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Executive influence on invention and commercialization: The moderating role of innovation radicalness

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Executive influence on invention and commercialization

The moderating role of innovation radicalness

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Abstract

Purpose – The purpose of this paper is to expand the understanding of the "front end" of innovation by examining the influence of top executives, who allocate the resources and cultivate the culture in which inventions are born, on the innovation process.
Design/methodology/approach – This paper suggests that the effect of executives on innovation can be better understood by explicitly separating innovation into the component processes of invention and commercialization. This allows us to consider how executive characteristics might have a different effect on technology development outcomes than they do on the subsequent transformation of those technologies into new products. The theory is tested on a sample of firms from the biomedical device industry.
Findings – The findings indicate that top management team (TMT) age and tenure have no effect on the type of technologies a firm develops (radical vs incremental) but do significantly affect the efficiency with which new technologies are turned into new products in some contexts. TMT heterogeneity affects both the type of technologies developed in the firm and also their transformation to new products. Interestingly, the effect of executives on commercialization depends on the type of underlying technologies which the firm has developed.
Originality/value – This paper contributes to the literatures on TMTs and innovation by offering a more granular explanation of how executives differentially impact the disaggregated stages of the innovation process, and thus also contributes to knowledge of the long-term innovation performance implications of executive leadership.

Keywords Innovation, Managerial discretion, Incremental, Top management teams, Radical, Commercialization, Invention

Paper type Research paper

Introduction

The development and introduction of innovations affect market share (Banbury and Mitchell, 1995), growth (Cho and Pucik, 2005), profitability (Roberts, 1999), organizational success (Ngo and O'Cass, 2013), and even the likelihood of a firm's survival (Bayus and Agarwal, 2007). Appropriately, the ability to innovate is seen as a critical determinant of performance for many companies (e.g. Bowen *et al.*, 2010). In extreme cases, innovation is the source of what Schumpeter (1950) referred to as "creative destruction," which leads to the downfall of entire industries and the general increase in economic output. Hence innovations lead to both creation of new markets as well as economic growth (Leifer *et al.*, 2000; Marvel and Lumpkin, 2007). Management scholars have rightfully devoted an enormous amount of

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work toward understanding underlying individual, firm, industry, and contextual factors affecting the likelihood of an organization being innovative (see Ahuja *et al.*, 2008 for an excellent review of the literature).

Ahuja *et al.* (2008) identify multiple roles that top management teams (TMTs) might play in influencing firm innovation. While top executives play an important role in shaping the attitudes and decision processes that define the organization and its strategic outcomes (Hambrick and Mason, 1984), they also act as resource allocators and gatekeepers who choose among alternate investments that might be pursued (Kickul and Gundry, 2001). Hence, TMT characteristics are seen to be critical factors that affect innovative efforts and outcomes such as the level of R&D spending (Balkin *et al.*, 2000) and the type of exploration undertaken (Alexiev *et al.*, 2010). Specifically, innovation is affected by TMT characteristics such as the age (Wu *et al.*, 2005) and tenure of the executive team (Bantel and Jackson, 1989), as well as executive incentives (Makri *et al.*, 2006).

However, Ahuja *et al.* (2008) also point out that a great deal remains unsettled despite the volume of work in this area. Central among those are contradictory empirical findings regarding whether and how particular TMT characteristics affect innovation, findings which point to unresolved gaps in our theoretical understanding of the phenomenon. For example, characteristics such as TMT age have been theorized and observed to have both positive and negative impacts on innovation within the organization. Older executives may be less high-tech savvy, suggesting that they might negatively influence innovation. However, they are also more experienced and likely have access to greater pools of resources, suggesting that they could positively influence innovation. These counter-indications strongly suggest that there are as-yet unidentified contextual factors that need to be understood theoretically and tested empirically in order to better understand the impact of TMTs on innovation. This understanding is important both from the perspective of building a full and robust body of theory around innovation and TMTs, as well as offering meaningful guidance to organizations that succeed or fail based on their ability to innovate.

We propose that contradictory theories and findings may be partially resolved by utilizing a more nuanced model of the innovation construct. While the extant literature tends to treat innovative efforts and innovative outcomes as one phenomenon (see Ahuja *et al.*, 2008), we suggest that deconstructing "innovation" into the component processes of "invention" and "commercialization" could be a fruitful path toward a deeper theoretical understanding. New technologies arise as the result of invention and are, in turn, developed into new products through a process of commercialization. Economically relevant innovation requires both processes to take place, and thinking about the model in this way opens new avenues for postulating how something like TMT characteristics might affect innovation as a whole.

