 1, if (R&D-R*) < 0
PV(t+1, t+2)	: Present Value of patents filed in years t+1 and t+2.
PV(t+1, t+3)	: Present Value of patents filed in years t+1, t+2, and t+3.
PV(t+2, t+3)	: Present Value of patents filed in years t+2 and t+3.

Firm Related Variables

Market to Book Value of Equity (MB)	: Common Shares Outstanding(CSHO)* Price Close (PRCC_F), divided by Common Equity (CEQ)
High Tech Dummy = 1	: if a firm is classified as high tech (see text for description)
Cash	: Cash and Short-Term Investments (CHE) divided by total assets (AT)
Size	: natural log of total assets (AT)
Firm Age	: the number of years since the firm appeared in COMPUSTAT
Leverage	: long-term debt (DLTT) plus long-term debt due in one year (DD1), divided by total assets (AT)
RHI	: 1- Herfindahl index
Dividend	: Cash Dividends (Cash Flow) (DV) divided by total assets (AT)
ROA Volatility	: 5-year standard deviation of ROA, where ROA= Operating Income Before Depreciation (OIBDP) divided by total assets for year t-1, (AT)
Sales Growth	: sales (SALE) for year t minus sales for year t-1, divided by total assets (AT)
Tangibility	: Property, Plant and Equipment - Total (Net) (PPENT) divided by total assets (AT)
Total Assets	: Assets - Total (AT)

Board Characteristics

Boardage	: the average age of the board.
Boardsize	: the number of board members of the board.
Gendratio	: the ratio of the total females on the board to the total number of board members.
Advanced	: the number of advanced degree holders on the board.
Directorships	: the number of directorships held by board members.
Auditcomm	: total number of outsiders on the audit committee.
Compcomm	: total number of outsiders on the compensation committee.
Govcomm	: total number of outsiders on the governance committee.
Majboard	: the percentage of outside board members.
Outsideceo	: the total number of CEOs of other companies on the board.
Outsidecfo	: the total number of CFO of other companies on the board.
Tenure	: the number of years a director sits on the board of a firm.

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Table 1: Descriptive Statistics

Panel A contains summary statistics for the full sample. Panel B and C present summary statistics for underinvesting and overinvesting subsamples. An observation is classified as underinvestment (overinvestment) if the actual R&D intensity (R&D) is less (greater) than optimal R&D intensity (R*). The variables in the table are classified into (Raw) Board Centrality Measures, R&D measures, and Other Firm Variables. All variables are winsorized at 0.5% and 99.5% levels. Board Network data is from NYSE BoardMag, RQ and R* data from WRDS and all other variables are from Compustat. Appendix A contains the variable definitions.

Panel A: Full Sample

Variable	N	Mean	Std Dev	Median	Max.	Min.
Board Centrality Measures						
Betweenness Centrality*100	12975	0.0071	0.0069	0.0051	0.1068	0.0000
Closeness Centrality*100	12975	23.1123	10.9522	21.7717	100.0000	11.1429
Degree Centrality	12975	0.0292	0.0146	0.0265	0.0966	0.0015
Eigenvector Centrality*100	12975	0.1187	0.3354	0.0107	12.8224	0.0000
R&D Measures						
R&D	12975	0.0685	0.0708	0.0465	0.6156	0.0000
RQ	12975	0.1083	0.0450	0.1010	0.3169	0.0184
R*	12975	0.0422	0.0337	0.0342	0.2829	0.0029
Under Inv. Dummy	12975	0.4050	0.4909	0.0000	1.0000	0.0000
Over Inv. Dummy	12975	0.5950	0.4909	1.0000	1.0000	0.0000
Other firm Variables						
Market to Book	12975	3.3110	3.5557	2.3288	31.0219	0.2025
Market to Book (*t+1*)	12975	3.2235	3.4369	2.2973	31.8819	0.1969
High Tech Dummy (HT)	12975	0.5148	0.4998	1.0000	1.0000	0.0000
Cash	12975	0.2362	0.1981	0.1854	0.9550	0.0000
Size	12975	6.6885	2.0104	6.4572	13.0850	1.7015
Firm Age	12975	14.1699	5.3816	14.0000	47.0000	1.0000
Leverage	12975	0.1368	0.1496	0.0961	0.7452	0.0000
Reversed Herfindahl Index (RHI)	12975	0.8629	0.1201	0.8984	0.9803	0.0000
Dividend	12975	0.0113	0.0257	0.0000	0.2698	0.0000
ROA Volatility	12975	0.0576	0.0686	0.0381	1.0667	0.0000
Sales Growth	12975	0.0941	0.2393	0.0700	0.0700	0.0700
Tangibility	12975	0.1776	0.1439	0.1380	0.9200	0.0010
Total Assets ($m)	12975	8056.83	32492.24	637.28	481645.00	5.4820

Panel B: Underinvestment Sample

Variable	**N**	**Mean**	**Std Dev**	**Median**	**Max.**	**Min.**
Board Centrality Measures						
Betweenness Centrality*100	5255	0.0072	0.0069	0.0053	0.0567	0.0000
Closeness Centrality*100	5255	23.5267	11.6121	22.0399	100.0000	11.1429
Degree Centrality	5255	0.0299	0.0152	0.0273	0.0878	0.0015
Eigenvector Centrality*100	5255	0.1421	0.2868	0.0175	2.6425	0.0000
R&D Measures						
R&D	5255	0.0205	0.0221	0.0144	0.4494	0.0000
RQ	5255	0.1144	0.0464	0.1057	0.3169	0.0184
R*	5255	0.0504	0.0426	0.0381	0.2829	0.0029
R&D-R*	5255	-0.0297	0.0344	-0.0195	0.0000	-0.2143
Other firm Variables						
Market to Book	5255	3.2589	3.7496	2.2601	31.0219	0.2025
Market to Book (*t+1*)	5255	3.2007	3.6518	2.2432	31.8819	0.1969
High Tech Dummy (HT)	5255	0.2337	0.4232	0.0000	1.0000	0.0000
Cash	5255	0.1489	0.1542	0.0961	0.9550	0.0000
Size	5255	7.0410	1.9886	6.9121	13.0850	1.7015
Firm Age	5255	14.6714	5.6111	15.0000	25.0000	1.0000
Leverage	5255	0.1794	0.1550	0.1622	0.7452	0.0000
Reversed Herfindahl Index (RHI)	5255	0.8293	0.1457	0.8750	0.9799	0.0000
Dividend	5255	0.0162	0.0293	0.0070	0.2698	0.0000
ROA Volatility	5255	0.0448	0.0627	0.0303	1.0667	0.0000
Sales Growth	5255	0.1072	0.2500	0.0779	1.7382	-0.8162
Tangibility	5255	0.2266	0.1601	0.1880	0.9200	0.0030
Total Assets ($m)	5255	10893.22	42292.08	1004.32	481645	5.482

