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Top management team's innovation-related characteristics and the firm's explorative R&D: an analysis based on patent data

Chul Lee[1] · Gunno Park[2] · Klaus Marhold[1] · Jina Kang[1]

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Abstract This study investigates the relationship between characteristics of the firm's top management team (TMT) and its research and development (R&D) activities. Specifically, this research analyzes how observable characteristics of the TMT, such as functional experiences or educational background, and average tenure affect the firm's proportion of explorative R&D activities. From the perspective of the upper-echelon theory, we hypothesize that the TMT's functional experiences with R&D or science or engineering educational backgrounds increase the firm's tendency towards explorative R&D. Moreover, we propose that the average tenure of TMT members with innovation-related experiences would have a positive moderation effects on these relationships. The hypotheses are tested using a dataset containing biographical information of the TMT members, financial, and patent data of 89 firms in U.S. high-tech industries from 2006 to 2009. Firm's explorative R&D activities are analyzed using data on patent citations, patent classes, and non-patent references. The empirical analysis shows that the top managers' educational background in science or engineering as well as their previous functional experiences with R&D have a positive effect on the firm's explorative innovation activities. We also find that the size of these effects increases with a longer tenure of these TMT members. Our findings provide implications related to the effects of organizational characteristics on the establishment of a R&D strategy and highlight the role of TMT members with innovative experiences in directing a firm's R&D activities and outcomes.

Keywords R&D · Patent analysis · Innovation · Top management team · Exploration

JEL Classification M12 · O31 · O32

✉ Jina Kang
profkang@snu.ac.kr

[1] Technology Management, Economics, and Policy Program (TEMEP), College of Engineering, Seoul National University, 1 Gwanak-ro, Gwanak-gu, Seoul 151-744, South Korea

[2] Samsung SDS, SDS West Campus, Olympic-ro 35, Songpa-gu, Seoul 138-240, South Korea

Introduction

Exploitative innovation and explorative innovation are both essential for firms in terms of ambidexterity (March 1991; Gupta et al. 2006), but their individual characteristics and potential returns are different and firms might not be able to pursue both to the same extent at the same time (March 1991; He and Wong 2004). Industries which are characterized by long product life-cycles and established technologies are often focusing on the pursuit of exploitative innovation which improves their performance by using accumulated technological knowledge to enhance process management (Benner and Tushman 2003). On the other hand, for high-tech industries, known for short life-cycles and cutting-edge technology, pursuing mainly exploitative innovation poses the danger of diminishing competitiveness as the repeated application of existing technologies and knowledge prevents the firms from seizing new technological opportunities and entering new markets (D'Aveni 1994). Rather than relying on existing knowledge, firms in today's technology intensive industries, i.e., industries which focus on research and development (R&D) rather than manufacturing, have to pursue new and emerging technologies to increase their competitiveness (Schumpeter 1942; Garcia et al. 2003; Gupta et al. 2006). Consequently, for firms in these industries, the importance of explorative innovation, which aims to explore new technologies through research and experimental activities, has increased (Rosenberg 1990; Uotila et al. 2009).