Moreover, while it is reasonable to expect that TMTs do impact innovation within their organizations, it is critically important to better understand the factors that affect the size of that impact. While organizations tend to reflect the characteristics and mindsets of their top executives (Hambrick and Mason, 1984), there is also evidence that the degree to which such shaping occurs depends on characteristics of the organization and environment (Hambrick and Finkelstein, 1987). Some contexts offer executives the power and freedom to exert a significant influence over the behavior and outcomes of their organizations, while in other contexts the potential for executive influence is muted by limits on either their authority or their range of potential action. Although a number of external and internal factors have been proposed to affect managerial discretion (e.g. environmental munificence and dynamism, organizational size and slack, etc.), there is still work to be done in developing a better theoretical understanding of how the internal technological environment of a firm either enhances or impedes the influence exerted by top executives.

We contribute to these questions by first focusing on the front end of the innovation process to hypothesize how TMT characteristics affect the specific types of inventions that a firm is likely to produce. Combining logic from the upper echelons perspective and the creativity literature, we suggest that executive team characteristics such as age, tenure, and heterogeneity will affect how radically the firm innovates. Second, we look at how those same executive characteristics influence the efficiency with which a firm is able to convert new technologies into new products, essentially building a link between the front end of the invention and the economically critical process of commercialization. Third, we bring discretion theory to bear on the executive-innovation linkage to address factors that either limit or enhance the influence executives have on innovation. Contextual factors give some executives greater latitude of action while constraining others, leading to observed executive effects that differ systematically across contexts. We examine one particularly relevant factor that is likely to affect executive influence over commercialization of new ideas: the radicalness of those underlying inventions (Ahuja and Lampert, 2001).

Theory

The beginning point for our development is the deconstruction of the innovation process into its constituent elements of invention and commercialization. Innovation is of economic value only if it involves the implementation of a new idea that addresses an existing problem. From an industrial point of view, this can mean marketing a new product that meets a previously unfulfilled need or introducing a new production process that significantly reduces cost or increases quality. In either case, the idea that underlies the innovation would offer no direct contribution if it were simply conceived of and then discarded. For our purposes, the term "invention" refers to the creation of a potentially promising new idea, "commercialization" refers to the implementation of a new idea in a potentially valuable way, and "innovation" refers to the process which encompasses both of those constituent steps. It is important to note that innovation simply cannot happen in the absence of new ideas. If there are no new ideas, then there will be nothing to commercialize and consequently no economic advance. Given a certain body of new ideas, only some of them are likely to go on to be commercialized. However, if the pool of ideas is dry, then there will be no new products at all.

This definitional deconstruction of innovation into its component processes is certainly not a new idea. Referencing a discussion held at a 1970 meeting of the Industrial Research Institute (IRI), Roberts (1988, p. 12) says that "Innovation is composed of two parts: (1) the generation of an idea or invention, and (2) the conversion of that invention into a business or other useful application." Porter (1990) makes a similar distinction when stating that innovation is "a new way of doing things (termed an invention by some authors) that is commercialized" (p. 780). Freeman and Soete (1997) and Afuah (1998) also suggest that innovation is a multi-step process. However, the majority of studies on innovation has either treated the entire process as a single concept, or has studied one part or the other while referring to it as innovation. An example of this confounding is found in Datta *et al.* (2013). Although they focus on developing a "framework of commercialization" (p. 147), they write in terms of the "commercialization of innovation" and include discovery efforts such as R&D and creativity in their model of commercialization. Their work contributes to the conversation by explicitly recognizing commercialization as a distinct process, but at the same time blends it with what is more accurately referred to as "invention."

We suggest that distinctly separating and identifying the multiple constituent processes involved in innovation could yield better insights. Our goal here is to gain greater theoretical and empirical clarity by explicitly treating innovation as a multi-step process. We postulate that different management processes are at work and that top management characteristics may have differential impact on these two processes.

Using the two-part structure of innovation as the foundation, we begin developing hypotheses by recognizing that executives matter and that firms tend to become reflections of their top managers (Hambrick and Mason, 1984), an effect which seems to have gotten significantly stronger over time (Quigley and Hambrick, 2015). Managers make strategic and resource allocation decisions (Bantel and Jackson, 1989) that shape both firm behavior and subsequent results, they interact directly with employees in ways which can either facilitate or inhibit the generation and pursuit of new ideas (Mohan *et al.*, 2017), and their innovativeness can contribute directly to the innovation capabilities of their firms (Wang and Dass, 2017). The decisions managers make are influenced by their cognitive frames and decision-making biases (Tversky and Kahneman, 1974). For example, Tang *et al.* (2015) find a positive link between executive hubris and firm innovation. Given the difficulty associated with ascertaining the cognitive frames of TMTs directly, observable demographic characteristics are often used as imperfect proxies for those unobservable psychological constructs. Ahuja *et al.* (2008) identify age, organizational tenure, and team heterogeneity as characteristics that are linked to innovation in the firm. While these linkages have been studied before, the relationships are largely unsettled. Older managers may suffer from decreases in memory and the ability to learn, and may be both less technology-savvy and more risk-averse than younger counterparts (Vroom and Pahl, 1971; Bantel and Jackson, 1989; Burke and Light, 1981). This might point toward a negative relationship between managerial age and the innovation of firms under their control. However, countervailing arguments suggest that age is associated with experience, connections, and access to resources that may make older managers valuable as sources of inputs necessary for innovation (Nelson and Winter, 1982; Hambrick and Mason, 1984; Wu *et al.*, 2005).