Panel C: Overinvestment Sample

Variable	N	Mean	Std Dev	Median	Max.	Min.	Difference in Means (T-Stat)
Board Centrality Measures							
Betweenness Centrality*100	7720	0.0070	0.0070	0.0050	0.1068	0.0000	1.70*
Closeness Centrality*100	7720	22.8303	10.4707	21.6142	100.0000	12.3026	3.48***
Degree Centrality	7720	0.0287	0.0142	0.0260	0.0966	0.0030	4.47***
Eigenvector Centrality*100	7720	0.1028	0.3641	0.0075	12.8224	0.0000	6.84***
R&D Measures							
R&D	7720	0.1012	0.0739	0.0852	0.6156	0.0011	-90.21***
RQ	7720	0.1042	0.0436	0.0975	0.3169	0.0184	12.61***
R*	7720	0.0366	0.0245	0.0317	0.2829	0.0029	21.11***
R&D-R*	7720	0.0638	0.0610	0.0467	0.3226	0.0000	-111.26***
Other firm Variables							
Market to Book	7720	3.3465	3.4172	2.3751	31.0219	0.2025	-1.35
Market to Book (*t+1*)	7720	3.2390	3.2828	2.3370	31.8819	0.1969	-0.61
High Tech Dummy (HT)	7720	0.7062	0.4555	1.0000	1.0000	0.0000	-60.52***
Cash	7720	0.2956	0.2026	0.2614	0.9523	0.0000	-46.78***
Size	7720	6.4486	1.9898	6.1420	13.0814	2.1759	16.65***
Firm Age	7720	13.8285	5.1924	14.0000	47.0000	1.0000	8.65***
Leverage	7720	0.1078	0.1385	0.0377	0.7452	0.0000	26.94***
Reversed Herfindahl Index (RHI)	7720	0.8857	0.0922	0.9036	0.9803	0.0000	-24.87***
Dividend	7720	0.0080	0.0223	0.0000	0.2698	0.0000	17.32***
ROA Volatility	7720	0.0663	0.0710	0.0457	1.0667	0.0000	-18.12***
Sales Growth	7720	0.0851	0.2314	0.0646	1.7382	-0.8162	5.07***
Tangibility	7720	0.1443	0.1209	0.1092	0.8573	0.0010	31.65***
Total Assets ($m)	7720	6126.1	23406	464.972	479921	8.8100	7.43***

Table 2: Summary Statistics of Board Characteristics: Underinvestment and Overinvestment Samples

This table presents the summary statistics of board level characteristics. Boardage is the average age of the board. Boardsize is the number of board members of the board. Gendratio is the ratio of the total females on the board to the total number of board members. Advanced is the number of advanced degree holders on the board. Directorships is the number of directorships held by board members. Auditcomm, Compcomm, Govcomm are the total number of outsiders on the audit committee, compensation committee, and the governance committee. Majboard is the percentage of outside board members. Outsideceo, and Outsidecfo is the total number of CEOs, and CFO of other companies on the board.

	Underinvestment Sample			**Overinvestment Sample**			**T-Stats**
Board Level Characteristics	N	Mean	Std Dev	N	Mean	Std Dev	**Difference in Means**
Boardage	5246	52.99	7.73	7686	50.70	8.96	15.54***
Boardsize	5255	12.32	3.47	7720	11.76	3.53	8.95***
Gendratio	5255	0.10	0.09	7720	0.08	0.08	9.29***
Advanced	5255	0.62	0.95	7720	1.07	1.41	-21.91***
Directorships	5255	21.80	11.91	7720	20.75	12.54	4.82***
Outside Member Participation							
Auditcomm	5255	3.64	1.32	7720	3.35	1.20	12.87***
Compcomm	4635	3.42	1.48	6412	3.01	1.38	14.88***
Govcomm	4635	3.30	1.91	6412	2.88	1.77	11.67***
Majboard	5255	0.63	0.11	7720	0.61	0.11	11.30***
Outsideceo	5255	1.44	1.40	7720	1.27	1.20	6.93***
Outsidecfo	5255	0.22	0.46	7720	0.21	0.45	0.27

Table 3: Board Centrality and R&D Productivity

This table presents results from multivariate regressions of Research Quotient (dependent variable) on Board Centrality (independent variable) and relevant control variables. An observation is classified as underinvestment (overinvestment) if the actual R&D intensity (R&D) is less (greater) than optimal R&D intensity (R*). All variables except HT are winsorized at 0.5% and 99.5% and then standardized. Firm clustered standard errors is employed. T-statistics are given in parenthesis. Coefficients significant at the 1%, 5%, and 10% are marked by ***, **, * respectively.