An important element of firms' R&D strategies in high-tech industries is to determine the proportion of explorative R&D activities among the total R&D (Mudambi and Swift 2014). Still, even though the need to pursue ambidexterity strategies in order to capture advantages and complement of both exploitative and explorative innovation is clear (Rothaermel and Alexandre 2009), a large number of firms emphasize exploitative innovation to lower the uncertainties of the R&D process (Greve 2007). Though firms in high-tech industries generally have a high propensity to engage in explorative R&D and face similar external influences such as the intensity of the competition, individual firms place different emphasis on explorative activities (Greve 2007; Uotila et al. 2009; Mudambi and Swift 2014). Firm strategies, including the R&D strategy, are conscious decisions of the firm. Thus even firms in the same industry, which face a similar technological environment, exhibit different approaches to solving technological problems and planning for the future. One of the reasons for this difference is the decisions makers of each firm have different perceptions about future opportunities and the role of R&D in achieving set business objectives (Heavey and Simsek 2013). As R&D activities are considered to be one of the most important and resource-consuming activities for firms in high-tech industries, the firms' top level decision makers are actively involved in planning and conducting R&D projects (Qian et al. 2013). Consequently, previous research highlighted the influence of the firm's decision makers, such as the top management team (TMT), on organizational behavior such as R&D investments (Kor 2006; Chen et al. 2010). Hambrick and Mason (1984) proposed the upper echelon theory which explains the behavior and performance of organizations as the result of managerial decisions which are mainly influenced by the cognitive base of the TMT. They argued that the characteristics of TMT members such as their background, age, or tenure influence the formation of the individuals' cognitive base, which is reflected in the TMT's decision making (Hambrick and Mason 1984; Bantel and Jackson 1989; Wiersema and Bantel 1992; Daellenbach et al. 1999). From the perspective of the upper echelon theory, an organization's R&D strategy is mainly influenced by the TMT's propensity to favor explorative activities, its perception of technological opportunities, and its risk perception (Hambrick and Mason 1984; Tabak and Barr 1999). For example, a risk-avoiding conservative TMT is more likely to pursue exploitative R&D projects whose risk can be better estimated rather than explorative R&D projects which are inherently more prone to risks. On the other hand, a preference for solving problems through investigating new technologies and innovation increases the likelihood of the TMT giving more support to explorative R&D (Alexiev et al. 2010).

Previous studies on the influence of TMT characteristics have often focused on individual characteristics and did not study the interaction of different characteristics on the decision making (Tabak and Barr 1999; Barker and Mueller 2002). Studies which investigated the relationship between the TMT and the firm's R&D activities have often adopted a financial perspective and focused on total R&D investments (Barker and Mueller 2002; Kor 2006; Chen et al. 2010). Even though the importance of R&D for firms is ever increasing, not much literature focused on which factors related to the firm's decision makers affect the firm's organizational behaviors in terms of R&D activities. While recent research paid attention to the relationship between TMT characteristics and the firm's R&D (Alexiev et al. 2010; Talke et al. 2010; Ding 2011; Qian et al. 2013; Li et al. 2014), those studies did not provide an in-depth analysis of the two different kinds of R&D activities, i.e., explorative and exploitative R&D, a firm can pursue. From a methodological perspective, previous literatures focused on the technological side of the firm's R&D activities (Ahuja and Lampert 2001; Geiger and Makri 2006). However, recent industrial R&D is increasingly linked to the scientific domain (Fleming and Sorenson 2004; Lee et al. 2016).

Aiming to provide a more detailed picture of how the characteristics of the TMT influence a firm's R&D activities as well as to include both scientific and technological aspects of the firm's R&D activity, this research analyzes how the R&D strategy of the firm is influenced by its TMT's preference for explorative R&D activities. Specifically, it investigates how R&D-related functional experiences as well as science or engineering-oriented educational backgrounds of the TMT members influence their cognitive base and risk preferences which are related to explorative R&D. We also investigate how the duration of the TMT members' tenure affects the decision making on explorative R&D projects. To allow for an in-depth analysis of the firms' R&D activities, this research goes beyond the use of financial data and adopts patent data, especially data on patent citations, patent classes, and non-patent references to include both technological and scientific aspects of innovation. This research elucidates how the firm's internal characteristics, specifically those related to its management team, affect the organization's behaviors toward R&D activities through an empirical analysis conducted using a dataset of firms in high-tech industries and their patent data. Additional analysis provides insights into how the firm's explorative R&D activity relates to firm growth.

This study is structured as follows: In "Literature and Hypotheses" section, we discuss the different directions the R&D activities of a firm can take by looking at R&D strategy from the perspectives of exploitation and exploration. We then present hypotheses on how the characteristics of the firms' TMT affect the firms' choice of explorative over exploitative R&D. In "Methodology" section, we introduce our data, methods and variables for testing our hypotheses using a sample of US high-technology firms. The empirical results of these tests, as well as additional robustness tests and analysis are introduced in "Results" section. We conclude the study with a discussion of the results and the presentation of implications and limitations in "Conclusion" and "Discussion" sections.