A two-stage model of innovation that considers invention and commercialization separately allows us to reconcile some of the disparate views. It is possible that TMT characteristics affect front-end invention in one way, and subsequent conversion of those technologies to new products in another. Ahuja *et al.* (2008) suggest that perhaps executive characteristics such as age and organizational tenure have a bigger impact on the type of innovations undertaken, as follows:

> Older managers may be more interested in incremental and process innovations which are less risky and shorter term. Younger managers may, on the other hand, have greater incentives to invest in radical innovations which have a greater impact in the longer term. Unfortunately, this possibility has not yet been tested (p. 63).

As applied in our framework, younger managers might be more likely to encourage creation of more radical technologies. To the extent then that older managers are more risk-averse and less technology-savvy, we would expect older managers to be biased toward encouraging more incremental, less radical inventions. Inventions that represent relatively small improvements to existing products or processes will suffer from less demand uncertainty and will be easier to understand in the framework of knowledge about existing products and processes when compared to more radical departures. Hence we propose the following hypothesis:

H1a. The average age of the executive team will be negatively related to the radicalness of inventions.

On the other hand, the logic that positively relates executive age to experience, connections, and access to resources might be more relevant to subsequent commercialization of technologies that were developed at the front end. While the creation of a new idea is likely to take place at the level of individuals or small groups and can often be accomplished with little or no additional resources (Jewkes *et al.*, 1959), the commercialization process is more likely to involve large numbers of people from across an organization and require large amounts of complementary resources. Bridging the gap between invention and commercialization requires a complex series of steps that draw on a heterogeneous mix of firm resources and capabilities. Older executives who are better connected and better able to tap into resources across the organization will be in a stronger position to effectively facilitate commercialization of technologies, as follows:

H1b. The average age of the executive team will positively moderate the relationship between the number of inventions a firm develops and the number of new products they subsequently introduce.

Our understanding of the effect of organizational tenure on invention suffers from similar contradictory theories. Psychological commitment to the status quo, which results from a long tenure (Bantel and Jackson, 1989; Staw and Ross, 1978), argues in favor of a negative relationship between tenure and innovation. In contrast, increased internal networks and ability to effectively operate within the organization (Penrose, 1995; Nelson and Winter, 1982) argue for a positive effect on innovation. Some researchers have even suggested an inverted U-shaped relationship between managerial tenure and innovation (Wu *et al.*, 2005).

Here again, we can tease apart these effects by looking at front-end invention as separate from downstream commercialization. A longer tenure is expected to result in executives who are more embedded in the status quo and more committed to existing ways of doing business and is likely to affect the type of inventions a particular team of executives will tend to encourage. The natural bias would be toward innovations that improve or enhance existing products and processes rather than innovations that involve more radical changes. Longer-tenured executives have likely had a hand in creating the context of the current operations and products, and thus might be expected to focus more on exploiting those operations and products through incremental improvement rather than exploring for more radical departures from the status quo:

H2a. The average tenure of the executive team will be negatively related to the radicalness of inventions.

The positive effect of tenure through the mechanism of increased network access and political influence is likely to bear more strongly on the process of commercialization, where cooperation from across the organization must be mobilized. An executive who has been with an organization for a long period of time will be more deeply embedded in the internal network of relationships, will better understand who the relevant decision makers are across the various functions involved with new product commercialization, and will also understand the cultural and political approaches to garnering support that are most likely to be successful. These advantages allow longer-tenured executives to be more effective champions for the commercialization of particular inventions. Thus, we propose the following hypothesis:

H2b. The average tenure of the executive team will positively moderate the relationship between the number of inventions a firm develops and the number of new products they subsequently introduce.

It is also likely that the diversity represented within the TMT could have a significant influence on both the type of inventions a firm produces as well as the conversion of inventions into products. In terms of the effect on invention, we build on the logic in the extant literature on innovation in team settings. There is a significant body of work pointing to the effect of team diversity on creativity. Teams in which the members have multiple non-overlapping knowledge domains generate innovations of more variable value (i.e. big successes, but also big failures; Taylor and Greve, 2006). Cognitively diverse teams generate more creative outcomes (Kurtzberg, 2005), as do R&D teams with higher collective levels of social capital (Chen *et al.*, 2008).

Although suggestive, this is not sufficient evidence for us to definitively conclude that more diverse executives in the TMT would result in a more radically inventive organization.

The majority of studies examining diversity and creativity have focused on the diversity of the team directly responsible for generating the invention. While it is more likely that the inventions themselves will come from groups lower in the organizational hierarchy – such as R&D teams or operations-level workers – there is evidence to indicate that TMTs do exert a direct influence on those efforts. Participative leadership (Somech, 2006) and transformational leadership (Kearney and Gebert, 2009; Shin and Zhou, 2007) both affect the inventive outputs of others in the organization. There is also anecdotal evidence that companies that are interested in developing radical inventions will work to develop executives who exhibit the characteristics that lead to radical inventions at the team level (e.g. cognitive diversity, access to wide ranging social networks, etc.; see Cohn *et al.*, 2008). Thus:

H3a. The heterogeneity of the executive team will be positively related to the radicalness of inventions.