	Full Sample				Underinvestment Subsample				Overinvestment Subsample			
VARIABLES	**RQ**	**RQ**	**RQ**	**RQ**	**RQ**	**RQ**	**RQ**	**RQ**	**RQ**	**RQ**	**RQ**	**RQ**
Betweenness	0.0021**				0.0017				0.0028**			
	(1.9913)				(0.9191)				(2.3096)			
Betweenness^2	-0.0001				0.0004				-0.0003			
	(-0.7112)				(0.7937)				(-1.5038)			
Closeness		0.0149***				0.0109				0.0234***		
		(2.6643)				(1.3818)				(2.9726)		
Closeness^2		-0.0053***				-0.0041				-0.0083***		
		(-2.8801)				(-1.5933)				(-3.1677)		
Degree			0.0045***				0.0037**				0.0068***	
			(3.4814)				(2.0060)				(4.2063)	
Degree^2			-0.0012***				-0.0009				-0.0016***	
			(-2.8250)				(-1.3388)				(-3.3687)	
Eigenvector				0.0009				-0.0004				0.0019**
				(1.2312)				(-0.2291)				(2.1483)
Eigenvector^2				-0.0000				0.0001				-0.0000*
				(-1.0761)				(0.2212)				(-1.6554)
MB	0.0006***	0.0006***	0.0006***	0.0007***	0.0009***	0.0009**	0.0008**	0.0009***	0.0005*	0.0004*	0.0004*	0.0005*
	(2.8858)	(2.6896)	(2.6903)	(2.9759)	(2.7144)	(2.5625)	(2.5367)	(2.8598)	(1.8787)	(1.6829)	(1.7245)	(1.9205)
HT	0.0001	0.0002	0.0001	0.0003	0.0072**	0.0070**	0.0071**	0.0070**	0.0073***	0.0074***	0.0071***	0.0076***
	(0.0753)	(0.1092)	(0.0414)	(0.1403)	(2.0540)	(1.9928)	(2.0036)	(1.9932)	(3.1968)	(3.2452)	(3.1422)	(3.3128)
Cash	0.0085***	0.0085***	0.0084***	0.0086***	0.0171***	0.0172***	0.0171***	0.0171***	0.0087***	0.0086***	0.0085***	0.0088***
	(8.0248)	(8.0674)	(7.9620)	(8.1117)	(7.6055)	(7.6114)	(7.5967)	(7.5464)	(7.8271)	(7.8064)	(7.7110)	(7.9656)
Size	-0.0011	-0.0012	-0.0020*	-0.0006	0.0024	0.0026	0.0017	0.0035**	-0.0037***	-0.0042***	-0.0056***	-0.0034***
	(-1.0259)	(-1.1742)	(-1.6770)	(-0.5713)	(1.4460)	(1.5735)	(0.9552)	(2.1948)	(-3.1361)	(-3.4732)	(-3.8994)	(-3.0254)
Firm Age	-0.0044***	-0.0047***	-0.0047***	-0.0044***	-0.0027*	-0.0030**	-0.0031**	-0.0026*	-0.0033***	-0.0036***	-0.0035***	-0.0035***
	(-4.2164)	(-4.4835)	(-4.4677)	(-4.2301)	(-1.8173)	(-2.0176)	(-2.0652)	(-1.7528)	(-2.6807)	(-2.9350)	(-2.8492)	(-2.8054)

Leverage	-0.0021**	-0.0021**	-0.0023***	-0.0021**	-0.0014	-0.0014	-0.0016	-0.0013	-0.0031***	-0.0031***	-0.0034***	-0.0030***
	(-2.4607)	(-2.4678)	(-2.6800)	(-2.3768)	(-1.2109)	(-1.1889)	(-1.3168)	(-1.1344)	(-2.8799)	(-2.8759)	(-3.1068)	(-2.7755)
RHI	0.0005	0.0005	0.0006	0.0005	0.0023	0.0024	0.0025	0.0023	-0.0023	-0.0023*	-0.0022	-0.0024*
	(0.4795)	(0.5003)	(0.5608)	(0.4612)	(1.5323)	(1.5918)	(1.6460)	(1.5562)	(-1.6447)	(-1.6562)	(-1.5667)	(-1.7096)
Dividend	-0.0030***	-0.0030***	-0.0029***	-0.0032***	-0.0043***	-0.0042***	-0.0043***	-0.0043***	-0.0034***	-0.0033***	-0.0030***	-0.0036***
	(-4.1601)	(-4.1577)	(-4.0231)	(-4.3310)	(-3.9489)	(-3.9124)	(-3.9277)	(-3.9471)	(-3.5328)	(-3.5174)	(-3.2120)	(-3.7965)
Constant	0.0912***	0.0973***	0.0912***	0.0906***	0.0933***	0.0981***	0.0933***	0.0924***	0.0820***	0.0915***	0.0814***	0.0833***
	(10.6874)	(10.8754)	(10.7736)	(10.7206)	(10.1263)	(9.9767)	(10.4389)	(10.1296)	(18.5942)	(17.4616)	(22.4956)	(22.1223)
Industry fixed effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Year fixed effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Firm fixed effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Observations	12,975	12,975	12,975	12,975	5,255	5,255	5,255	5,255	7,720	7,720	7,720	7,720
Adjusted R-squared	0.1705	0.1714	0.1727	0.1693	0.2323	0.2302	0.2309	0.2286	0.1925	0.1956	0.1990	0.1915

Table 4: Board Centrality and R&D Intensity

This table presents results from multivariate regressions of R&D Intensity (dependent variable) on Board Centrality (independent variable) and relevant control variables. An observation is classified as underinvestment (overinvestment) if the actual R&D intensity (R&D) is less (greater) than optimal R&D intensity (R*). All variables except HT are winsorized at 0.5% and 99.5% and then standardized. Firm clustered standard errors is employed. T-statistics are given in parenthesis. Coefficients significant at the 1%, 5%, and 10% are marked by ***, **, * respectively.

	Full sample				Underinvestment Sample				Overinvestment Sample			
VARIABLES	**R&D**	**R&D**	**R&D**	**R&D**	**R&D**	**R&D**	**R&D**	**R&D**	**R&D**	**R&D**	**R&D**	**R&D**
Betweenness	0.0091***				0.0041***				0.0099***			
	(5.0099)				(5.1246)				(4.4013)			
Betweenness^2	-0.0010***				-0.0008***				-0.0009***			
	(-2.6121)				(-3.8820)				(-2.8694)			
Closeness		0.0473***				0.0191***				0.0606***		
		(4.5985)				(4.5863)				(3.8122)		
Closeness^2		-0.0166***				-0.0069***				-0.0205***		
		(-5.0916)				(-5.2698)				(-4.0191)		
Degree			0.0162***				0.0063***				0.0188***	
			(7.9228)				(7.3183)				(6.6138)	
Degree^2			-0.0032***				-0.0017***				-0.0037***	
			(-4.9994)				(-4.8570)				(-4.6442)	
Eigenvector				0.0043***				0.0039***				0.0047***
				(4.6927)				(4.4408)				(3.2254)
Eigenvector^2				-0.0001***				-0.0005***				-0.0001***
				(-3.7925)				(-3.7740)				(-2.6928)
MB	0.0027***	0.0027***	0.0026***	0.0028***	0.0011***	0.0010***	0.0010***	0.0011***	0.0040***	0.0039***	0.0039***	0.0041***
	(8.0464)	(7.8983)	(7.6124)	(8.3563)	(6.2371)	(6.0239)	(6.0297)	(6.2887)	(9.0085)	(8.8512)	(8.7190)	(9.1582)
HT	0.0366***	0.0369***	0.0363***	0.0371***	0.0069***	0.0068***	0.0069***	0.0069***	0.0265***	0.0270***	0.0261***	0.0274***
	(12.8411)	(12.9896)	(12.8937)	(12.9983)	(4.5197)	(4.4824)	(4.5390)	(4.5159)	(7.4295)	(7.5639)	(7.3998)	(7.6338)
Cash	0.0188***	0.0190***	0.0186***	0.0193***	0.0069***	0.0071***	0.0069***	0.0070***	0.0130***	0.0131***	0.0127***	0.0135***