Literature and hypotheses

Two directions of R&D strategy

Innovation can be divided into explorative innovation and exploitative innovation depending on how much new knowledge has been used in the invention processes (March 1991; Benner and Tushman 2003). Exploitative innovation influences firms' short-term performance by refining and implementing existing knowledge (March 1991; Benner and Tushman 2003). R&D processes related to exploitative innovation are characterized by a relatively low level of technological uncertainty as they are based on either accumulated knowledge or familiar technologies with the goal of incrementally improving existing products (March 1991). By utilizing established facilities and employees and pursuing projects based on familiar knowledge and skills, firms can conduct exploitative R&D activities with small budgets and at relatively low risk. In contrast to exploitative R&D, explorative R&D requires the firm to deal with unfamiliar and new knowledge (Stuart and Podolny 1996) and often involves testing experimental alternatives that might create outcomes only in the long-term (March 1991; Ahuja and Lampert 2001; Benner and Tushman 2003). In addition, accessing and searching for novel, emerging, pioneering technologies (Ahuja and Lampert 2001), and basic sciences (Gibbons and Johnston 1974; Rosenberg 1990) requires considerable resources to both increase the understanding of the new knowledge and to apply the new concepts towards innovative outcomes. Even deploying substantial resources into explorative R&D projects, high technological uncertainties during the invention process may result in outcomes that are far different from the initial expectations and might not be commercially viable (March 1991). In this respect, previous literature discussed ambidexterity strategies allowing firms to balance risk and performance by simultaneously conducting both exploitative and explorative R&D (He and Wong 2004; Li et al. 2008). Especially given the increasing volatility and speed of change of the technological environment, in which firms face high risks and uncertainties, ambidexterity is an effective R&D strategy (Uotila et al. 2009). However, even if organizations pursue such an ambidexterity strategy, they tend to favor one strategy over the other (Greve 2007). Recent research showed a tendency towards investing more resources into exploitative R&D projects due to their relatively lower risk compared to explorative R&D (Greve 2007; Mudambi and Swift 2014). However, overly focusing on exploitative innovation can result in organizations falling victim to structural inertia (Hannan and Freeman 1984) which reduces the ability to adapt to the fast-changing technological environment and prevents them from capturing future opportunities (He and Wong 2004; Uotila et al. 2009). Organizations which mainly depend on their established routines and learning through exploitative activities can fall into a so-called competency trap (Levitt and March 1988; Katila 2002). In high-tech industries where being the first to adopt new technologies often translates into a competitive advantage, explorative R&D projects can provide a larger potential for future growth than exploitative activities (Rosenberg 1990; Greve 2007). Consequently, for firms in these industries, even though they are trying to balance their R&D activities under ambidexterity strategies, long-term survival requires them to focus on increasing the proportion of their explorative R&D (Rosenberg 1990; D'Aveni 1994; Garcia et al. 2003; Gupta et al. 2006; Belderbos et al. 2010).

Top management team background and the firm's R&D direction

According to Dearborn and Simon (1958), an individual will apply the skills and problem solving methods learned from past functional experience to solve future problems. Individuals who possess experiences of working in R&D-related functions will have experienced that an organization's technological competitiveness is enhanced by its effort to explore novel and emerging technologies, even if such a pursuit involves dealing with considerable uncertainties and risks (Daellenbach et al. 1999). Such experiences in R&D functions make individuals less sensitive towards facing the risks and uncertainties caused by explorative innovation activities (March and Shapira 1987; March 1988) which leads to them preferring explorative R&D projects (Daellenbach et al. 1999). Similar to the work experience, the educational background has been identified as one of the key factors which determine the way TMT members approach managerial decisions (Hambrick and Mason 1984; Hitt and Tyler 1991; Wiersema and Bantel 1992). Both engineering and science emphasize the importance of innovation (Gibbons and Johnston 1974) and the inevitable risky nature of problem-solving processes (Wiersema and Bantel 1992). Consequently, TMT members whose cognitive base was formed by majoring in engineering or sciences, would prefer to enhance the organization's competitiveness through technological innovation (Tyler and Steensma 1998; Barker and Mueller 2002) rather than through low-risk strategies. Therefore, they are more likely to actively support explorative R&D projects which aim at a technological paradigm shift. Together, functional experiences and the educational backgrounds of TMT members directly affect the formation of their cognitive base which shapes their attitude towards explorative R&D as well their propensity to take or avoid risks. The influence of the TMT members' background on the direction of the firm's R&D leads to the following hypotheses:

