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RESEARCH ARTICLE

Outside CEOs and innovation

Trey Cummings | Anne Marie Knott

Department of Strategy, Olin Business School, Washington University, St Louis, Missouri

Correspondence
Trey Cummings, Department of Strategy, Olin Business School, Washington University, One Brookings Drive, Campus Box 1156, St Louis, MO 63130.
Email: treycummings@wustl.edu

Research Summary: Innovation is the principle driver of firm and economic growth. Thus, one disturbing trend that may explain stagnant growth is a 65% decline in firms' R&D productivity. We propose that the rise of outside Chief Executive Officers (CEOs) may be partially responsible for the decline because those CEOs are more likely to lack technological domain expertise necessary to manage R&D effectively. While this proposition was motivated by interviews with Chief Technology Officers (CTOs), we test it at large scale. We find that firm R&D productivity decays during the tenure of outside CEOs relative to that of inside CEOs. We further find this effect is more pronounced for firms with high R&D intensity and for firms employing outside CEOs with more remote experience, lending circumstantial support for the underlying assumption regarding lack of expertise. Note that this is not a call for boards to avoid outside CEOs, rather it is recommendation to consider the implications for innovation.

Managerial Summary: While outside CEOs offer advantages over internal candidates, we argue one unintended consequence is weaker innovation. This argument was prompted by two coincident trends: a 65% decline in companies' R&D productivity and a doubling of outside Chief Executive Officers (CEOs). The argument was reinforced by interviews with Chief Technology Officers (CTOs), who recounted shifts in orientation from R&D as an investment to R&D as an expense that occurred shortly in response to a new CEO. We felt this shift was more likely with outside CEOs because they may lack technological domain expertise necessary to effectively

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manage R&D. Our results are consistent with the argument—company R&D productivity decreases under outside CEOs. Note, however, that we don't advocate avoiding outside CEOs, rather we recommend R&D firms consider technological domain expertise during CEO hiring.

KEYWORDS

CEO, compensation, expertise, innovation, R&D

1 | INTRODUCTION

Innovation has historically been viewed as the primary driver of firm and economic growth (Romer, 1990; Solow, 1957). Accordingly, one disturbing trend that may explain stagnant growth is the 65% decline in firms' R&D productivity shown in Figure 1. This has been documented both using the RQ[1] measure (Knott, 2017) as well as a newer measure called "Idea TFP" (Bloom, Jones, Van Reenen, & Webb, 2017). Identifying a means to reverse that trend has the potential to benefit firms as well as the economy. In order to do that, however, we first need to understand sources of the decline.

Our starting point for understanding sources of the R&D productivity decline was to identify management trends that were as dramatic as the decline itself. One such trend is the increasing prevalence of outside Chief Executive Officers (CEOs) documented by Murphy and Zabojnik (2007), and upheld in our own data (Figure 2). Figure 2 shows that the proportion of outside CEOs doubled from the 1980s to the 2000s. Murphy and Zabojnik argued that the rise in outside CEOs stems, in part, from an increased prevalence of "general skills," such as financial and human capital management, which are fungible across firms. While the rise may also be explained by other things, if it does stem from increased general skills, these general skills likely come at the expense of context-specific skills. Context-specific skills have been found to be important to CEOs' capabilities (Bailey & Helfat, 2003), particularly dynamic managerial capabilities affecting firm performance, such as innovation (Helfat & Martin, 2015).

The reason we felt the rise in outside CEOs was a viable candidate for the decline in RQ is that it resonates with concerns raised during interviews with Chief Technology Officers (CTOs). These were open-ended interviews conducted as part of an National Science Foundation (NSF) study to identify factors contributing to differences in firms' RQ.[2] A story we repeatedly heard in those interviews was that of major changes in R&D strategy occurring as a consequence of new ownership and/or a change in CEO. In these instances, firms shifted from an orientation of "R&D as a driver of growth" to "R&D as an expense." We thought this shift was more likely to happen with outside CEOs because they may lack technological domain expertise necessary to effectively manage the firm's R&D.

[1]RQ is the firm-specific elasticity of R&D that can be interpreted as the percentage increase in revenues from a 1% increase in R&D spending with other elasticities and inputs held constant (Knott, 2008). A more detailed definition is presented in Section 5.
[2]http://www.nsf.gov/awardsearch/showAward?AWD_ID=0965147

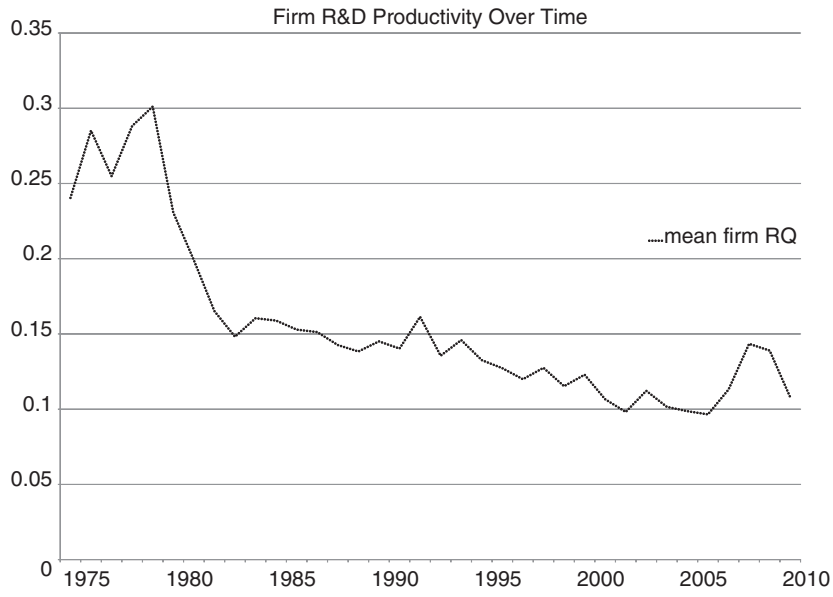

FIGURE 1 Decline in aggregrate firm R&D productivity since 1975

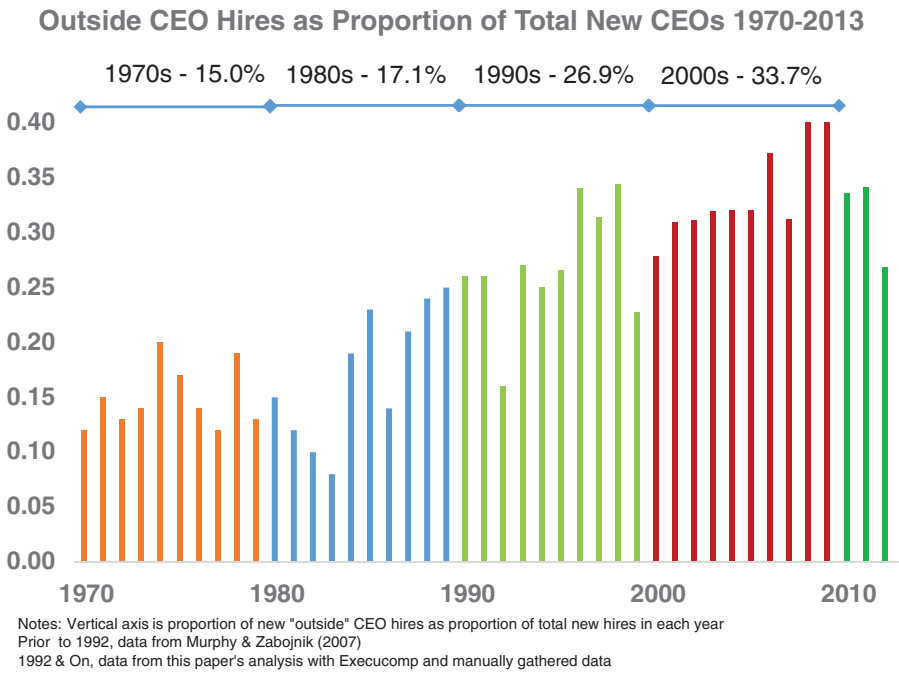

FIGURE 2 Increase in outside CEO hires over time

Some insight into actions outsiders take that detrimentally affect innovation comes from Hughes Aircraft Company after it hired its first outside CEO in 1992. Upon assuming the CEO role, C. Michael Armstrong, a former IBM executive, made changes to innovation processes and organizational structure that likely contributed to the breakup of Hughes a decade later. While we discuss these changes in greater detail in Section 4, we provide a preliminary snapshot here. First, project

selection criteria shifted from technical merit to financial returns. This led to a reduction in exploratory and long-time horizon projects, whose returns couldn't be quantified. Second, while Hughes' R&D had previously been centralized, Armstrong took steps to decentralize it. This created a tendency toward projects that were parochial to the business units at the expense of projects that bridged multiple units.