	(12.1536)	(12.2571)	(12.3156)	(12.3117)	(7.3733)	(7.6400)	(7.5378)	(7.3875)	(7.5322)	(7.5819)	(7.4895)	(7.8071)
Size	-0.0173***	-0.0172***	-0.0218***	-0.0157***	-0.0054***	-0.0055***	-0.0069***	-0.0050***	-0.0276***	-0.0278***	-0.0328***	-0.0257***
	(-9.8344)	(-9.7555)	(-10.4871)	(-9.7094)	(-7.7111)	(-7.8456)	(-8.3825)	(-7.1635)	(-11.4530)	(-11.2478)	(-11.4363)	(-11.7254)
Firm Age	0.0015	0.0007	0.0005	0.0014	0.0010*	0.0007	0.0006	0.0011**	-0.0006	-0.0013	-0.0012	-0.0010
	(0.9438)	(0.4686)	(0.2946)	(0.8760)	(1.8551)	(1.1791)	(1.0030)	(1.9943)	(-0.2675)	(-0.5430)	(-0.5291)	(-0.4073)
Leverage	-0.0057***	-0.0057***	-0.0063***	-0.0054***	-0.0025***	-0.0025***	-0.0028***	-0.0025***	-0.0056***	-0.0054**	-0.0062***	-0.0052**
	(-4.0637)	(-3.9842)	(-4.4763)	(-3.7995)	(-4.8990)	(-4.9553)	(-5.5709)	(-4.9057)	(-2.6420)	(-2.5283)	(-2.9294)	(-2.4157)
RHI	0.0037***	0.0037***	0.0040***	0.0036***	0.0012**	0.0012**	0.0013***	0.0012**	0.0032	0.0030	0.0035	0.0028
	(2.8383)	(2.8085)	(3.0382)	(2.7571)	(2.5708)	(2.5711)	(2.9438)	(2.5407)	(1.1684)	(1.0855)	(1.2436)	(1.0226)
Dividend	-0.0044***	-0.0045***	-0.0042***	-0.0050***	-0.0003	-0.0004	-0.0004	-0.0005	-0.0002	-0.0002	0.0006	-0.0009
	(-3.8674)	(-3.9785)	(-3.6455)	(-4.3430)	(-0.5719)	(-0.6443)	(-0.6424)	(-0.9039)	(-0.1002)	(-0.1545)	(0.3761)	(-0.6070)
Constant	0.0359***	0.0539***	0.0330***	0.0334***	0.0164***	0.0236***	0.0157***	0.0157***	0.0466***	0.0701***	0.0417***	0.0495***
	(9.0608)	(9.1186)	(8.5537)	(8.4234)	(7.8834)	(8.6037)	(8.0830)	(7.7067)	(5.8358)	(7.8251)	(6.2882)	(9.1348)
Industry fixed effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Year fixed effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Firm fixed effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Observations	12,975	12,975	12,975	12,975	5,255	5,255	5,255	5,255	7,720	7,720	7,720	7,720
Adjusted R-squared	0.3592	0.3600	0.3707	0.3533	0.3253	0.3320	0.3430	0.3196	0.2693	0.2711	0.2834	0.2624

Table 5: Board Centrality and Distortion in R&D Intensity

This table presents multivariate regression results estimating the association between board centrality and distortion in R&D investment. The dependent variable is Absolute difference between Actual R&D intensity and Optimal R&D intensity i.e., Abs(RNDDIFF). An observation is classified as underinvestment (overinvestment) if the actual R&D intensity (R&D) is less (greater) than optimal R&D intensity (R*). All variables except HT are winsorized at 0.5% and 99.5% and then standardized. Firm-clustered standard errors are employed. T-statistics in parenthesis. Coefficients significant at the 1%, 5%, and 10% are marked by ***, **, * respectively.

	Underinvestment Subsample (RNDDIFF < 0)				**Overinvestment Subsample (RNDDIFF > 0)**			
VARIABLES	**Abs (RNDDIFF)**	**Abs (RNDDIFF)**	**Abs (RNDDIFF)**	**Abs (RNDDIFF)**	**Abs (RNDDIFF)**	**Abs (RNDDIFF)**	**Abs (RNDDIFF)**	**Abs (RNDDIFF)**
Betweenness	-0.0003				0.0072***			
	(-0.1919)				(3.9947)			
Betweenness^2	0.0001				-0.0007***			
	(0.3392)				(-3.1668)			
Closeness		0.0087				0.0385***		
		(0.7236)				(3.3566)		
Closeness^2		-0.0023				-0.0130***		
		(-0.6890)				(-3.4977)		
Degree			-0.0009				0.0133***	
			(-0.4881)				(5.7645)	
Degree^2			0.0003				-0.0031***	
			(0.5329)				(-4.4730)	
Eigenvector				-0.0030*				0.0028**
				(-1.8471)				(2.3557)
Eigenvector^2				0.0006***				-0.0000*
				(2.6085)				(-1.9007)
Market to Book	0.0016***	0.0015***	0.0016***	0.0016***	0.0022***	0.0022***	0.0021***	0.0023***
	(4.7757)	(5.2337)	(4.7344)	(4.9800)	(5.8266)	(5.7276)	(5.6102)	(6.0257)
HT	-0.0024	-0.0023	-0.0024	-0.0025	0.0227***	0.0231***	0.0225***	0.0233***
	(-0.7195)	(-0.6862)	(-0.7160)	(-0.7394)	(7.4992)	(7.5917)	(7.4620)	(7.6536)
Cash	0.0033*	0.0033**	0.0033*	0.0033*	0.0136***	0.0137***	0.0133***	0.0140***