Hypothesis 1 The higher the proportion of TMT members with functional experiences in R&D-related positions, the more the firm will focus on explorative R&D activities.

Hypothesis 2 The higher the proportion of TMT members with an academic background in engineering or science, the more the firm will focus on explorative R&D activities.

The moderating effect of TMT members' average tenure

It is known that TMT members' tenure in the organization can affect their decision making (Hambrick and Mason 1984; Bantel and Jackson 1989; Chen et al. 2010). Finkelstein (1992) and Hambrick (2007) state that the TMT decision making process can be biased in accordance with the differing power of individual TMT members. In the context of TMTs, power can be divided into structural, ownership, expert, and prestige power (Finkelstein 1992). From the perspective of structural power, it is generally accepted that senior TMT members have more power than junior members and can control large amounts of resources and exert considerable influence to strategic decision more easily (Finkelstein 1992). For example, Finkelstein (1992) found that firm behavior was more focused on acquisition strategy in firms with high proportion of powerful TMT members with a financial background. Adopting this research results to the R&D perspective, we can hypothesize that a firm's R&D-related decisions are not only influenced by the TMT members' background and experience but also their power within the TMT as represented by their tenure in the organization. When the TMT consists of only a few members which have innovative experiences and have a relatively short tenure, their limited power will make it difficult to support large resource consuming R&D projects such as explorative R&D (Hambrick 2007). In addition, individuals with a short tenure as members of a firm's TMT can feel the pressure to show their values and abilities and prove themselves within a short period of time (Kor 2006; Chen et al. 2010). Even high performance can be archived by pursuing explorative R&D, the high uncertainties and risks inherent in explorative activities make short-tenured members reluctant to support it (March and Shapira 1987). This can result in junior members of the TMT preferring to be associated with innovation projects that are able to obtain short-term performances, a characteristic of exploitative R&D projects. On the other hand, as a member with a long tenure in the TMT, the abilities are already verified and members feel less pressure to choose projects geared towards short-term performance (Kor 2006; Chen et al. 2010). Senior members also have more power within the TMT which makes it easier for them to support large and riskier R&D projects such as explorative activities. If senior members with innovative experiences hold a large majority in the TMT, the firm is expected to engage in more explorative activities. Therefore, we propose that the average tenure of the TMT members who possess innovation-related backgrounds or experiences will influence the relationship between the proportion of such TMT members and the firm's level of engaging in explorative R&D activities.

Hypothesis 3a The relationship between the proportion of TMT members with functional experiences in R&D-related positions and the firm's focus on explorative R&D activities is positively moderated by the average tenure of these TMT members.

Hypothesis 3b The relationship between the proportion of TMT members with an academic background in engineering or science and the firm's focus on explorative R&D activities is positively moderated by the average tenure of these TMT members.

Methodology

Data

To test the suggested hypotheses, this research collected biographical information of the TMT members, firm-level financial information, and patent data of 89 US firms in high-tech industries. Specifically, we chose our sample firms from eight high-tech industries including chemicals, electronics, pharmaceutical and biotechnology and semiconductors due to the high importance of explorative innovation in these industries (Gittelman and Kogut 2003; West and Iansiti 2003). Table 1 shows the detailed composition of our data set. Firms from the technology hardware and equipment as well as software and computer services industries account for around half of the sample. The sample also includes firms from industries such as chemicals or pharmaceutical and biotechnology, in which R&D is mainly based on scientific knowledge (Narin and Olivastro 1992; Makri et al. 2010; Subramanian and Soh 2010).