While team heterogeneity is linked to creativity and problem solving, it is also linked to internal dysfunction and conflict, which can impede successful task completion (Roberge and van Dick, 2010; Chatman and Flynn, 2001). There is evidence to suggest that homogeneity at the top is necessary to achieve the consensus needed to push new technologies through to commercialization (Amason *et al.*, 2006). Therefore, although we expect a positive relationship between executive heterogeneity and radicalness of invention, we expect a negative effect of heterogeneity on the conversion of inventions to new products:

H3b. The heterogeneity of the executive team will negatively moderate the relationship between the number of inventions a firm develops and the number of new products they subsequently introduce.

While the important influence of executives on firm-level decisions and outcomes is well established, the strength of that influence depends on particular elements of the environment. For example, the extent to which a firm will be a reflection of the cognitive frames and biases of the top executives depends on the discretion available to the executive (see Wangrow *et al.*, 2015 for a review). It has been argued that managers will have more discretion, and thus a greater influence on firm behaviors and outcomes, "when there is a great deal of means-end ambiguity" (Hambrick, 2007, p. 335). Discretion is enhanced or limited by industry-level characteristics such as dynamism and munificence as well as firm-level characteristics such as size and slack (Hambrick and Abrahamson, 1995; Key, 2002). In our context, we argue that there will be greater means-end ambiguity, and thus greater managerial discretion, in firms where radical invention is more prevalent. Given the potentially frame-breaking, competency-destroying, boundary-spanning nature of radical inventions, relevant stakeholders are less likely to fully understand the implications of any particular managerial decision regarding those technologies, and thus are less likely to impose boundaries on the manager's actions. This greater latitude of action in turn allows the executives to have a greater influence over the process.

Taken from another perspective, the relatively clear means-end linkages associated with incremental inventions may also mean that there is less need for managerial intervention. When the technology in question is a relatively simple extension of the firm's existing portfolio of technologies and products, lower level employees and managers within the organization are more likely to be able to marshal the resources needed to bring the technology to fruition. However, more radical technologies, which may in some cases address needs consumers themselves are not yet aware of, are likely to require more powerful champions to break through the political resistance to become new products. Taken together, the reduced ability for interested stakeholders to constrain managerial action when dealing with radically new technologies, whose ultimate effects might be murky, combined with the increased need for top management involvement when the upside potential of commercializing a more radical technology is unclear, leads us to our next hypothesis:

H4. The relationships hypothesized in *H1b*, *H2b*, and *H3b* will be stronger among firms with more radical inventions.

Sample and variables

The context for testing our hypotheses is the biomedical device industry, which is an ideal setting for the current study. First, it is an industry where innovation is a critical component of firm performance and competitive advantage. Second, because the underlying technologies can be reverse engineered by the competition once products hit the market, there is incentive for firms to use the patent system to protect inventions rather than trying to rely on internal trade secrets. This reduces concern that inventions might be unobservable. Third, because the industry is regulated by the Food and Drug Administration (FDA), the introduction of new products can be tracked by referring to the publicly available FDA database of product registrations.

Our sample encompasses all publicly traded companies in the biomedical device industry (SIC codes 3841-3845) that were in continuous operation from 2002 through 2006. The data were sourced from Compustat, and a five-year window was chosen to account for the lag between patent issuance and the introduction of a new product. There are 121 firms that meet the criteria, although missing variables reduce the sample size for various regressions.

The dependent variable for testing *H1a*, *H2a*, and *H3a* is the degree of radicalness evident in the firm's inventions, and hence we must be clear about what we mean by "radical" and "incremental." This can be tricky, as the literature is full of alternative definitions. Dewar and Dutton (1986) say that radical innovations "contain a high degree of new knowledge" (p. 1422) while Chandy and Tellis (1998) take a market-oriented perspective when they suggest that a radical innovation involves both a high degree of technological newness and a large increase in customer need fulfillment per dollar. Rosenkopf and Nerkar (2001) offer a similar two-by-two typology that spans both technological and firm boundaries. According to Garcia and Calantone (2002), "radical innovations often do not address a recognized demand but instead create a demand previously unrecognized by the consumer" (p. 121). Although there is potential validity in all of these definitions, we choose to move forward with the Dewar and Dutton (1986) definition of a radical innovation as being one that contains a "high degree of new knowledge." We do so out of a concern that many of the other definitions either explicitly or implicitly include elements of both invention and commercialization. Since a fundamental feature of our theoretical model is the deconstruction of innovation into those two distinct component processes, our construct definitions and resultant operationalizations must be similarly distinct.