	(1.9351)	(1.9672)	(1.9395)	(1.9134)	(9.0564)	(9.1297)	(8.9968)	(9.2903)
Size	-0.0048***	-0.0053***	-0.0045***	-0.0046***	-0.0183***	-0.0182***	-0.0215***	-0.0168***
	(-3.9202)	(-3.4723)	(-3.3822)	(-3.7711)	(-9.6481)	(-9.5361)	(-9.6170)	(-9.5625)
Firm Age	-0.0024**	-0.0026**	-0.0024**	-0.0024**	0.0008	0.0004	0.0004	0.0006
	(-2.1285)	(-2.1878)	(-2.0513)	(-2.1132)	(0.4371)	(0.2233)	(0.2257)	(0.3329)
Leverage	-0.0037***	-0.0036***	-0.0036***	-0.0035***	-0.0017	-0.0015	-0.0021	-0.0014
	(-3.4634)	(-3.4871)	(-3.4467)	(-3.3733)	(-1.0731)	(-0.9576)	(-1.3514)	(-0.8742)
RHI	0.0011	0.0011	0.0011	0.0011	0.0028	0.0027	0.0030	0.0025
	(1.1572)	(1.1841)	(1.1432)	(1.1286)	(1.1998)	(1.1125)	(1.2328)	(1.0698)
Dividend	0.0017*	0.0018*	0.0017*	0.0017*	-0.0022*	-0.0023*	-0.0016	-0.0027**
	(1.6699)	(1.7451)	(1.6563)	(1.6626)	(-1.8255)	(-1.9446)	(-1.3462)	(-2.2873)
Constant	0.0206***	0.0238***	0.0204***	0.0196***	0.0286***	0.0433***	0.0269***	0.0301***
	(3.5491)	(3.3943)	(3.6910)	(3.4909)	(5.1360)	(6.7514)	(6.1989)	(7.3670)
Industry fixed effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Year fixed effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Firm fixed effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Observations	5,255	5,255	5,255	5,255	7,720	7,720	7,720	7,720
Adjusted R-squared	0.1563	0.1580	0.1565	0.1584	0.2149	0.2145	0.2247	0.2092

Table 6: Robustness Check Using Value of Patent Filings

This table presents the results from a robustness check using a newly developed methodology by Kogan, Papanikolaou, Seru, Stoffman (2017) to estimate the value of patent grants. The patent data from Google Patents for all utility patents issued by the USPTO between 1/1/1926 to 11/2/2010 is combined with the returns data from CRSP and our sample to estimate the value of each patent grant. The dependent variable, $PV(t+k, t+j)_{i,t}$, is the sum of the present values of all patents pertaining to the filing years $t+k$ to $t+j$, for firm i at time t. An observation is classified as underinvestment (overinvestment) if the actual R&D intensity (R&D) is less (greater) than optimal R&D intensity (R*). All variables except HT are winsorized at 0.5% and 99.5% and then standardized. Firm-clustered standard errors are employed. The control variables are the same as in previous tables and are not displayed. T-statistics in parenthesis. Coefficients significant at the 1%, 5%, and 10% are marked by ***, **, * respectively.

Panel A: Dependent variable is the sum of the present values of all patents pertaining to the filing years t+1 to t+2, for firm *i* at time *t*.

	Underinvestment Sample				**Overinvestment Sample**			
VARIABLES	**PV (t+1, t+2)**	**PV (t+1, t+2)**	**PV (t+1, t+2)**	**PV (t+1, t+2)**	**PV (t+1, t+2)**	**PV (t+1, t+2)**	**PV (t+1, t+2)**	**PV (t+1, t+2)**
Betweenness	0.0225***				0.0384***			
	(3.0770)				(3.6080)			
Betweenness^2	-0.0049***				-0.0086***			
	(-2.7412)				(-3.2971)			
Closeness		0.0573*				0.0906**		
		(1.6884)				(2.1180)		
Closeness^2		-0.0227**				-0.0299**		
		(-2.0647)				(-2.1901)		
Degree			0.0149**				0.0246**	
			(2.0164)				(2.3509)	
Degree^2			0.0001				-0.0054*	
			(0.0193)				(-1.8220)	
Eigenvector				-0.0137**				-0.0113**
				(-2.1313)				(-2.3006)
Eigenvector^2				0.0012*				0.0001
				(1.8372)				(1.2198)
Controls	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Firm/Industry/Year Fixed Effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Observations	1,485	1,485	1,485	1,485	6,422	6,422	6,422	6,422
Adjusted R-squared	0.2654	0.2616	0.2669	0.2567	0.1659	0.1627	0.1633	0.1621

Panel B: Dependent variable is the sum of the present values of all patents pertaining to the filing years t+2 to t+3, for firm *i* at time *t*.

	Underinvestment Sample				Overinvestment Sample			
VARIABLES	**PV (t+2, t+3)**	**PV (t+2, t+3)**	**PV (t+2, t+3)**	**PV (t+2, t+3)**	**PV (t+2, t+3)**	**PV (t+2, t+3)**	**PV (t+2, t+3)**	**PV (t+2, t+3)**
Betweenness	0.0147**				0.0307***			
	(2.5009)				(3.6140)			
Betweenness^2	-0.0032**				-0.0068***			
	(-2.2884)				(-3.1511)			
Closeness		0.0349				0.0758**		
		(1.3049)				(2.1188)		
Closeness^2		-0.0147*				-0.0240**		
		(-1.6685)				(-2.1010)		
Degree			0.0091				0.0204**	
			(1.3794)				(2.3227)	
Degree^2			0.0006				-0.0041*	
			(0.1950)				(-1.6692)	
Eigenvector				-0.0113**				-0.0089**
				(-2.3295)				(-2.3543)
Eigenvector^2				0.0010**				0.0001
				(2.2024)				(1.3188)
Controls	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Firm/Industry/Year Fixed Effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Observations	1,446	1,446	1,446	1,446	6,129	6,129	6,129	6,129
Adjusted R-squared	0.2575	0.2557	0.2596	0.2528	0.1725	0.1696	0.1703	0.1689

Panel C: Dependent variable is the sum of the present values of all patents pertaining to the filing years t+1 to t+3, for firm *i* at time *t*.