In the context of this study, the TMT includes the firm's CEO, CFO, COO, CTO and heads of business units (Finkelstein and Hambrick 1996; Tabak and Barr 1999; Kor 2003). Biographical information for 1550 individual members of the TMTs who worked at the sample firms during the period from 2006 to 2009 was collected from Corporate Affiliations provided by LexisNexis and the Who's Who provided by Marquis. Financial indicators for each firm were obtained from the Compustat database provided by Standard and

Table 1 Composition of the data set

Industry	Number of sample firms	Percentage
Automobiles	4	4.5
Chemicals	11	12.3
Electronics	6	6.7
Industrial engineering	3	3.4
Technology hardware and equipment	26	29.2
Pharmaceutical and biotechnology	14	15.7
Semiconductors	4	4.5
Software and computer services	21	23.6

Poors and the Datastream database of Thomson Reuters. For analyzing R&D activities, this research relies on US patent data, especially data on patent citations, patent classes, and non-patent references (NPRs). To assign patents to different technological fields, this research uses the US Patent Classification System (USPC), which classifies each US patent into one of around 450 classes, which are further subdivided into a total of around 150,000 subclasses, based on the technological characteristics of the invention. The USPC, representing particular technologies, allows us to identify the technological fields that influenced the focal patents' invention processes. The citation information of US patents is divided into patent citations and non-patent references. Non-patent references refer to journal papers, conference proceedings, textbooks, databases, company reports and other documents that influenced the patented invention (Callaert et al. 2006). Detailed information on 13,363 patents granted to the sample firms with application dates from 2003 to 2010 were collected from the patent database provided by the United States Patent and Trademark Office (USPTO). The final dataset contains 356 firm year observations of 89 firms over a 4-year timespan (2006–2009). To test our suggested hypotheses, we adopted panel analysis which allows for a longitudinal analysis in order to capture the dynamic relations between the dependent variable and explanatory variables by observing samples from the same individuals, in this case firms, over time. Specifically, we employed generalized estimating equations (GEEs) models with a logit link function in order to address the proportional values of our dependent variables.

Variables

Dependent variable

Explorative R&D activities (patent citations, classes, non-patent references) For calculating a firm's degree of focus on explorative R&D, this research adopts a concept based on the analysis of patent citations previously used in the studies of Katila and Ahuja (2002) and Phelps (2010). It is based on the understanding that using new-to-the-firm knowledge in the R&D process is exploration whereas the repeated use of the same knowledge is considered as exploitation. To investigate how explorative the firm's R&D is, the proportion of new to previously used knowledge is calculated using backward citation data. When the firm cites a patent for the first time, it is using new knowledge, whereas further references to the same patent at a later time can be seen as using already known knowledge in the invention process. Specifically, the backward citations of patents which were applied by firm i in the three years preceding the observation year ($t-3 \sim t-1$) were compared with those of the patents applied for in the year after the observation year ($t+1$). The delay is due to the time it takes for the TMT's decisions to have an effect on the direction of the firm's R&D activities and its outcomes.

$$\text{Explorative R\&D activities (patent citations)}_{\text{it}} = \frac{\text{NEW CITATIONS}_{\text{it}}}{\text{TOTAL CITATIONS}_{\text{it}}}$$

In addition to the methodology described above we also calculated the firm's explorative R&D activities using patent class and non-patent reference data. Patent class data is used in a similar way to patent citations, i.e., to distinguish new knowledge and technologies used in the innovation process from knowledge and technologies that the firm used before. In this case, if an applied patent is classified in a subclass that the firm has not been applying in for the three years before the focal year, it is considered as exploring a new technological field. On the other hand, future applications for patents in the same subclass are seen as exploitative activities using previously known technology.

$$\text{Explorative R\&D activities (patent classes)}_{\text{it}} = \frac{\text{NEW SUBCLASSES}_{\text{it}}}{\text{TOTAL SUBCLASSES}_{\text{it}}}$$