While the interviews surfaced the "Outside CEO" hypothesis and a handful of publicly available accounts support it, the goal of this article is to examine whether it holds more broadly across firms. To accomplish this, we combine financial data of U.S. firms from Compustat with firm R&D productivity from the WRDS RQ database and data on CEO identity and compensation from Execucomp.

We find first that firms with outside CEOs have lower R&D productivity—on average they exhibit lower RQ than firms with internal CEOs. These results hold when controlling for firm size, firm-fixed effects, and year effects as well as in placebo models and propensity-score matching models that consider endogenous choice of outside CEOs. Second, we find the lower R&D productivity of firms with outside CEOs is correlated with proxies for CEO expertise and experience, and that the effect is more pronounced in firms that depend heavily on R&D. This combination provides strong circumstantial evidence that lack of domain expertise is driving the outside CEO effect. Third, we find that firms with inside CEOs and outside CEOs differ in at least one dimension of R&D behavior: While firms with inside CEOs increase R&D investment in the presence of long-term incentives, firms with outside CEOs do not. This differential response to incentive compensation hints at the possibility that CEOs know their type (whether they have sufficient expertise to drive growth through R&D). Thus, it may be possible to design contracts that sort candidate CEOs on this unobservable expertise ex ante. If so, boards may be able to continue to hire outside CEOs for all the reasons they are valued, while avoiding their adverse impact on innovation. We discuss some correlational evidence that a high delta contract (high sensitivity of pay to changes in stock price) might accomplish this.

The article proceeds as follows. First, we review the prior literature on the relationship between CEOs and innovation. We follow that by reviewing the literature on outside CEOs. Next, we advance the Outside CEO and Innovation hypothesis. We then describe our empirical approach and discuss results as well as their implications.

2 | PRIOR THEORY OF THE RELATIONSHIP BETWEEN CEOS AND INNOVATION

Prior theories of the relationship between CEOs and innovation take two forms. The first form pertains to characteristics of CEOs that might predispose them to positively or adversely affect innovation. These studies have implications for selection of CEOs ex ante. The second form of theories considers the impact of various forms of governance on CEO innovative behavior. These studies have implications for managing CEOs ex post.

The earliest work in the first vein examined traits such as risk aversion and intertemporal discounting (Laverty, 1996) that cause CEOs' discount rates to differ from those of the firm, and accordingly, lead to suboptimal investment. One condition under which this might occur is when there are specific grant and exercise dates for stocks/options. The concern is that CEOs might attempt to maximize stock value on those dates by decreasing R&D. Because R&D is expensed in the current period, while its benefits aren't enjoyed until future periods, CEOs could increase profits

(and market value) in the short run and never incur the long-term costs of reduced future innovation. There is substantial evidence this occurs (Laverty, 1996).

More recent studies in this vein examine the impact of CEO overconfidence on innovation using Malmendier and Tate's (2005) measure of a CEO's tendency to postpone exercising options that are "in the money." Galasso and Simcoe (2011) found that innovation increases in this measure of overconfidence and that the effect is more pronounced under competition. A later study in the finance literature (Hirshleifer, Low, & Teoh, 2012) using the same measure obtains similar results.

Work in the second vein considers the impact of various governance factors on CEO innovation behavior. One such stream in the accounting literature examines whether CEOs smooth earnings (e.g., through increasing/decreasing R&D) to better match analyst forecasts. CEOs have an incentive to do this because the market punishes stocks for missing those forecasts. Again, evidence suggests this occurs (Bushee, 1998). However, evidence also indicates this is less likely for firms with extensive analyst coverage, presumably because analysts have sufficient depth of firm knowledge to recognize when CEOs are smoothing earnings (Yu, 2008).

Given this ability and tendency for CEOs to manipulate earnings, other studies examined mechanisms beyond analyst coverage to mitigate this tendency. These studies found that liquidity hurts innovation (Fang, Tian, & Tice, 2014), greater takeover provisions (weaker governance) increase innovation (Becker-Blease, 2011), and CEO ownership (Bange & De Bondt, 1998) and institutional ownership (Aghion, Reenen, & Zingales, 2013; Bange & De Bondt, 1998; Bushee, 1998) both increase innovation. The main implication from these studies is that governance affects CEO innovation behavior in non-obvious ways.

The most direct way to affect CEO behavior, of course, is through incentive compensation, which ties CEO pay to the long run value of the firm (typically reflected in its stock price). Dechow and Sloan (1991) examined how incentive compensation affects innovative behavior by looking at firm R&D spending as CEOs approach retirement. They find that retirement-age CEOs invest less in R&D unless compensated through long-term incentives. In related work, Lerner and Wulf (2007) looked at both CEOs and R&D managers. They showed that CEO long-term incentives have a negative (though insignificant) impact on innovation (measured as patents) when controlling for R&D manager compensation. Looking at an alternative dimension of compensation, Gormley, Matsa, and Milbourn (2013) showed that convex compensation increases innovation (measured as R&D spending). Thus, prior literature on CEOs and innovation indicates that CEO characteristics and governance of CEOs both affect innovation.

3 | PRIOR THEORY OF OUTSIDE CEOS

The CEO succession literature has been fairly prolific for the last half century. Of particular interest for this article is the stream on CEO origins: whether the CEOs has been promoted from within the ranks of the firm (inside CEO) versus hired away from another firm (outside CEO) (Kesner & Sebora, 1994). The literature has investigated strategic reasons for hiring outside CEOs, firm antecedents that predict the hiring of outside CEOs, and the performance implications of hiring outside CEOs.

Firms face trade-offs in hiring inside versus outside CEOs as well as trade-offs within the experience set of outside CEOs (Howard, 2001). On the supply side, firms with a large number of quality internal candidates are less likely to look outside. As evidence of this, the probability of hiring an outside CEO decreases with firm size and firm age (Dalton & Kesner, 1983; Helmich, 1975; Pfeffer & Salancik, 1977).

On the demand side, one key reason firms choose outside CEOs is to effect organizational change (Virany, Tushman, & Romanelli, 1992). The literature finds the probability of hiring an outside CEO increases with both high growth (exploring potential) and low performance (correcting mistakes) (Datta & Guthrie, 1994). In fact, both positive and negative performance associated with organizational change is magnified with an outside CEO (Zhang & Rajagopalan, 2010).

Conversely, firms may hire an inside CEO to generate loyalty and hope for future internal candidates (Howard, 2001), capitalize on insider knowledge and networks (Harris & Helfat, 1997), minimize organizational turbulence (Zhang & Rajagopalan, 2004), and minimize information asymmetry (Zajac, 1990).

Note, however, that there are degrees of "outsideness" that the literature also examines. Hiring from outside the firm but within the industry (low level of outsideness) expands the pool of candidates while retaining industry skills, thus lowering the hiring risk associated with an outside CEO (Harris & Helfat, 1997). However, firms may want high levels of outsideness (outside the industry as well as the firm) to learn about novel or exploratory strategies that may not exist within the industry.

These findings suggest there are complex trade-offs in the CEO succession choice. On one hand, inside CEO candidates provide organizational stability, bring firm and industry specific knowledge and skills, and increase motivation for current employees. On the other hand, outside CEO candidates increase the pool of applicants, may bring a relevant subset of industry specific knowledge and skills, and are more likely to bring novel or exploratory strategies to the firm, but increase knowledge and skill information asymmetry (Zhang, 2008). It is not surprising, then, that empirical evidence of overall performance of inside versus outside CEOs has been mixed. Inside CEOs have been shown to be more profitable (Zajac, 1990) and have higher performance after the death of the prior CEO (Worrell & Davidson III, 1987), while outside CEOs have been shown to increase shareholder wealth (Lubatkin, Chung, Rogers, & Owers, 1986), perform better under bankruptcy (Worrell & Davidson III, 1987), and perform worse when there is a simultaneous and significant change in other top management team (TMT) members (Shen & Cannella, 2002).