	Underinvestment Sample				Overinvestment Sample			
VARIABLES	**PV (t+1, t+3)**	**PV (t+1, t+3)**	**PV (t+1, t+3)**	**PV (t+1, t+3)**	**PV (t+1, t+3)**	**PV (t+1, t+3)**	**PV (t+1, t+3)**	**PV (t+1, t+3)**
Betweenness	0.0287***				0.0539***			
	(2.9107)				(3.6756)			
Betweenness^2	-0.0062**				-0.0121***			
	(-2.5789)				(-3.3243)			
Closeness		0.0690				0.1310**		
		(1.5172)				(2.1614)		
Closeness^2		-0.0277*				-0.0422**		
		(-1.8647)				(-2.1812)		
Degree			0.0183*				0.0360**	
			(1.7411)				(2.4491)	
Degree^2			0.0005				-0.0078*	
			(0.0948)				(-1.8986)	
Eigenvector				-0.0184**				-0.0146**
				(-2.1435)				(-2.1962)
Eigenvector^2				0.0016*				0.0001
				(1.9348)				(1.1329)
Controls	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Firm/Industry/Year Fixed Effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Observations	1,485	1,485	1,485	1,485	6,422	6,422	6,422	6,422
Adjusted R-squared	0.2654	0.2616	0.2669	0.2567	0.1659	0.1627	0.1633	0.1621

Table 7: SEM Regressions: Board Centrality. R&D Intensity, and Market to Book value of Equity

This table presents results of simultaneous equations estimation of R&D at year t and Market to book at year t+1 (MB (t+1)) on Board Centrality and other control variables. An observation is classified as underinvestment (overinvestment) if the actual R&D intensity (R&D) is less (greater) than optimal R&D intensity (R*). All variables except HT are winsorized at 0.5% and 99.5% and then standardized. Firm-clustered standard errors are employed. T-statistics in parenthesis. Coefficients significant at the 1%, 5%, and 10% are marked by ***, **, * respectively.

Panel A: Full sample

	Full Sample							
VARIABLES	**R&D(t)**	**MB(t+1)**	**R&D(t)**	**MB(t+1)**	**R&D(t)**	**MB(t+1)**	**R&D(t)**	**MB(t+1)**
Betweenness	0.0083***	0.3251***						
	(9.0525)	(7.1868)						
Betweenness^2	-0.0009***	-0.0454***						
	(-3.7558)	(-4.8210)						
Closeness			0.0403***	2.3588***				
			(9.7738)	(12.1491)				
Closeness^2			-0.0141***	-0.7803***				
			(-10.4387)	(-12.5182)				
Degree					0.0158***	0.4400***		
					(18.1754)	(9.3760)		
Degree^2					-0.0031***	-0.0628***		
					(-11.0532)	(-3.5833)		
Eigenvector							0.0039***	0.2074***
							(9.1074)	(5.3949)
Eigenvector^2							-0.0001***	-0.0054***
							(-7.1331)	(-6.0069)
Market to Book	0.0027***		0.0026***		0.0025***		0.0028***	
	(12.9374)		(12.7334)		(12.1019)		(13.3729)	
HT	0.0366***	-0.1900***	0.0367***	-0.1664***	0.0362***	-0.1789***	0.0369***	-0.1925***
	(32.9123)	(-3.1173)	(33.0519)	(-2.7287)	(32.9738)	(-2.9455)	(33.0561)	(-3.1550)

Cash	0.0186***		0.0187***		0.0189***		0.0191***	
	(23.7580)		(24.0569)		(24.7033)		(24.4254)	
Size	-0.0174***	0.0928**	-0.0170***	0.0372	-0.0218***	-0.0356	-0.0159***	0.1257***
	(-23.4370)	(2.4275)	(-23.4479)	(1.0053)	(-26.1112)	(-0.8344)	(-22.7252)	(3.4255)
Firm Age	0.0006		-0.0001		0.0011*		0.0006	
	(1.0076)		(-0.0889)		(1.9180)		(1.0371)	
Leverage	-0.0055***	0.7988***	-0.0055***	0.7959***	-0.0061***	0.7743***	-0.0053***	0.8080***
	(-7.7614)	(13.5608)	(-7.6385)	(13.5658)	(-8.6594)	(13.0778)	(-7.3802)	(13.7125)
RHI	0.0050***		0.0050***		0.0050***		0.0049***	
	(10.2167)		(10.1378)		(10.3574)		(10.1074)	
Dividend	-0.0048***	0.7588***	-0.0050***	0.7513***	-0.0045***	0.7583***	-0.0054***	0.7386***
	(-8.2221)	(13.8801)	(-8.4924)	(13.8941)	(-7.7430)	(13.9347)	(-8.9671)	(13.7658)
R&D		9.8280***		9.6416***		9.4471***		10.1443***
		(14.5135)		(14.3641)		(13.9248)		(15.0174)
Tangibility		-0.2411***		-0.2247***		-0.2455***		-0.2710***
		(-4.5524)		(-4.3286)		(-4.6834)		(-5.2987)
ROA Volatility		0.6714***		0.6776***		0.6587***		0.6598***
		(8.7312)		(8.9054)		(8.6461)		(8.5718)
Sales Growth		0.3148***		0.3378***		0.3366***		0.3217***
		(4.7198)		(5.0248)		(5.0240)		(4.7717)
Firm/Industry/Year Fixed Effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Constant	0.0364***	2.7304***	0.0489***	3.4104***	0.0375***	2.7362***	0.0363***	2.7137***
	(41.8644)	(55.1159)	(31.8050)	(42.9817)	(43.9584)	(52.7065)	(42.5279)	(55.1384)
Observations	12,975	12,975	12,975	12,975	12,975	12,975	12,975	12,975