Finally, we proxy the firm's explorative R&D using non-patent references. As these non-patent sources, e.g., scientific articles, are often related to basic science, patents which cite a large number of these sources are considered more fundamental and explorative (Trajtenberg et al. 1997; Callaert et al. 2014). On the other hand, patents whose citations are mostly directed at other patents are seen as containing more applied innovation or improvements to existing innovations. Meanwhile, Callaert et al. (2006) proposed that among the various non-patent references, only journal papers, conference proceedings, and books reflect scientific sources. Therefore, we only consider these scientific references as non-patent references in the context of this study. Specifically, similar to the approach of Verbeek et al. (2002) and Shirabe (2014), we used a text parsing algorithm to classify the elements of the non-patent reference including fields such as {author name}, {publication title}, {journal title}, {conference name}, {volume and issue number}, {publication year}, {publisher}, {publisher location}, and {pages}. We then standardized the texts and used the available information to classify them as journal papers, conference proceedings, books, or others.[1] For example, citations of journal papers generally contain the following fields: {author name}, {publication title}, {journal title}, {volume and issue}, {publication year}, and {pages}. Manual checks were conducted to ensure the correct classification of each non-patent reference. To measure the explorative R&D activities of the firms using non-patent references, we employ the science index, proposed by Trajtenberg et al. (1997), as described in the following formula:

$$\text{Explorative R\&D activities (NPRs)}_{\text{it}} = \frac{\text{NPCITES}_{\text{it}}}{\text{NPCITES}_{\text{it}} + \text{NCITED}_{\text{it}}}$$

where $\text{NPCITES}_{\text{it}}$ is the average number of scientific references and $\text{NCITED}_{\text{it}}$ is the average number of patent references of the patents applied by firm i in year t, respectively (Callaert et al. 2012).

[1] Verbeek et al. (2002), Callaert et al. (2006, 2012, 2014) and Shirabe (2014) demonstrate classifying methods for identifying scientific publications among non-patent references.

Independent variables

TMT R&D experience To measure TMT innovative experience, i.e., working experience in R&D functions, we used biographical information of the TMT members. We coded each member of the TMT of a firm with 1 if they had experiences of working in R&D-related functions, and 0 if the individual had no such experience (Barker and Mueller 2002). The variable TMT R&D experience is the proportion of TMT members coded 1 for each firm and observation year.

TMT Eng/Sci education Similar to the R&D-related experience of the TMT members, also the information on their educational background is derived from biographical data. We coded each member of the TMT of a firm with 1 if they obtained a Bachelor, Master, or Ph.D degree in an engineering or science related field, and 0 if the individual had no such degree (Barker and Mueller 2002). The variable TMT Eng/Sci education is the proportion of TMT members coded 1 for each firm and observation year.

TMT average tenure Biographical information was also used to determine the individual TMT members' tenure. To address the influence of the tenure of TMT members' with R&D related experiences and backgrounds, we only considered individuals who had been coded by 1 for experience or education as described above. TMT's average tenure is then calculated as the average time in years that the individuals had served as members of the firm's TMT for each firm and observation year.

Control variables

R&D intensity A larger R&D budget helps to maintain and expand the number of researchers, facilities and materials for testing alternatives that can lead to innovation outputs. The amount of resources the firm is investing into R&D is expressed through the R&D intensity, i.e., the proportion of the firm's R&D expenses relative to its sales, of each firm in year t.

Firm size The size of the firm influences the type of R&D as well as the level of R&D activities. The resources of large firms might allow them to conduct more costly and risky R&D. Therefore, we included the log transformed volume of sales to control for differentiated innovation activities and performances between organizations of different sizes.

Firm innovation experience An organization with a lot of experience of successful R&D projects in the past indicates not only the existence of efficient routines for R&D processes but also serves as a measure for the technological capacity of each firm. This study uses the number of granted patents applied for in the past three years before the focal year to proxy for innovation experience. The variable is log transformed.