The preceding arguments suggest that firm and industry specific knowledge of inside CEOs versus the novel and exploratory knowledge of outside CEOs has implications for firm innovation, and by extension, long-run profits and market value. Thus, it is somewhat surprising we could find only two studies on the impact of outside CEOs on innovation. The first study by Wong and Chen (2018) argued that outside CEOs in family firms have greater innovative value due to their diverse backgrounds, networks, and ability to break the status quo. They tested this by examining abnormal stock returns after the new product announcements, and found that returns are higher in firms with outside CEOs. This result is not a surprise given that family firms with family CEOs have weaker management practices than family firms with nonfamily CEOs (Bloom, Genakos, Sadun, & Van Reenen, 2012).

A second study by Balsmeier and Buchwald (2014) is closer in nature to this study. The authors examined which type of CEO—inside (with firm specific skills) or outside (with broader perspective)—was more conducive to innovation. Using a small sample of 70 German firms from 2000 to 2008, they found that firms with outside CEOs have fewer patent applications. While their results are consistent with our hypothesis, the short window doesn't allow many observations of the same firm over multiple CEOs, so the bulk of this effect is likely selection rather than treatment.

Accordingly, we extend this work by employing a broader data set over a longer time frame, which better allows capturing true treatment effects. Further, we look at firm behavior (R&D spending), so we can determine at least, in part, what drives the performance difference. Finally, we have

CEO compensation data, so we can examine the extent to which firm innovative behavior under each type of CEO is affected by CEO incentives.

4 | THE OUTSIDE CEO HYPOTHESIS

In order for innovation to increase firm value, CEOs must invest optimally in R&D while maintaining or increasing the productivity of that investment. Although this is challenging for any investment, it is extraordinarily difficult for R&D because its outcomes are inherently stochastic. As one characterization of that, Stevens and Burley (1997) estimated it takes 125 funded R&D projects to achieve one commercial success. Accordingly, it seems plausible that managing a company that relies on R&D for growth (note that this includes many firms not typically thought of as technology companies, such as toys, foods, and consumer package goods) requires expertise regarding how the firm's R&D drives growth in its specific context.

If this argument is correct, outside CEOs are more likely to be detrimental to R&D than CEOs promoted from within the firm. Note, however, that his does not necessarily mean that the choice of an outside CEO is an irrational decision by the board of directors, nor does it mean that outside CEOs will degrade *overall* firm performance. As discussed in the previous section, firms may prefer outside CEO candidates for their expertise in areas other than technology, such as marketing, general managerial skills (e.g., prior CEO experience), or simply that no viable candidates exist within the company. Thus, we expect to find a negative relationship between outside CEOs and innovation, but are agnostic about the implications for other dimensions of performance.

Moreover, because technological domain expertise varies with the degree of "outsideness," we believe the effect of outside CEOs will become more pronounced as the CEO's prior industry becomes more distant from that of the new firm.

This argument that companies that rely on R&D for growth require CEOs with domain expertise follows the views in Harris and Helfat (1997) as well as Feldman and Montgomery (2015) that compensation is subordinate to ability in driving firm performance. In the case of R&D, in-depth knowledge allows the CEO to (a) grasp the potential for R&D to shape future opportunities for the firm, (b) make better informed resource allocation decisions, and (c) develop an intuitive understanding of how R&D practices affect R&D productivity.

A plausible counterargument to ours is that CEOs don't matter—perhaps because they hire CTOs to manage R&D for them. Of course, if CEOs don't matter, then (a) in equilibrium, firms wouldn't have them; or (b) CEOs wouldn't enjoy their 262% wage premium over the next four most highly paid executives in their firm as shown in an unreported analysis of Execucomp salary data.

To reinforce the argument that CEOs do affect R&D capability, it is perhaps useful to illustrate what actions outside CEOs take that can degrade that capability. Perhaps the best account comes from Hughes Aircraft Company in 1992 when it hired its first outside CEO, C. Michael Armstrong, following its acquisition by General Motors. Armstrong came to Hughes from IBM, where he had been head of IBM World Trade. Thus, in addition to being from outside the company, Armstrong was also from outside the industry. Further, his education (BS in business economics), represented a marked contrast to Hughes' prior CEOs who held PhDs in science and engineering, and had worked most of their careers at Hughes.

Until Armstrong's tenure, Hughes had been the pre-eminent defense electronics firm, generating new-to-the-world technologies like communications satellites. As an illustration of how advanced the company was, when asked why he chose Hughes versus a competitor, one customer replied "I

go to Hughes when I don't know what I want. Once you help me discover that, I go to the other guys because they can build it more cheaply."

The two most significant changes affecting R&D after Armstrong was appointed CEO were in project selection methodology and organizational structure. Looking first at project selection, prior to Armstrong's appointment, R&D proposals comprised one-page summaries of the challenges prompting the need for the project, the doors the project would open, and the resources the project would require. These proposals were deliberated by senior management (almost all of whom were themselves scientists and engineers) as everyone waited for the proverbial white smoke to appear. There was no need to quantify the financial returns to projects because the company ethos was "do the right thing and profits will follow."

Once Armstrong became CEO, he required R&D proposals to include return-on-investment (ROI) estimates. Since the majority of these projects involved basic and applied research, they were a decade or more away from commercialization and subject to unforecastable uncertainty. Accordingly, there was no meaningful ROI estimate. As an example, one proposal estimated ROI to be 2,047%.

The second significant change under Armstrong was decentralizing R&D at Hughes Research Labs (HRL). HRL conducted basic research broadly applicable to Hughes' businesses. Until his tenure, less than 5% of HRL's internal funding came directly from sectors (business units). This occurred when work at HRL was necessary to support sectors' contracts or sectors' internal R&D projects. After his appointment, Armstrong established a goal that 50% of HRL's funding should come from sectors (a 10× increase).

One concern with sector direction of funds was that because HRL's research had longer time horizons, HRL should be advising sectors on what was important rather than the other way around. A related concern was that being a world-class lab (necessary to attract top research talent) required that HRL maintain the longer horizons rather than shift toward the shorter horizons of sectors. This concern was even shared by some managers within the sectors. One sector manager explained that HRL provided two valuable services that might be compromised by giving control to sectors: It kept tabs on broader technology and it advanced new technologies. To illustrate his concern, he referred to one lab manager at HRL who had not gotten enough of his tasks funded by sectors. The lab manager was given discretionary funds for those tasks for one year, but was told it was not going to happen every year—"if there is no sector interest, maybe HRL shouldn't be doing these tasks." The sector manager commented, "Maybe HRL *should* be doing those tasks. Maybe they should be doing *exactly* those things no one at the sectors knows are needed."

Unfortunately, the combined impact of these changes was more dramatic than merely declining R&D productivity. Within 10 years of Armstrong's appointment, GM had completely sold off Hughes Aircraft Company in pieces (the military businesses for $9.5 billion to Raytheon in 1997, the satellite business for $3.75 billion to Boeing in 2000, and the DirectTV business for $26 billion to EchoStar in 2001), so the pre-eminent defense electronics firm no longer exists.

While the Hughes story offers rich detail, similar stories were relayed during the interviews motivating the Outside CEO hypothesis. In one account, the new CEO immediately cut R&D 20%, but the long-run consequence was that "R&D was no longer connected to top-level strategy. Rather it was a series of one-off projects." In another account, the new CEO shifted the nexus of R&D from centralized control to business-unit control, so the company "no longer did fundamental R&D." In a third account, "Historically the CEO didn't pay attention to what we spent [on R&D]. Projects were defined on their own merit. Typically entrepreneurial—go give it a try. Since the new CEO, we have more formal budgets and as a result, R&D has been cut." Finally, in a fourth account, the company

went from an old regime of "Give [the central R&D lab] $[confidential amount], and they'll figure out what to do with it" to a new regime in which the "business units tell [the central lab] what to do. We can only get money where we can demonstrate value. So we're mostly 'keeping wheels on the bus'. Now we don't have answers when the business units want them."

While the identity of the interviewed firms is confidential, it is easy to find similar examples from publicly available accounts in other firms. Figure 3 shows the R&D intensity and R&D productivity (measured as RQ) histories for three such firms: GE under Jack Welch, Trimble Navigation under Steve Berglund, and IBM under Lou Gerstner. In all three cases, there was a decline in R&D followed by a decline in RQ.

We also know some details about how the R&D strategy changed in these cases: GE shifted to a market power strategy of divesting businesses in which they were neither number one or two in their markets (televisions, semiconductors, and aerospace) and expanding into businesses that didn't rely on R&D (NBC, GE Capital); Trimble shifted from a strategy of developing its own technology to one of acquiring other firms for their technology; and IBM shifted to a strategy of reducing R&D and exploiting the existing stock of innovations by patenting (increasing patents almost 500%) and licensing them, and/or using them as chips to gain access to other firms' technology (Bhaskarabhatla & Hegde, 2014). In all three cases, the company's market value increased dramatically as it mined the value of knowledge from prior R&D investment, but it later decayed because it had depleted the stock of that knowledge.