We define "invention" as the creation of a potentially promising new technology that has not yet been commercialized. We operationalize this using the issuance of patents by the US Patent and Trademark Office (USPTO). We quantify the radicalness of a firm's patents following Ahuja and Lampert (2001), who measure radicalness as the degree to which the patents issued to a focal firm cite previous patents. This is a measure of radicalness to the extent that patents that are more significant departures from the prior state of the art will have less in common with preceding technologies and will thus be required to cite fewer prior patents. Since our hypotheses are at the firm level of analysis, this measure is calculated as the average number of previous patents that are cited by the focal firm's patents, with a smaller number representing a more radical portfolio of patents[1].

Data for the radicalness variable were collected by matching company names from our sample with names in the USPTO database in order to determine the unique "Assignee Code" associated with each company in the patent database. Using that code, we were then able to download data on those companies' patents from the repository. To reduce the impact of year-to-year variation in patent output, we calculated the radicalness measure for all patents received by the focal firm over the 2002-2006 timeframe. Therefore, for each company in the sample, we took the total number of backward citations reported on each of their patents during that five-year window, summed those values, and then divided by the number of patents issued during that timeframe. The resulting figure is the average number of backward citations per patent issued between 2002 and 2006.

H1b, *H2b*, and *H3b* are concerned with the effect of TMTs on the conversion of inventions into products. We proxy for inventions using the number of patents filed by a focal firm in 2002. The dependent variable for these tests is the number of new biomedical device products registered with the US FDA in 2006. The lag allows us to be more confident that any significant empirical results are the result of some causal effect and also accounts, albeit imperfectly, for the lag between development of a new technology and its commercial introduction, which can vary.

The independent variables for all regressions are the average age, average organizational tenure, and functional heterogeneity of the executive team. Information on executives was collected by first consulting the Lexis-Nexis Executive Compensation database to identify the executives for each company in 2004. Executive names were then used to search a number of online databases including Condé Nast Portfolio (www.portfolio.com), Forbes (www.forbes.com), Business Week (www.businessweek.com), and company SEC filings found on numerous outlets to determine relevant demographic information. Alternative spellings of names were used when necessary ("William Bolt" and "Bill Bolt" for "William J. Bolt"; "Bob Douglas" and "Rob Douglas" for "Robert Douglas," etc.); due care was exercised to ensure that the information did in fact belong to the specific person in question. Average age was then calculated by adding the ages of all executives in 2004 and dividing by the number of executives. Average tenure was similarly calculated as the sum of years spent with the company by all executives divided by the number of executives.

Functional heterogeneity was calculated using a modification of the Blau (1977) index. Based on our demographic data, we categorized each executive as having a background in science/engineering, business/economics, or other (political science or law for example). If those categories were mutually exclusive, then we could use the traditional Blau formulation of:

$$D = 1 - \sum_i p_i^2 \tag{1}$$

where p_i is the proportion of the team that belongs to category i. When the categories are mutually exclusive, this measure is bounded by 0 (no heterogeneity: all of the team in a single category) and 1 (many categories represented with no overlap). However, a particular executive may have an undergraduate degree in engineering and an MBA, or a degree in engineering and work experience in finance. When the categories are non-exclusive, the traditional Blau index can return a negative value for heterogeneity. We adjust the formula to be:

$$D' = \sum_i p_i - \sum_i p_i^2 \tag{2}$$

This restores the well-behaved bounds of the heterogeneity measure.

We also include several controls including executive team size, R&D intensity, debt-to-equity ratio, and executive turnover. We include the number of executives in 2004 to account for the fact that the heterogeneity of a team will be affected by its size (smaller teams will have lower maximum heterogeneity scores, and larger teams will have higher possible heterogeneity) and to control for the effects of team size observed in the creativity literature. R&D intensity is included to control for the effect that the level of resources directed to innovation could have on either the radicalness of innovation or the conversion of technologies to products. Debt-to-equity is included as a measure of organizational slack, a characteristic that has been linked to a firm's ability to innovate (Mousa and Chowdhury, 2014; Nohria and Gulati, 1996). And because the executive team (and thus executive team characteristics) may not be consistent over the entire window of our study, we include a measure of executive turnover from 2002 through 2006. This is calculated by counting the number of new executives hired from 2002 until 2006, adding the number of executives who departed during that time, and then dividing by the number of executives on staff in 2002 (Cho, 2006; Cho and Shen, 2007).

Results

The analyses to test *H1a*, *H2a*, and *H3a* were conducted using ordinary least squares (OLS) regressions in the Stata software package. Because the dependent variable used to test *H1b*, *H2b*, *H3b*, and *H4* is an integer count value (number of new products introduced in 2006), OLS is inappropriate. Examination of the data indicated significant overdispersion, suggesting that a negative binomial regression technique would be most appropriate. That determination was then confirmed in post-regression testing. *H1b*, *H2b*, *H3b*, and *H4* were tested using negative binomial regressions with robust standard errors in Stata.