Panel B: Underinvestment Subsample

	Underinvestment Subsample							
VARIABLES	**R&D(t)**	**MB(t+1)**	**R&D(t)**	**MB(t+1)**	**R&D(t)**	**MB(t+1)**	**R&D(t)**	**MB(t+1)**
Betweenness	0.0041***	0.5203***						
	(9.4314)	(6.4198)						
Betweenness^2	-0.0008***	-0.0979***						
	(-7.5099)	(-5.0358)						
Closeness			0.0178***	2.6063***				
			(8.2641)	(8.5870)				
Closeness^2			-0.0064***	-0.8554***				
			(-9.2201)	(-8.8593)				
Degree					0.0062***	0.5468***		
					(12.0856)	(7.7334)		
Degree^2					-0.0016***	-0.0746***		
					(-10.0088)	(-2.8675)		
Eigenvector							0.0021***	0.6696***
							(5.5057)	(6.6111)
Eigenvector^2							-0.0002***	-0.0989***
							(-4.0595)	(-7.3196)
Market to Book	0.0011***		0.0011***		0.0011***		0.0012***	
	(10.1411)		(9.8031)		(9.5662)		(10.4943)	
HT	0.0061***	-0.1843*	0.0060***	-0.1717*	0.0063***	-0.1342	0.0061***	-0.1896*
	(7.9526)	(-1.8807)	(7.8394)	(-1.7509)	(8.2653)	(-1.3660)	(7.8086)	(-1.9378)
Cash	0.0080***		0.0081***		0.0085***		0.0081***	
	(12.7163)		(13.0322)		(13.4102)		(12.7812)	
Size	-0.0057***	-0.0019	-0.0057***	-0.0178	-0.0068***	-0.1325**	-0.0049***	0.0339
	(-14.6924)	(-0.0327)	(-14.8054)	(-0.3205)	(-14.4139)	(-2.0773)	(-13.2936)	(0.6313)
Firm Age	0.0002		-0.0002		0.0003		0.0003	

	(0.8338)		(-0.6961)		(0.9884)		(1.0075)	
Leverage	-0.0025***	0.9979***	-0.0025***	0.9893***	-0.0028***	0.9572***	-0.0025***	0.9926***
	(-8.1090)	(10.5977)	(-8.2926)	(10.5635)	(-9.1210)	(10.0313)	(-8.0553)	(10.6080)
RHI	0.0016***		0.0015***		0.0016***		0.0016***	
	(7.6443)		(7.6028)		(7.7383)		(7.5935)	
Dividend	-0.0007**	1.0060***	-0.0007**	0.9905***	-0.0007**	0.9852***	-0.0009***	0.9755***
	(-2.1203)	(12.5252)	(-2.2953)	(12.5263)	(-2.2449)	(12.4902)	(-2.7815)	(12.4432)
R&D		37.8485***		37.0982***		36.6544***		38.9908***
		(8.0590)		(7.8870)		(7.7036)		(8.2893)
Tangibility		-0.0951		-0.1084		-0.1106		-0.0914
		(-1.1530)		(-1.3599)		(-1.3635)		(-1.1748)
ROA Volatility		0.5236***		0.5206***		0.5155***		0.5123***
		(4.0357)		(4.0961)		(4.0183)		(3.9116)
Sales Growth		0.2997***		0.3341***		0.3346***		0.3222***
		(3.4907)		(3.8654)		(3.9585)		(3.6857)
Firm/Industry/Year Fixed Effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Constant	0.0188***	2.2538***	0.0241***	2.9819***	0.0196***	2.2483***	0.0185***	2.2231***
	(37.4250)	(21.6829)	(26.9842)	(20.0834)	(38.7362)	(20.7171)	(37.2141)	(21.4893)
Observations	5,255	5,255	5,255	5,255	5,255	5,255	5,255	5,255

Panel C: Overinvestment Subsample

	Overinvestment Subsample							
VARIABLES	**R&D(t)**	**MB(t+1)**	**R&D(t)**	**MB(t+1)**	**R&D(t)**	**MB(t+1)**	**R&D(t)**	**MB(t+1)**
Betweenness	0.0103***	0.1977***						
	(9.0015)	(4.0488)						
Betweenness^2	-0.0010***	-0.0268***						
	(-3.8985)	(-4.0496)						
Closeness			0.0606***	1.6498***				
			(9.3777)	(6.9222)				
Closeness^2			-0.0203***	-0.5437***				
			(-9.8129)	(-7.0073)				
Degree					0.0184***	0.2145***		
					(14.2619)	(3.5193)		
Degree^2					-0.0038***	-0.0099		
					(-9.8142)	(-0.4196)		
Eigenvector							0.0066***	0.1438***
							(9.1168)	(2.7743)
Eigenvector^2							-0.0001***	-0.0039***
							(-7.9540)	(-3.5691)
Market to Book	0.0039***		0.0039***		0.0038***		0.0040***	
	(12.9485)		(12.8332)		(12.6769)		(13.1014)	
HT	0.0263***	-0.1007	0.0266***	-0.0900	0.0259***	-0.1022	0.0271***	-0.0999
	(17.1989)	(-1.2716)	(17.3594)	(-1.1354)	(17.0578)	(-1.2917)	(17.5853)	(-1.2549)
Cash	0.0126***		0.0126***		0.0128***		0.0134***	
	(13.3235)		(13.4139)		(13.8501)		(14.1807)	
Size	-0.0273***	0.3087***	-0.0273***	0.2564***	-0.0319***	0.2366***	-0.0259***	0.3272***