Technological diversity It can be argued that firms with a highly-diversified technology portfolio may be better at exploring knowledge from various fields while a low level of diversity indicates that the firm tends to focus on only a few fields. We adopted the Herfindahl index to calculate the firms' technological diversity. We measured technological diversity by analyzing the diversity of patent classes in which each firm applied for ultimately granted patents during the past three years. The formula used is

$$H = 1 - \sum_{i \in F} p_i^2$$

where F is the set of technological categories (patent classes) and p_i is the proportion of the firm's patents classified in technological category i. A value of the index close 1 indicates that the firm's R&D activities are conducted in various technology fields (high technological diversity) whereas low values close to 0 show that the firm's R&D is focused on a small range of technologies (low technological diversity).

TMT average age Previous research has suggested that the age of the TMT members has an influence on their managerial decisions (Hambrick and Mason 1984; Bantel and Jackson 1989; Kor 2003). Younger individuals prefer more challenging projects with high-risk and uncertainties, while older individuals often have a tendency to avoid risks (Carlsson and Karlsson 1970; Vroom and Pahl 1971). We calculated the average age of all the members in each firm's TMT in year t and standardized it.

Heterogeneity of the TMT (educational and functional background) Low heterogeneity of the TMT members, i.e., members share the same functional and educational background makes the communication easier because the knowledge base and ways of thinking of TMT members with shared backgrounds are very similar (Hambrick et al. 1996; Kor 2003). Increasing heterogeneity, however, causes conflicts of opinions (Hambrick and Mason 1984; Priem 1990) due to the different perspectives of TMT members with various experiences and knowledges (Bantel and Jackson 1989; Hambrick et al. 1996; Daellenbach et al. 1999). This research classified the educational background into engineering, science, economic, accounting/finance, business, legal and others. The functional background consists of R&D, accounting/finance, legal, production operations, administration, general counsel, marketing/sales and others (Daellenbach et al. 1999; Barker and Mueller 2002). The Herfindahl index was adopted to calculating the heterogeneity of the TMTs background for both education and functional experience respectively (Wiersema and Bantel 1992; Hambrick et al. 1996; Kor 2006).

Results

Prior to testing the proposed hypotheses, the descriptive statistics and the correlations between the variables were analyzed. Table 2 indicates that on average 24% of TMT members have R&D related functional experiences and 33% of TMT members possess degrees in science or engineering related fields, although differences exist between different industries. For example, for firms in the pharmaceuticals and biotechnology industry, individuals with a higher education in science or engineering account for about 45% of the TMT. A similarly high level, 41%, can be found in firms operating in the technology hardware and equipment industry. On the other hand, firms in industrial engineering exhibit a low propensity to constitute their TMT members with individuals possessing either R&D-related work experience (15%) or a science or technology education for (23%). The average of technological diversity was calculated as 0.82 and shows that the firms in the sample conducted their R&D activities in various technology fields rather than focusing on a few particular technologies. This indicates that firms are actively searching for diverse technologies to capture future opportunities in advance. The correlation results show a high level of correlation between Explorative R&D (Citation) and

Table 2 Descriptive statistics and correlation matrix (number of observations: 356)

	M	SD	Min	Max	1	2	3	4	5	6	7	8	9	10	11	12	13
1. Explorative R&D (Citation)	0.52	0.23	0.03	0.99	1												
2. Explorative R&D (Class)	0.22	0.18	0	0.99	0.78**	1											
3. Explorative R&D (NPR)	0.27	0.17	0	0.93	−.30*	−.16*	1										
4. TMT R&D experience	0.24	0.16	0	0.83	−.28*	0.24*	0.28*	1									
5. TMT Eng & Sci education	0.33	0.19	0	0.8	−.18*	−.22*	0.27*	0.56*	1								
6. TMT average tenure	5.91	2.24	1.5	13.9	−.13*	−.05	0.01	0.02	0.02	1							
7. R&D intensity	0.14	0.20	0.01	2.16	−.14*	−.14*	0.44*	0.35*	0.39*	0.14*	1						
8. Firm size[a]	8.73	1.53	4.15	12.11	0.02	−.10	−.18*	−.17*	−.11	0.02	−.42*	1					
9. Firm innovation experience[a]	5.59	1.65	1.61	9.80	−.21*	−.51*	−.19*	0.07	0.11	0.15*	−.15*	0.61**	1				
10. Technological diversity	0.82	0.14	0.23	1	0.17*	0.15*	−.34*	−.12	−.05	0.06	−.27*	0.41*	0.37*	1			
11. TMT average age[b]	0	0.74	−2.25	1.87	0.02	0.02	0.03	−.08	−.01	0.18*	0.04	0.31*	0.15*	0.15*	1		
12. Educational heterogeneity	0.66	0.10	0	0.82	0.13*	0.16**	0.04	−.08	−.01	0.07	−.16*	0.30*	0.07	0.24**	0.09	1	
13. Functional heterogeneity	0.76	0.04	0.5	0.84	−.05	−.09	0.16*	0.30**	0.12	−.02	0.17*	−.16*	0.05	−.18*	−.17*	0.21*	1