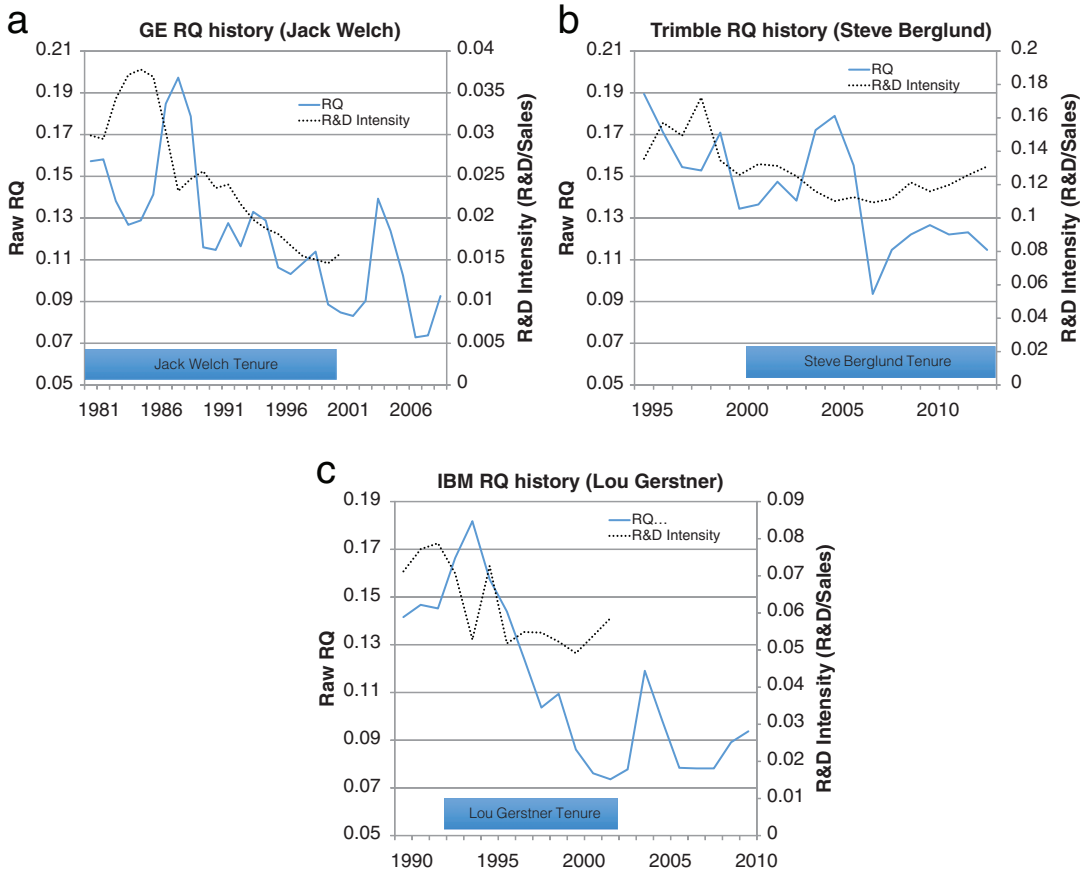

FIGURE 3 RQ and R&D intensity of GE, trimble natigation, and IBM

5 | EMPIRICAL APPROACH

While the above stories provide motivation and anecdotal support for the Outside CEO hypothesis, our goal is to determine if it holds under large-scale quantitative analysis. Our empirical approach begins with simple fixed-effects regressions of the relationship between outside CEOs and RQ. We next address potential endogeneity concerns through both placebo models and propensity-score matching models. Given empirical support for the CEO hypothesis, we then examine the extent to which the outside CEO effect is correlated with proxies for technological domain expertise (our underlying assumption about why CEOs might degrade R&D capability). We then conduct a robustness check of the main results, in which we replace RQ with an alternative measure of innovation, patents. Finally, we analyze firm R&D spending behavior under inside versus outside CEOs as well as how that spending behavior is affected by CEO long-term incentive compensation.

5.1 | Empirical model and variables

Our main test of the CEO hypothesis (Equation (1)) models firm R&D productivity (RQ) as a function of CEO type using a firm-fixed effects specification:

$$RQ_{it} = \beta_1 (Outside\ CEO)_{it} + \beta_2 (Log\_Size)_{it} + \beta_3 (CEO\_Controls)_{it} + \eta_i + \lambda_t + \varepsilon_{it}. \quad (1)$$

We model RQ of firm *i* in fiscal year *t* (RQ_{it}) as a function of *Outside CEO* (a dummy that takes the value 1 if the CEO was appointed from outside the firm), firm size measured as the log of assets and employees (*log(Assets)* and *log(Employees)*), and a set of *CEO Controls.* We include firm-fixed effects (η) as well as year effects (λ), and cluster standard errors by firm.

RQ (short for research quotient) is the *firm-specific output elasticity of R&D*—the exponent γ_i in firm i's production function (Equation (2)) (Knott, 2008). The way to interpret RQ is that it is the percentage increase in revenues from a 1% increase in R&D when other inputs and their elasticities are held constant. Accordingly, RQ is the firm-level equivalent of the most common means used by economists to measure industry-wide returns to R&D (Hall, 1993; Hall, Mairesse, & Mohnen, 2010).

$$Output = Capital^{\alpha_i} * Labor^{\beta_i} * R\&D^{\gamma_i} * Spillovers^{\delta_i} * Advertising^{\phi_i} \quad (2)$$

RQ is estimated with a random coefficients model using successive seven-year windows of firm financial data. This estimation process and its robustness checks are described in the user manual for the WRDS RQ database,[3] where we obtained the RQ data for our empirics.

We choose RQ as our primary measure of innovative output because it offers three advantages over patent-based measures. First, it is *universal*—it can be estimated for all firms that conduct R&D. In contrast, fewer than 50% of firms who conduct R&D patent their innovations (Cooper, Knott, & Yang, 2018). Second, RQ is *uniform*—it essentially compares dollars of output to dollars of input, thus it is unitless. In contrast, patents have highly variable value—10% of patents account for 85% of the economic value of all patents (Scherer & Harhoff, 2000). Finally, RQ is *reliable* in that empirical tests over 47 years of data indicate its behavior matches propositions from firm-level models of endogenous growth: R&D spending, growth, and market value all increase significantly with RQ (Knott & Vieregger, 2018). In contrast, two of the three propositions fail to hold when using patent

[3]WRDS RQ database. This 13-page manual describes the theory underpinning RQ, 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.

intensity as the proxy for R&D productivity and one fails to hold when using TFP as the proxy for R&D productivity. Beyond the implications of these results for the reliability of the RQ measure, they also imply RQ is better aligned with practice. This is because market value (which is correlated with RQ) is the principle measure CEOs attempt to maximize in forming firm strategy.

The fact that RQ is estimated using a seven-year window data has implications for our empirics. In particular, it implies that the impact of a CEO's R&D decisions in a given year will be gradually incorporated in the firm's RQ over the next seven years. We attempt to capture that effect in Figure 4. If we treat t as the base year of a CEO, then the top bar in Figure 4 shows that RQ in year $t + 5$ will reflect two years of R&D decisions from the prior CEO and five years from the current CEO. Thus, the new CEO is only responsible for 71% of the firm's RQ in that year. It isn't until year $t + 7$ that the full impact of the new CEO's decisions is reflected in RQ. If we further assume there is a one-year lag between R&D decisions and innovative outcomes, then the full impact of those decisions won't be fully felt until year eight.

Given this gradual incorporation of the CEO's decisions in RQ over seven years, we sequentially examine RQ in each year from the base year through the eighth year. We expect to find that *Outside CEO* is increasingly negative and significant in explaining outcomes (RQ).

5.2 | Data

The main data for our empirics come from three sources within the Wharton Research Data Services (WRDS): Compustat, RQ, and Execucomp databases. The Compustat database is used for firms' financial data; the WRDS RQ database, for firms' research quotient (RQ); and the Execucomp database, for detailed executive work histories and personal characteristics. Executive biographies and other resources are used to supplement Execucomp when necessary.

Execucomp contains individually identifiable executive compensation and attribute data for the top five executives at each firm based on SEC requirements for such reporting at public firms. As the Execucomp database is only available from 1992 and on, this becomes the initial analysis year. Raw data from each data source was gathered from 1992 to 2013. All three data sources were merged in Stata using the combined gvkey-year that identifies each firm by year.