Although it is common practice to report results of moderation analyses as a series of hierarchical regressions (Aiken and West, 1991), more recent work by Edwards (2009) and others suggests that this approach may be inappropriate. Namely, by offering a model with only controls, then a model with controls and direct effects, then models which introduce moderators, our regressions will almost certainly suffer from omitted variable biases. If there are variables that we have theoretical reason to believe will have an effect on the phenomenon being studied, the coefficients in any regression that does not include those variables will be biased. Thus, any interpretation of results in a base model or a model including only control and direct effect variables will suffer from omission of interaction terms representing the moderating effects. Because of this, we report only fully populated models that include all variables relevant to testing the hypotheses in question. Descriptive statistics of the study variables are shown in Table I.

The results of the OLS regression testing *H1a*, *H2a* and *H3a* are reported in Table II. We do not find support for either *H1a* or *H2a*. Neither average age nor average tenure of the executive team is significantly associated with radicalness. This fails to support either our hypotheses or the supposition by Ahuja *et al.* (2008) that those executive characteristics could predict the type of innovation likely to emerge from a focal firm.

However, we do find support for *H3a*. There is a significant negative relationship between heterogeneity in the executive team and number of backward citations in firm patents ($p < 0.05$). Given that a lower number of backward citations are indicative of a more radical patent portfolio, the negative coefficient suggests that increasing levels of heterogeneity are associated with fewer backward citations and thus more radical innovations.

The negative binomial tests of the moderated relationships predicted by *H1b*, *H2b*, and *H3b* are reported in Table III. Our hypotheses predicted that executive team characteristics will affect the efficiency of converting new technologies to new products. The dependent variable in all models is the number of new products introduced in 2006. Surprisingly, we find no support for any of the three hypotheses. Neither the average age of the executive team nor their functional diversity was found to significantly moderate the conversion of inventions into new products. Organizational tenure was found to have an effect exactly opposite of what was theorized. The average length of time executives have been with a focal firm has a significant negative moderating influence on the relationship between number of patents received and number of new products introduced ($p < 0.05$). However in

Variable	1	2	3	4	5	6	7	8	9	10	11
1. Patent backward citations 2002-2006	1.00										
2. Patent technology classes 2002-2006	−0.01	1.00									
3. New products introduced 2006	−0.07	−0.13	1.00								
4. Patents filed 2002	0.27**	−0.17	0.57***	1.00							
5. R&D intensity	−0.11	−0.13	−0.06	−0.05	1.00						
6. Number of executives 2004	−0.12	0.07	0.21**	0.13	−0.19*	1.00					
7. Debt-to-equity 2004	−0.04	−0.11	0.07	0.18*	−0.07	0.01	1.00				
8. Executive turnover 2002-2006	0.22	0.15	−0.06	0.07	0.03	0.13	0.26***	1.00			
9. Average executive age 2004	−0.06	−0.03	0.08	0.17*	−0.10	−0.19**	0.11	−0.12	1.00		
10. Average executive organizational tenure 2004	−0.14	0.06	0.16	0.19**	−0.15	−0.08	0.04	−0.39***	0.36***	1.00	
11. Executive functional heterogeneity (modified Blau) 2004	−0.26*	0.20	−0.13	−0.07	−0.08	0.43***	−0.10	0.01	−0.13	0.05	1.00
Mean	34.48	1.55	2.54	1.66	1.22	4.85	0.47	1.20	48.78	7.37	0.39
SD	48.29	0.79	7.40	2.91	8.82	1.86	0.56	1.34	5.25	4.62	0.20

Notes: $^{*}p < 0.10$; $^{**}p < 0.05$; $^{***}p < 0.01$

Table I.
Pairwise correlations and descriptive statistics

light of *H4* that the executive effect will depend on the radicalness of the underlying technologies, we observe these results with caution. While there appears to be no influence of age and heterogeneity with respect to commercialization in the sample as a whole, the existence or absence of an effect may be a function of the technological context, which is addressed in *H4*.

To test *H4*, we split the sample into two categories: those firms with above-average radicalness in their inventions and those firms with below-average radicalness in their inventions. We then run negative binomial regressions with robust standard errors on each subsample. By comparing the significance of the moderating effect between the above-average and below-average subsamples, we can draw some inferences regarding the relative strength of the moderating executive effect. These results are reported in Table IV.

Here we obtain a fascinating pattern of results that both directly contradicts *H4* but also provides context-dependent support for *H1b* and *H3b*. Looking at results for the two subsamples, the interaction terms representing the moderating effect of executive characteristics on the relationship between inventions and new products are significant for firms that have incremental patent portfolios, but non-significant for firms with more radical patents. This pattern of results suggests that the executive effect is less evident when the underlying technologies are radical, in contradiction to the direction predicted in *H4*.