	(-25.1734)	(5.9495)	(-25.1334)	(5.1913)	(-25.4877)	(4.1791)	(-25.3737)	(6.5277)
Firm Age	0.0003		-0.0005		0.0016*		0.0000	
	(0.3101)		(-0.5543)		(1.7209)		(0.0377)	
Leverage	-0.0053***	0.6629***	-0.0050***	0.6634***	-0.0060***	0.6551***	-0.0049***	0.6686***
	(-4.7599)	(8.9137)	(-4.5271)	(8.9161)	(-5.4497)	(8.7652)	(-4.3975)	(8.9409)
RHI	0.0054***		0.0053***		0.0054***		0.0052***	
	(5.1175)		(4.9404)		(5.0976)		(4.8733)	
Dividend	0.0002	0.3775***	0.0001	0.3784***	0.0011	0.3789***	-0.0006	0.3623***
	(0.2299)	(6.5202)	(0.1473)	(6.5667)	(1.2149)	(6.4948)	(-0.6908)	(6.3233)
R&D		10.1631***		9.9649***		10.0771***		10.3320***
		(12.8053)		(12.6711)		(12.6570)		(13.0624)
Tangibility		-0.2448***		-0.2209***		-0.2569***		-0.2599***
		(-3.6348)		(-3.3122)		(-3.8410)		(-3.8803)
ROA Volatility		0.7007***		0.7068***		0.6873***		0.6969***
		(7.7537)		(7.8131)		(7.6156)		(7.7120)
Sales Growth		0.3315***		0.3411***		0.3360***		0.3356***
		(3.6240)		(3.7206)		(3.6497)		(3.6396)
Firm/Industry/Year Fixed Effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Constant	0.0583***	2.4532***	0.0771***	2.9475***	0.0595***	2.4295***	0.0585***	2.4448***
	(41.7804)	(30.2885)	(31.4680)	(26.7799)	(42.7978)	(28.6662)	(41.9161)	(30.2078)
Observations	7,720	7,720	7,720	7,720	7,720	7,720	7,720	7,720

Table 8: Board Busyness and Overinvestment Subsample

Panel A contains median values of some selected variables the overinvestment sample in our paper and the corresponding variable median values in Cashman, Gillan, and Jun (2012) sample. Panel B presents the results multivariate regression from of Absolute (R&D Intensity – Optimal R&D) (dependent variable) on Board Busyness (BUSY) as independent variable and other control variables. BUSY is defined as the fraction of the board with directors holding greater than or equal to 3 directorships. Panel C presents the results multivariate regression from of Absolute (R&D Intensity – Optimal R&D) (dependent variable) on Ind_Busy as independent variable and other control variables. Ind_Busy is the average distance between the SIC codes of the focal firm and firms standardized by director centrality, where directors hold directorships, across all directors in the focal firm. An observation is classified overinvestment if the actual R&D intensity (R&D) is greater than optimal R&D intensity (R*). All variables except HT are winsorized at 0.5% and 99.5% and then standardized. Firm-clustered standard errors are employed. T-statistics in parenthesis. Coefficients significant at the 1%, 5%, and 10% are marked by ***, **, * respectively.

Panel A: Medians of selected variables

	Overinvestment sample in our paper (medians)	Cashman, Gillan, and Jun (2012) sample (medians)	
Variables	n=7720	S&P 500	non-S&P 500
Market to Book	2.37	1.79	1.53
Assets ($m)	464	7039	792
Firm Age (Years)	14	32	13
Outside directors (%)	62	77	67
Board size	11	10	8

Panel B: Traditional measure of Busyness and Overinvestment

	Overinvestment subsample			
VARIABLES	**Abs (RNDDIFF)**	**Abs (RNDDIFF)**	**Abs (RNDDIFF)**	**Abs (RNDDIFF)**
Betweenness	0.0054**			
	(2.4979)			
Busy*Betweenness	-0.0108**			
	(-2.0045)			
Closeness		0.0009		
		(0.4856)		
Busy*Closeness		0.0428		
		(0.7626)		
Degree			0.0134***	
			(4.8707)	
Busy*Degree			-0.0210***	
			(-4.3192)	
Eigenvalue				0.0015***
				(2.6201)
Busy*Eigenvalue				-0.0036*
				(-1.6932)
Busy	0.0295***	0.0447***	0.0147	0.0369***
	(2.9989)	(3.2141)	(1.1635)	(4.0564)
MB	0.0022***	0.0022***	0.0021***	0.0022***
	(5.7702)	(5.7748)	(5.6217)	(5.8033)
HT	0.0225***	0.0227***	0.0224***	0.0228***
	(7.4439)	(7.4565)	(7.4498)	(7.5187)
Cash	0.0134***	0.0137***	0.0133***	0.0136***
	(8.9180)	(9.0612)	(8.9005)	(9.0094)
Size	-0.0187***	-0.0186***	-0.0216***	-0.0186***
	(-9.5854)	(-9.0997)	(-9.6269)	(-9.4918)
Firm Age	0.0009	0.0008	0.0004	0.0008
	(0.4473)	(0.4167)	(0.2086)	(0.4198)
Leverage	-0.0017	-0.0016	-0.0020	-0.0016
	(-1.1113)	(-0.9947)	(-1.2629)	(-1.0245)
RHI	0.0029	0.0028	0.0030	0.0028
	(1.2108)	(1.1348)	(1.2541)	(1.1268)
Dividend	-0.0021*	-0.0024**	-0.0018	-0.0024*
	(-1.7583)	(-2.0197)	(-1.5203)	(-1.9585)
Constant	0.0210***	0.0189***	0.0217***	0.0184***
	(3.5500)	(2.8356)	(3.9060)	(2.9466)
Industry/Firm/Year Fixed Effects	Yes	Yes	Yes	Yes
Observations	7,720	7,720	7,720	7,720
Adjusted R-squared	0.2165	0.2148	0.2236	0.2154

Panel C: Busyness measures using SIC Distance from Focal Firm and Overinvestment

Variables	Overinvestment Sample			
	Abs (RNDDIFF)	**Abs (RNDDIFF)**	**Abs (RNDDIFF)**	**Abs (RNDDIFF)**
Ind_Busy (Betweenness)	1.0695*			
	(1.8854)			
Ind_Busy (Closeness)		0.0004		
		(1.0785)		
Ind_Busy (Degree)			0.3511*	
			(1.6996)	
Ind_Busy (Eigenvector)				0.0420
				(1.4791)
Constant	0.0277***	0.0278***	0.0272***	0.0285***
	(7.1171)	(7.1860)	(6.7964)	(7.4434)
Controls	Yes	Yes	Yes	Yes
Industry/Firm/Year Fixed Effects	Yes	Yes	Yes	Yes
Observations	7,720	7,720	7,720	7,720
Adjusted R-squared	0.2085	0.2083	0.2085	0.2085