5.2.1 | Variables

As mentioned previously, the main explanatory variable, *Outside CEO*, takes the value 1 if the CEO has verifiable executive experience in an outside firm within two years of being hired as CEO at the new firm. This two-year window follows prior efforts to capture "heir apparent" CEOs hired from outside to groom them for CEO (Harris & Helfat, 1997).

Outside CEO was constructed from the Execucomp data set that lists the top five executive positions within the firm as well as an indicator for the CEO position. The variable was created by first sorting CEO gvkey-year to generate a dummy variable for CEO changes. Second, data was sorted by executive year to generate a dummy variable for firm change and a variable for tenure at the

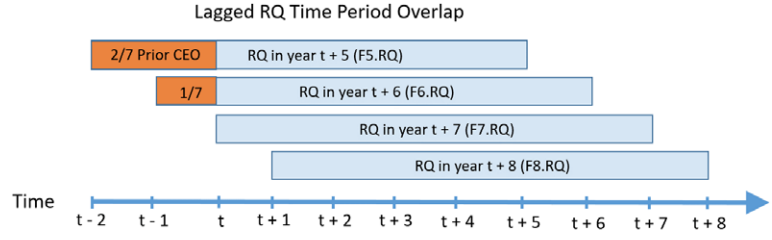

FIGURE 4 RQ and CEO base-year overlap

current firm as well as attributes of the previous firm. Third, after all non-CEO executives were removed from the sample, *Outside CEO* was generated for all new CEOs based on the *CEO Change* dummy variable and the new CEO's tenure at the firm (if <2).

Since Execucomp only provides information on the CEO's current employment, we had no background data on the first CEO for each firm, nor information for CEOs not previously among the top five executives at a public firm (637 total or approximately 15% of CEOs). To avoid deleting these observations, we manually collected CEO prior employment data via company press releases, company websites, and Bloomberg Executive Profiles.

This secondary investigation started with an executive biography search through Bloomberg Executive Biographies to determine the CEO's work history. If the executive did not have a Bloomberg Executive Biography, the company and executive histories were searched via the company website. Finally, in the few instances where neither were available, additional resources were consulted to generate the work history. The *Outside CEO* variable was manually coded from this information using the same methodology (tenure <2) as the automatically generated coding. Background information was found for all but a few executives. The *Interim CEO* dummy variable was generated when the new CEO was replaced the following year (with less than one full year in office).

We assessed the reliability of our coding by comparing our *Outside CEO* counts to those of Murphy and Zabojnik (2007). Our coding indicates that 30.0% of new CEOs appointed in 1992–2013 were outside CEOs. Murphy and Zabojnik reported 26% of new CEOs in the 1990s were outsiders as were 32.4% during the first half of the 2000s. We judge the comparison to be rough confirmation of our *Outside CEO* coding. Note that one difference between our coding and theirs is that Murphy and Zabojnik treated CEOs with missing background as insiders, whereas we conducted the secondary investigation of executive histories to determine the exact CEO background (which many times is not internal).

RQ, our primary dependent variable, is the firm-specific output elasticity of R&D and was gathered directly from the WRDS RQ database. In addition to the primary dependent and explanatory variables, we introduce a number of control variables in our full model. We employ three measures of firm size to control for the known relationship between firm scale and R&D spending: *Log (employees)*, our main control for scale, is the log value of full-time equivalent employees, measured in 1,000 employees (variable *emp* in Compustat). *Log(revenues)*, a secondary control for scale, is the log value of company revenues in million dollars (variable *revt* in Compustat). *Log(assets)*, a tertiary control for scale, is the log value of company assets in million dollars (variable *asset* Compustat). *Log(R&Dspending)*, our primary measure of firm innovation behavior, is the log value of company R&D spending in million dollars (variable *xrd* in Compustat). *CEO-Age* is a control for the tendency of CEOs to reduce R&D as they approach retirement (variable *age* in Execucomp). Lastly, *Interim_CEO*, is a control for CEOs that are appointed during the transition to a long-term CEO. The variable is set equal to 1 if the Execucomp *CEO flag* equals 1 for a single year.

In addition to these control variables, we include year effects and firm-fixed effects to control for macroeconomic variations across time and time invariant firm effects, respectively. Analysis was limited to firms that had R&D spending of $1M or greater in each firm year. R&D spending under this threshold creates volatility in estimating RQ. The resulting data set comprises 7,182 firm-year observations with RQ data as well as the required CEO and control variables. Execucomp was missing some values for *CEO Age*, *Prior CEO Experience*, and *CEO's Prior Firm RQ.* This limited observations requiring these variables to 6,935, 5,552, and 4,627 observations, respectively. These data are summarized in Table 1.

TABLE 1 Data descriptive statistics

Descriptive statistics Variable	Obs	Mean	Std. dev.	Min	Max
Outsider CEO	7,182	0.302	0.46	0	1
RQ	7,182	0.104	0.04	−0.13	0.64
CEO Total Tenure	7,182	7.114	3.82	1	20
Interim_CEO	7,182	0.043	0.20	0	1
log(Employees)	7,182	1.848	1.67	−5.30	6.29
log(Assets)	7,182	7.616	1.77	1.02	13.6
log(Revenue)	7,182	7.480	1.74	0.34	13.0
log(R&D Spending)	7,182	4.140	1.82	−4.42	9.41
CEO Age	6,935	54.46	6.46	35	81
Prior CEO Experience	5,552	0.063	0.24	0	1
CEO's Prior Firm RQ	4,627	0.104	0.05	−0.68	0.34
LT_Incentives	3,385	0.473	0.28	0	1

5.2.2 | Secondary databases

In addition to these primary data, we utilize data from two supplementary databases to support robustness checks. The first database includes long-term compensation because prior work has shown a link between long-term incentive compensation and innovation (Lerner & Wulf, 2007). *LT_Incentives* follows the Lerner and Wulf definition as the proportion of CEO pay that is stock options or restricted stock. *LT_Incentives* was generated from Execucomp data and is the computed percentage of executive's total compensation (*tdc1*) comprised by restricted stock (*rstkgrnt*) plus stock options grants (*option_awards_blk_value*). Use of *LT_Incentives* limits analysis to 3,385 firm-year observations.

The second supplementary database uses patent counts as an alternative measure of firm innovation. Patent counts were obtained from the NBER patent database that matches patents to firm gvkey. Because this data set ends in 2006 and only 50% of firms that conduct R&D patent their innovations (Cooper et al., 2018), this limits patent analysis to 2,617 firm-year observations.

6 | RESULTS

Table 2 presents results for our primary analysis of Equation (1). The table presents a separate model for each lag relative to the base year. As mentioned previously, this is to reflect a gradual incorporation of the CEO's impact over the seven-year RQ window.

The results are consistent with expectations under the Outside CEO hypothesis. RQ gradually decreases in years five through seven for firms with an outside CEO. Not only is the effect in year seven (F7.RQ) different from zero within a 95% confidence interval, it also is significant economically. The coefficients on *Outside CEO* are associated with nontrivial reductions in RQ for years six through eight of −2.9%, −7.3%, and −5.0%, respectively.

Endogeneity Issues

Our earlier discussion of the outside CEO literature makes it clear that firms choose outside CEOs in response to strategic considerations. Accordingly, the decline in RQ associated with outside CEOs may reflect these choices rather than being a true treatment effect. Ideally, we could identify

TABLE 2 Lagging base model correlation of outside CEO on RQ

	(1) RQ	(2) F.RQ	(3) F2.RQ	(4) F3.RQ	(5) F4.RQ	(6) F5.RQ	(7) F6.RQ	(8) F7.RQ	(9) F8.RQ
Outsider CEO	0.000423	0.000693	0.000095	0.000878	0.001211	−0.000281	−0.002835	−0.007652	−0.005416
	(0.0023)	(0.0024)	(0.0025)	(0.0029)	(0.0030)	(0.0032)	(0.0032)	(0.0029)	(0.0031)
log(Employees)	−0.014081	−0.011375	−0.007852	−0.007334	−0.000521	0.006766	0.005874	0.006765	0.004359
	(0.0041)	(0.0051)	(0.0035)	(0.0040)	(0.0042)	(0.0048)	(0.0044)	(0.0042)	(0.0039)
log(Assets)	0.009562	0.007897	0.006518	0.005656	0.000248	−0.008225	−0.012483	−0.013886	−0.009931
	(0.0038)	(0.0042)	(0.0033)	(0.0030)	(0.0028)	(0.0038)	(0.0042)	(0.0041)	(0.0034)
CEO Age	−0.000053	−0.000036	−0.000106	−0.000148	−0.000175	−0.000093	−0.000109	0.000018	−0.000096
	(0.0001)	(0.0001)	(0.0001)	(0.0001)	(0.0001)	(0.0001)	(0.0001)	(0.0002)	(0.0002)
Interim CEO	−0.000574	−0.005697	−0.007078	−0.008671	−0.006909	−0.003609	0.007800	0.003498	0.010819
	(0.0026)	(0.0032)	(0.0041)	(0.0039)	(0.0038)	(0.0032)	(0.0075)	(0.0044)	(0.0054)
N	6,874	6,079	5,419	4,784	4,184	3,632	3,113	2,657	2,261

Note. All models with year and firm-fixed effects; standard errors clustered by firm and in parenthesis.

a natural experiment in which CEOs are randomly assigned to firms to ensure that results capture a true treatment effect for outside CEOs. While no such experiment is feasible, we undertake a number of efforts to mitigate endogeneity concerns.