Table II. Regression results demonstrating the effect of executive characteristics on the radicalness of innovation

Dependent variable: backward citations Variable	Coefficients
R&D intensity	−2.96
Number of executives	−1.41
Debt-to-equity	−10.59
Executive turnover 2002-2006	−10.28
Avg. executive age	−1.34
Average executive tenure	−1.65
Executive heterogeneity	−74.57**
Constant	165.43**
F	1.90*
Adjusted R^2	0.11

Notes: $^*p < 0.10$; $^{**}p < 0.05$; $^{***}p < 0.01$

Table III. Regression results demonstrating the moderating effect of executive characteristics on the invention-new product relationship

Dependent variable: new products introduced 2006 Variable	Coefficients
(1) R&D intensity	−3.84***
(2) Number of executives	0.40***
(3) Debt-to-equity	0.83
(4) Executive turnover 2002-2006	−1.05***
(5) Patents filed 2002	0.65
(6) Avg. executive age	−0.08
(7) (5) × (6)	−0.00
(8) Average executive tenure	0.12**
(9) (5) × (8)	−0.03**
(10) Executive heterogeneity	0.72
(11) (5) × (10)	−0.60
Constant	1.42
Wald χ^2	74.41***
α	2.30

Notes: $^*p < 0.10$; $^{**}p < 0.05$; $^{***}p < 0.01$

Dependent variable: new products introduced 2006 Variable	High radicalness (low backward citations)	Low radicalness (high backward citations)
(1) R&D intensity	−10.55**	−3.74*
(2) Number of executives	0.35	0.49**
(3) Debt-to-equity	0.07	1.47**
(4) Executive turnover 2002-2006	−1.20***	−0.19
(5) Patents filed 2002	1.06	−1.03
(6) Avg. executive age	−0.06	−0.17
(7) (5) × (6)	−0.01	0.05**
(8) Average executive tenure	0.07	0.29***
(9) (5) × (8)	−0.02	−0.06**
(10) Executive heterogeneity	−2.48	3.37
(11) (5) × (10)	0.04	−1.43**
Constant	3.29	1.25
Wald χ^2	76.00***	142.92***
α	2.32	0.63

Notes: *$p < 0.10$; **$p < 0.05$; ***$p < 0.01$

Table IV. Regression results demonstrating how the moderating effect of executive characteristics on the invention-new product relationship depends on the radicalness of innovation

In low-radicalness firms, where executives do appear to matter, both executive age and heterogeneity act in the manner predicted by *H1b* and *H3b*. Older executives positively moderate the relationship between inventions and new products, while more heterogeneous executive teams have a negative moderating effect. Tenure of executives continues to have a negative moderating effect, opposite the direction predicted by *H2b*.

Discussion and limitations

Our motivation for the study was to deconstruct the innovation construct into the components of invention and commercialization to more fully understand the role TMT characteristics play. Our theorizing and models included the role played by TMT age, tenure, and heterogeneity in the radicalness of inventions the firm makes, and the ability to convert inventions to new product introductions. Our results suggest that executive age and tenure do not, in fact, affect the type of inventions a firm develops as Ahuja *et al.* (2008) proposed. There are several possible explanations for this. It is possible that the degree of information asymmetry associated with early-stage development of new technologies limits the influence executives either can or choose to exert. Perhaps at that stage, executives have the authority to allocate resources, but lack the understanding to offer any direction as to how those resources should be expended. It is possible too that other unobserved characteristics of the organizations such as resistance to change or other political barriers may be preventing executive influence from being exerted (Radaelli *et al.*, 2017). However, we do find that more heterogeneous executive teams are associated with more radical inventions, as would be predicted by extending group-level creativity research to the executive level.

We also find support for a moderating role of executive tenure on the conversion of patents into products in the sample at large, although opposite to the direction we anticipated. Executive teams with a longer average tenure actually exert a negative moderating effect on the relationship between inventions and patents. It is possible that we are seeing the agency effects of executives nearing the end of their career at a given firm, where the exploitation of existing products carries more immediate personal rewards compared to the longer-term benefits of pushing inventions through to new products, although much more detailed study would be required to determine whether that was in fact the case. We find no moderating role for executive age or heterogeneity in the sample at large.

Recognizing the importance of context deepens our understanding of the phenomenon. It turns out that executive age has a positive moderating effect on the relationship between inventions and new products, and that executive heterogeneity has a negative moderating influence, but only when the underlying technologies are more incremental in nature. While the directions of those effects are congruent with *H1b* and *H3b* (older executives are better able to tap into resources necessary for commercialization, while more diverse teams suffer from more internal conflict and therefore are less effective at efficiently overseeing the commercialization process), the fact that we see the effect of executives in firms with incremental inventions rather than radical is somewhat at odds with the tradition of executive discretion theory. The perspective of executive cognition may provide a lens to interpret this result: perhaps executives recognize their own limitations in understanding radical inventions and thus adopt a more hands-off approach, as they are less willing to offer personal input to the process when they feel less comfortable that they understand what is going on.