Placebo test

We know from the literature that one reason firms hire outside CEOs is to reverse poor performance. If that performance includes low RQ, then the lower RQ associated with *Outside CEO* might reflect reverse causality. Our earlier results in Table 2 suggest this is unlikely—there was no evidence the RQ of *outside CEOs* differed from that of inside CEOs during the first four years of their tenure. Nevertheless, we investigate that possibility more formally through a leading model of firm RQ (Table 3), which expands results from Table 2 to include the three years leading up to the new CEO. The table and corresponding Figure 5 show no difference between the RQ of firms hiring *outside CEOs* versus inside CEOs for the three years leading up to the hire and the first four years subsequent to that. Thus, there appears to be no evidence that firms hiring outside CEOs have an inherently lower RQ than those promoting their CEO from within the firm.

Propensity-score matching model

Beyond RQ, there are potentially other firm characteristics that might jointly increase the probability of hiring an outside *CEO* and degrade future R&D capability. We examine that possibility through a propensity-score matching model (Rosenbaum & Rubin, 1983), which compares treated firms (*outside CEOs*) and control firms (inside CEOs) that are similar in their propensity for treatment. Propensity-score matching models yield unbiased estimates, assuming the variables matched in the model account for all treatment propensity.

The model we employ matches on all available firm characteristics capturing the antecedents of hiring *outside CEO*s discussed in Section 3. These include net income (the need to correct poor performance), firm growth (lack of internal candidates), firm size (lack of internal candidates), and R&D spending (need for domain expertise). We employ single nearest-neighbor matching models with caliper limits of 0.10. Caliper limits of this magnitude have been shown to reasonably limit biases that can result from inexact matching (Austin, 2011).

The results in Table 4 (and corresponding Figure 6) for the propensity-score matching model are consistent with the main empirical results (Table 2) that RQ declines in firms employing outside CEOs relative to firms employing inside CEOs. Accordingly, the negative coefficient of *Outside CEO* in Table 2 persists when controlling for these known antecedents of hiring outside CEOs.

In further endogeneity checks (available from the authors), we created a matching model on CEO characteristics that might cause them to switch firms and again obtained results qualitatively similar to the primary results in Table 2.

Is the outside CEO effect correlated with expertise?

Underpinning the Outside CEO hypothesis is an assumption that the lower RQ of firms with outside CEOs stems from the CEO's lack of technological domain expertise. We now examine the plausibility of that assumption. In particular, we restrict attention to the subsample of firms with outside CEOs and examine the extent to which proxies for their expertise are correlated with RQ. The proxies for which we had data include prior managerial and R&D experience, prior firm RQ as well as the technical proximity (captured by industry SIC) of the CEO's prior industry. These measures are likely to be correlated with expertise because technologies across firms and industries can differ substantially as can the expertise gained from work experience across firms. If lack of expertise is

TABLE 3 Placebo test: Full lead and lag models

	(1) L3.RQ	(2) L2.RQ	(3) L.RQ	(4) RQ	(5) F.RQ	(6) F2.RQ	(7) F3.RQ	(8) F4.RQ	(9) F5.RQ	(10) F6.RQ	(11) F7.RQ	(12) F8.RQ
Outsider CEO	0.002046	0.000350	0.000379	0.000423	0.000693	0.000095	0.000878	0.001211	−0.000281	−0.002835	−0.007652	−0.005416
	(0.0023)	(0.0022)	(0.0024)	(0.0023)	(0.0024)	(0.0025)	(0.0029)	(0.0030)	(0.0032)	(0.0032)	(0.0029)	(0.0031)
log(Employees)	−0.006717	−0.005479	−0.007688	−0.014081	−0.011375	−0.007852	−0.007334	−0.000521	0.006766	0.005874	0.006765	0.004359
	(0.0044)	(0.0040)	(0.0041)	(0.0041)	(0.0051)	(0.0035)	(0.0040)	(0.0042)	(0.0048)	(0.0044)	(0.0042)	(0.0039)
log(Assets)	0.004487	0.004014	0.005011	0.009562	0.007897	0.006518	0.005656	0.000248	−0.008225	−0.012483	−0.013886	−0.009931
	(0.0047)	(0.0043)	(0.0043)	(0.0038)	(0.0042)	(0.0033)	(0.0030)	(0.0028)	(0.0038)	(0.0042)	(0.0041)	(0.0034)
CEO Age	0.000050	−0.000016	−0.000002	−0.000053	−0.000036	−0.000106	−0.000148	−0.000175	−0.000093	−0.000109	0.000018	−0.000096
	(0.0002)	(0.0002)	(0.0001)	(0.0001)	(0.0001)	(0.0001)	(0.0001)	(0.0001)	(0.0001)	(0.0001)	(0.0002)	(0.0002)
Interim CEO	0.006805	0.008485	0.002378	−0.000574	−0.005697	−0.007078	−0.008671	−0.006909	−0.003609	0.007800	0.003498	0.010819
	(0.0037)	(0.0036)	(0.0030)	(0.0026)	(0.0032)	(0.0041)	(0.0039)	(0.0038)	(0.0032)	(0.0075)	(0.0044)	(0.0054)
N	4,726	5,399	6,076	6,874	6,079	5,419	4,784	4,184	3,632	3,113	2,657	2,261

Note. All models with year and firm-fixed effects; standard errors clustered by firm and in parenthesis.

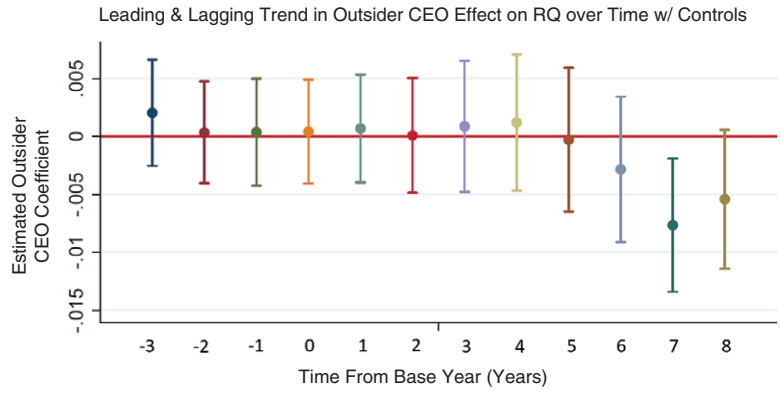

FIGURE 5 Placebo test: Full lead and lag models plot

driving the lower RQ of firms with outside CEOs, we expect to find that having prior managerial and R&D experience, and being from an industry closer to that of the new firm, should decrease the RQ penalty associated with firms having outside CEOs.

Table 5 reveals that the RQ of firms with outside CEOs increases with each form of CEO expertise other than raw work experience (CEO age). First, RQ increases with the CEO's prior CEO experience. This is consistent with the intuition that general managerial skills *do* play a part in R&D productivity. However, only about 20% of outside CEOs have such experience. Second, the new firm's RQ increases with the RQ of the CEO's prior firm. Thus, CEOs may gain general innovation expertise with respect to structuring and managing R&D. Third, RQ decreases as the CEOs prior domain becomes more distant from the current firm. In particular, RQ decreases as the prior experience moves outside the new firm's three-digit industry, two-digit industry, and ultimately, one-digit industry. While this analysis is correlational rather than causal, it is consistent with the assumption underlying the Outside CEO hypothesis that the lower RQ of firms with outside CEOs stems from lack of expertise.

Robustness tests

While endogeneity is perhaps the greatest concern in interpreting the results in Table 2 as a true treatment effect, we also conduct additional robustness checks. Our first check explores if the *Outside CEO* effect is consistent across firm types. In particular, we examine if results differ across firm size and R&D intensity through subsample analyses in which we split the sample by median size or by median R&D intensity.

Looking first at firm size, results in Table 6 indicate that while *Outside CEO* has a slightly larger negative coefficient in large firms (Column 1), it is not different from that of small firms (Column 2) (within a 95% confidence interval). Looking next at firm R&D intensity, we obtain a different result. The negative coefficient on *Outside CEO* is substantially higher in firms with high R&D intensity than those with low R&D intensity. This latter result provides additional circumstantial evidence that the outside CEO effect is driven by lack of domain expertise—R&D expertise is likely to matter most in firms that rely more heavily on R&D.

As a final robustness check of our main result, we retest Equation (1) utilizing patent counts in lieu of RQ as the dependent variable. This is intended to demonstrate that results are robust to choice of innovation measure. The measure counts the number of patents ultimately granted and matched to the CEO-firm-year in the year of application. Because patent counts are truncated at zero, we implement a negative binomial incidence rate ratio model with firm-fixed effects.[4]

TABLE 4 Matching model on firm characteristics

	(1) RQ	(2) F.RQ	(3) F2.RQ	(4) F3.RQ	(5) F4.RQ	(6) F5.RQ	(7) F6.RQ	(8) F7.RQ	(9) F8.RQ
Outsider CEO	−0.000346	−0.001856	−0.001596	−0.002769	−0.003660	−0.004387	−0.004765	−0.009109	−0.007414
	(0.001)	(0.001)	(0.001)	(0.001)	(0.002)	(0.002)	(0.002)	(0.002)	(0.002)
N Observations	7,165	5,498	5,480	4,732	4,098	3,529	3,003	2,535	2,122
N Treated	2,152	1,817	1,547	1,315	1,110	924	765	631	513
N Unique Matches	1,545	1,341	1,167	960	842	686	607	485	397

Notes. Average treatement effect from single nearest neighbor propensity-score matching. Matched on: firm size (revenue), net income, R&D spending, and growth (two-year revenue growth).

Table 7 reveals the number of patents is lower in firms with outside CEOs (Column 1). The magnitude of this decrease, 7.7%, is qualitatively similar to the decrease in RQ from Table 2, though it is not significant within a 95% confidence interval because of the smaller sample size (fewer than 50% of firms patent their R&D).

In additional tests available from the authors, we investigate other sample construction explanations for the main result that RQ decreases in firms with outside CEOs. Those results indicate that segmenting by industry, removing subsequent *Outside CEOs*, increasing the CEO tenure restrictions, and limiting analysis to the first year of the *Outside CEO* do not materially affect the results (other than increasing the standard error due to decreased sample sizes).

Does the behavior of firms with outside CEOs differ?

Given that the lower RQ of firms with outside CEOs appears to be a true treatment effect, the next question is the nature of that treatment: What do firms with outside CEOs do differently that might lead to lower RQ? Our interviews revealed some insights in that regard. In particular, they identified reducing R&D, managing R&D financially (using ROI) rather than strategically, and decentralizing decision-making (which creates a tendency toward short-termism) as actions new CEOs take that materially affected the nature of R&D. Unfortunately, the only behavior for which data is publicly available is R&D spending, so we examine that next.

Results for analysis of that behavior are presented in Table 8. The results reveal that the R&D spending of firms with outside CEOs does not substantially differ from firms with inside CEOs within a 95% confidence interval.

We next investigate whether that behavior is correlated with incentives. In doing so, we first attempt to replicate the stylized fact that CEO incentive compensation is associated with increased R&D spending (Dechow & Sloan, 1991; Lerner & Wulf, 2007). The results in Column 1 of Table 9 (which pools firms with inside and outside CEOs) are consistent with that. Firms in which CEO compensation is more closely tied to the long-term performance of the firm have higher R&D investment in the base year.

We then examine whether results for incentive compensation are affected by CEO type by comparing outside (Column 2) and inside (Column 3) CEO subsamples. Column 2 (for the inside CEO subsample) matches those in Column 1. Firms with inside CEOs and long-term incentive compensation have higher R&D investment. In contrast, Column 3 indicates that in firms with outside CEOs, there is little relationship between incentive compensation and R&D investment. Thus, the stylized

[4]In results available from the authors, we also test a model with mean patent citations. The results show no significant difference between insiders and outsiders.

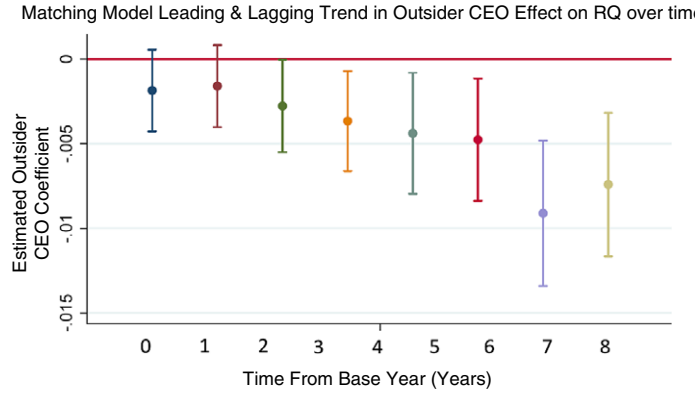

FIGURE 6 Matching model on firm characteristics plot

TABLE 5 Outside CEO subsample analysis

	(1) F7.RQ
Prior CEO Experience	0.024053
	(0.0092)
Prior Firm's RQ	0.237981
	(0.1320)
Outside1DigitSIC	−0.032007
	(0.0144)
Outside2DigitSIC	−0.000883
	(0.0160)
Outside3DigitSIC	−0.001853
	(0.0255)
Outside4DigitSIC	0.016681
	(0.0221)
CEO Tenure	0.003295
	(0.0014)
CEO's Age	−0.001563
	(0.0007)
Interim CEO	0.033555
	(0.0187)
log(Employees)	−0.007457
	(0.0062)
log(Assets)	0.002576
	(0.0062)
N	227

Note. Models with year and random effects

fact from the prior literature that long-term compensation increases R&D investment seems to stem from the fact the majority of firms have inside CEOs. Note that these results hold when using patents as the measure of behavior (Table 7, Models 2 and 3). In fact, long-term incentives decrease patents in firms with outside CEOs (though not significantly when using a 95% confidence interval).

TABLE 6 Subsample analysis: Size and R&D intensity

	(1) F7.RQ	(2) F7.RQ	(3) F7.RQ	(4) F7.RQ
Outsider CEO	−0.009528	−0.007516	−0.012736	−0.002077
	(0.0050)	(0.0029)	(0.0047)	(0.0034)
log(Employees)	0.014059	0.002676	0.008649	0.001358
	(0.0072)	(0.0057)	(0.0054)	(0.0064)
log(Assets)	−0.017846	−0.009205	−0.013847	−0.013039
	(0.0054)	(0.0068)	(0.0053)	(0.0064)
CEO Age	−0.000059	−0.000081	−0.000003	−0.000071
	(0.0003)	(0.0001)	(0.0002)	(0.0003)
Interim CEO	0.001061	0.004990	0.008005	−0.006644
	(0.0068)	(0.0060)	(0.0052)	(0.0057)
N	1,357	1,300	1,388	1,269
	Large Size	Small Size	High R&D Intensity	Low R&D Intensity

Notes. All models with year and firm-fixed effects. Standard errors in parenthesis.

TABLE 7 Correlation of outside CEOs and incentives on patent count

	(1) Patent Count Negative Binomial All CEOs	(2) Patent Count Negative Binomial Outside CEOs	(3) Patent Count Negative Binomial Inside CEOs
Outsider CEO	−0.077101		
	(0.046)		
Long-term Compensation %		−0.012854	0.092346
		(0.071)	(0.060)
Log of Firm Revenue	0.050418	0.219879	0.030816
	(0.020)	(0.049)	(0.023)
CEO Age	−0.000517		
	(0.003)		
N	2,617	678	2012

Notes. All models with year and firm-fixed effects. Standard errors in parenthesis.