Our results provide an interesting and valuable challenge to our understanding of how the upper echelons perspective interacts with firm-level innovation. In the spirit of Salancik and Pfeffer (1977), Hambrick and Finkelstein (1987), and others, we have explored an important set of contingencies determining the extent to which TMT characteristics are likely to affect firm-level innovations, as well as gained greater insight into the kinds of influence executives exert. Importantly, we have added nuance to prior literature by looking beyond how executives influence the level of innovative effort, and instead considering how the influence of managerial characteristics varies across different types of innovation.

We have also added to the literature by explicitly recognizing and empirically testing a more detailed model of innovation. By separating innovation into the component processes of the invention and commercialization, we are better able to understand where in the process different forces such as executive influence come to bear. Specifically, we tease apart previously conflicting theoretical models of how particular TMT characteristics might influence firm-level innovation. Whether executive age, tenure within the organization, and heterogeneity have a positive, negative, or non-significant influence over innovation depends on which dimension and which stage of the process we consider. Drawing a distinction between the component stages that make up the larger construct of innovation, not just theoretically but as an integral part of our empirical models, has the potential to reveal a great deal of nuance that would otherwise remain unrecognized.

This explicit deconstruction of innovation into its distinct constituent parts has implications for a broad spectrum of research aimed at understanding the antecedents and consequences of what has, by and large, been treated as a monolithic construct up to this point. We seek to emphasize the idea that the processes of invention and commercialization differ, and therefore success in either stage could hinge on different management backgrounds and skills that are needed in each stage. That supposition is directly hypothesized, tested, and supported in this paper.

The theory and findings presented here also carry practical implications. From the perspective of shareholders and boards of directors, if commercialization of new technologies is important to firm performance, then limiting the average tenure through relatively frequent turnover in the executive team would seem to be an effective approach. If more radical inventions are desired, then more heterogeneity in the executive team should be sought. If a company succeeds in developing more radical inventions, then boards should recognize that the subsequent impact of those executives on the commercialization process will be muted and should make decisions with regard to incentives and oversight accordingly. For firms with relatively incremental invention portfolios, the exploitation of those inventions through commercialization is facilitated by selecting executive teams that are relatively old and homogeneous. As with almost everything else in business, understanding the context is critical to putting the right kind of team in place.

Our work is not without limitations. First, potential problems can arise from testing theory in a single-industry setting (Sharp *et al.*, 2013). While our context has positive attributes for the current study, we acknowledge that our findings may not be generalizable across other domains. There is an opportunity to expand our work across multiple industries to explore conditions that may modify our findings. Second, our empirical tests make some strong assumptions regarding the temporal relationship between patenting and new product introduction. Clearly, patents vary in the time that elapses between the patent issuance and introduction of a new product based on that technology, with many patents never finding commercial application at all. While it would be ideal to link particular products to their specific underlying patents, that is unfortunately not possible with our data. However, this does not necessarily limit the meaningfulness of our results. In fact, the distribution of time lags between patenting and new product introduction should actually introduce statistical noise, which if anything would bias against any significant findings.

Third, while we were guided by Ahuja *et al.* (2008) to focus on executive age, tenure, and functional heterogeneity, there are other characteristics that might be equally relevant. Future work can expand the present model to consider other demographic variables. For example, where we found no significant effect of average executive age on the radicalness of innovation, perhaps the distribution of ages is more relevant. Interactions among individual executive characteristics may also be important to explore in future research. For example, what does it mean for firm-level innovation if the most senior executives have backgrounds in science or engineering compared to a firm with more marketing-oriented executives? Marvel and Lumpkin (2007) found that technology entrepreneurs with prior knowledge of underlying technologies develop more radical innovations, while those with prior marketing knowledge develop less radical innovations. It would be a worthwhile next step to explore whether that pattern extends to the context of top executives in established companies.

There are also other elements of organizational context which we do not include in the current model. For example, the presence of formal processes to choose which inventions should be moved on to commercialization has been linked to greater success rates for both radical and incremental inventions (Eling *et al.*, 2016). It is possible that executive characteristics interact with these formal processes in interesting ways, such that executive influence may be either enhanced or muted when the commercialization process is highly formalized. This additional moderating influence bears further investigation.

Finally, we acknowledge that the current model gives us a limited view of the actual processes at work. The specific mechanisms through which executives exert influence over commercialization of radical new inventions is something that we cannot fully ascertain with secondary data. Perhaps executives act directly on specific projects through championing, or perhaps their impact is more diffuse through their role as symbolic leaders (Pfeffer, 1981) or as the wellspring of organizational values (Miles, 2007). Clearly, some executives will be more politically connected and influential than others, allowing them to exert a disproportionate effect on innovation compared to their colleagues, while some will simply be more interested in directly affecting innovation processes than others. In-depth research on specific firms and their innovative processes will be needed to address such questions.

While recognizing limitations, the model offered and tested here represents a significant contribution to the conversation on innovation. By separating the construct into its constituent processes we have taken a step toward a more fine-grained and nuanced understanding of a critically important phenomenon.

Note

1. Our results were substantially the same when using the Shane (2001) technology class measure of radicalness.

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