This result that firms with inside versus outside CEOs differ in their response to incentive compensation is new. It suggests that CEOs with greater domain expertise might attempt to increase the firm's market value by increasing R&D, while outside CEOs who lack that expertise, might attempt to increase market value in other ways. Note that this is purely speculative. It is also possible that other elements of compensation that are correlated with long-term compensation are driving the differences in R&D behavior (spending or patents) between firms with inside versus outside CEOs.

Summarizing our empirical results, we find first that RQ declines in firms with outside CEOs. Second, the lower RQ of outside CEOs is correlated with proxies for domain expertise. Third and relatedly, the lower RQ of firms with outside CEOs disproportionately affects those that depend more heavily on R&D. Fourth, while there is no significant difference in R&D spending between firms with inside and outside CEOs ignoring compensation, the two types of firms respond differently to long-term incentive compensation. In particular, firms with inside CEOs increase R&D and patenting in the presence of long-term incentive compensation while firms with outside CEOs do not.

7 | COMPENSATION CONTRACT IMPLICATIONS

So far, we have argued that the outside CEO effect is driven by lack of domain expertise. In this view, the ability to identify technological opportunities, to correctly value their returns, and to organize and manage R&D requires deep experience with the firm's technology. On average, insiders are more likely to possess domain expertise than outside CEOs. Note, however, that some outsiders might have such expertise if, for example, they came from a closely related industry (as evidenced by the results in Table 5). Conversely, not all insiders possess domain expertise. For example, CEOs from accounting, human resources, or legal functions are unlikely to possess technological domain expertise even if their entire professional experience has been within the same firm.

Accordingly, for firms that rely on R&D, a simple decision rule of only promoting CEOs from inside the firm is ill-advised. Not only is an insider rule a poor proxy for domain expertise, its use prevents firms from utilizing the other advantages of outside CEOs discussed in Section 3. Rather, what firms need is a means to identify domain expertise ex ante so they can simultaneously enjoy the other advantages of outside CEOs while also satisfying their innovation goals. We now interpret our results in that light.

Our result that firms with outside CEOs and inside CEOs respond differently to CEO incentive compensation suggests there may be an ex post separating equilibrium in which CEOs with domain expertise increase R&D while CEOs lacking domain expertise do not. What's nice about this separating equilibrium, if it exists, is that it implies CEOs know their type (whether they have the ability to increase market value through R&D) even if their type isn't observable by the board.

While the possibility that CEOs know their type may be beneficial in generating optimal behavior ex post, what is more promising about that possibility is that boards may be able to exploit it in ex ante selection. In particular, boards may be able to devise a separating contract that attracts CEOs with domain expertise while dissuading CEOs that lack such expertise. One possibility is a "high delta contract." Delta is a measure of the sensitivity of CEO wealth to changes in the firm's stock price. Since R&D is more stochastic than other investments, high delta contracts should screen out CEOs lacking domain expertise because the costs of experimenting with insufficient expertise and being wrong under these contracts are too high relative to contracts with alternative compensation structures. Thus, as long as there are firms that grow through innovation and offer compensation tied to delta as well as firms that grow through other means and offer conventional incentive compensation, CEOs with domain expertise should choose the former firms, and CEOs with more generalized ability should choose the latter firms.

TABLE 8 Correlation of outside CEOs and R&D spending

	(1) Log(RDSpend)	(2) F1.Log(RDSpend)
Outsider CEO	0.011890	0.012079
	(0.016)	(0.015)
log(Revenue)	0.684698	0.793510
	(0.013)	(0.013)
Interim CEO	0.053646	0.014787
	(0.025)	(0.030)
N	7,117	6,318

Note. All models with year and firm-fixed effects.

TABLE 9 Correlation of long-term incentives and R&D spending

	(1) Log(RDSpend)	(2) Log(RDSpend)	(3) Log(RDSpend)
Long-term Incentive Compensation	0.071824	0.043473	0.081036
	(0.027)	(0.051)	(0.033)
log(Revenue)	0.610030	0.511901	0.566055
	(0.023)	(0.049)	(0.029)
N	3,196	886	2,310
		Outside Only	Inside Only

Note. All models with year and firm-fixed effects.

Preliminary analysis (available from the authors) indicates that high delta contracts may already achieve some degree of sorting. In particular, the average level of delta is significantly lower for outside CEOs than internal CEOs. Note that an alternative interpretation of the sorting is that incoming CEOs play a role in designing their compensation, and outside CEOs are pushing compensation away from high delta contracts. Futher, since delta contracts have been used elsewhere to capture risk-seeking, an additional interpretation is that outside CEOs are more risk averse.

8 | SUMMARY

We proposed that the 65% decline in firms' R&D productivity (RQ) might stem, at least in part, from the increased prevalence of outside CEOs. The underlying assumption behind this Outside CEO hypothesis is that outside CEOs lack technological domain expertise to effectively manage the firm's R&D. Our results are consistent with the hypothesis. We find that firms who hire outside CEOs experience a 5–7% decline in RQ relative to firms hiring an inside CEO. Moreover, the decline becomes more pronounced as the CEO's prior experience deviates more from the new role and when the new firm is more heavily dependent on innovation (higher R&D intensity).

Investigating how firms with outside CEOs behave differently relative to firms with inside CEOs, we find they differ in R&D investment. In particular, while firms with inside CEOs increase R&D investment in the presence of long-term incentives, firms with outside CEOs do not. This differential response to incentive compensation suggests CEOs may know their type (whether they have sufficient expertise to drive growth through R&D). Thus, there may be contracts that sort potential CEOs ex ante on this unobservable expertise.

Taken together, the results suggest that firms with inside CEOs are better at managing innovation because the CEOs are more likely to have the requisite domain expertise to drive growth from R&D. This expertise seems to manifest itself in at least one dimension of behavior (greater R&D investment in response to long-term incentive compensation). CTO interviews indicate it likely manifests itself in other ways as well, though we have no data to test these other behaviors.

There are limitations to these results. First, our primary analysis treated all outside CEOs the same. Subsequent results suggest that CEOs from outside the firm but within the same industry may have the necessary domain expertise. Furthermore, not all inside CEOs have or exploit their expertise. Thus, domain expertise may be a necessary, but not a sufficient condition for productive innovation. Second, our analysis was limited to the CEO position, ignoring the rest of the TMT. While it is highly likely the TMT (most notably the CTO) will affect innovation, the team composition is typically chosen by the CEO. Thus, it an extension of ways in which the CEO can affect innovation.

An interesting follow-on study could analyze how TMTs of outside CEOs differ from those of inside CEOs.

One prescriptive caution in our results is that an *outside CEO* is a coarse proxy for domain expertise. Therefore, a board strategy of avoiding outside CEOs is ill-advised. Outside CEOs may provide benefits that offset any disadvantages related to innovation. Our main prescription is that firms that rely on R&D for growth need a more informative means for selecting CEOs on their domain expertise ex ante and managing them conditional on that expertise ex post. We provide suggestive evidence that a high delta contract might accomplish both.

Our results that CEO characteristics (in this case, outsider/insider) affect the firm's innovative behavior are consistent with prior results regarding other CEO characteristics such as overconfidence (Galasso & Simcoe, 2011; Hirshleifer et al., 2012). In addition, our results resonate with prior work showing that other forms of CEO expertise affect firm performance (Feldman & Montgomery, 2015; Harris & Helfat, 1997).

The main academic contribution of our study is setting forward and testing the Outside CEO hypothesis as one possible explanation for the 65% decline in RQ. The main practical implication of our study is that R&D-intensive firms may be able to reverse their RQ decline (and thereby increase their market value and contribute to restoring economic growth) by considering domain expertise when hiring CEOs.

Beyond these main contributions, we also offer insights for the literature we relied on for our study. First, for the dynamic managerial capabilities literature, this article adds empirical support that CEOs can affect the dynamic capabilities of the firm through transfer of managerial human capital (knowledge, education, experience, and skills) (Becker, 1964; Helfat & Martin, 2015; Kor & Mahoney, 2005). Our article introduces a new critical dimension of human capital—technological domain expertise. Second, for the governance literature, we refine the prior stylized fact that incentive compensation increases R&D. We find this holds only for firms with inside CEOs (those who presumably have domain expertise and know they have the requisite expertise to increase R&D profitably). Third, for the CEO and innovation literature, we identify two additional CEO characteristics potentially affecting innovation: CEO origin (hired from outside, versus promoted internally) and domain expertise. Fourth, and finally, for the literature on CEO succession, we introduce an additional dimension of performance on which outsiders may differ from insiders—innovation (both measured as RQ and as patent counts). We also open the black box of outsideness, showing that innovative performance decreases as the CEOs prior domain is more removed from the new domain.

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