** $p < 0.01$; * $p < 0.05$; two-tailed tests

[a] Transposed to log scale

[b] Standardized

Explorative R&D (Class), indicating that firms who are patenting technologies in new technological fields are also actively exploring new knowledge.

Tables 3, 4 and 5 show the results of the empirical tests based on measuring explorative R&D activities through patent citations, patent classes, and non-patent references, respectively. In all three tables, Model 1 contains all of the control variables and Model 6 contains all control and independent variables as well as further explanatory variables including interaction effects. The results in Table 3 show that the firm's innovation experience negatively influences its explorative R&D activities. On the contrary, firms are more turning towards explorative R&D as the average age of the TMT members and the

Table 3 Regression results for explorative R&D based on patent citations

Dependent variable Explorative R&D (citations)	Model 1	Model 2	Model 3	Model 4	Model 5	Model 6
Control variables						
R&D intensity	−0.186 (0.282)	−0.0734 (0.283)	−0.149 (0.279)	−0.0831 (0.289)	−0.139 (0.295)	−0.108 (0.292)
Firm size[a]	0.0449 (0.0624)	0.0391 (0.0599)	0.0421 (0.0625)	0.0299 (0.0598)	0.0416 (0.0640)	0.0316 (0.0630)
Firm innovation experience[a]	−0.269*** (0.0554)	−0.254*** (0.0569)	−0.263*** (0.0572)	−0.232*** (0.0559)	−0.248*** (0.0551)	−0.236*** (0.0580)
Technological diversity	2.409*** (0.734)	2.319*** (0.710)	2.389*** (0.726)	2.299*** (0.694)	2.376*** (0.690)	2.304*** (0.703)
TMT average age[b]	0.140* (0.0789)	0.129* (0.0786)	0.138* (0.0786)	0.169** (0.0785)	0.163** (0.0774)	0.171** (0.0795)
Educational heterogeneity	−0.0313 (0.899)	−0.144 (0.968)	−0.0597 (0.925)	0.00350 (1.030)	−0.0162 (0.959)	0.0131 (1.045)
Functional heterogeneity	1.014 (1.370)	1.744 (1.369)	1.044 (1.354)	1.630 (1.283)	1.157 (1.342)	1.678 (1.371)
_Cons	−1.499 (1.321)	−1.699 (1.279)	−1.423 (1.334)	−1.008 (1.254)	−1.067 (1.294)	−1.110 (1.345)
Independent variables						
TMT R&D experience (R&D Exp)		1.030** (0.478)		2.479** (1.117)		2.668** (1.305)
TMT Sci/Eng education (S&E Edu)			0.229* (0.384)		0.808* (0.858)	0.334* (0.937)
TMT average tenure (Tenure)				0.124** (0.0509)	0.0928 (0.0574)	0.121 (0.0591)
R&D Exp × Tenure				0.246* (0.150)		0.254* (0.183)
S&E Edu × Tenure					0.101* (0.130)	0.0158* (0.153)
Observations	356	356	356	356	356	356
Wald Chi-square	30.75***	35.56***	32.85***	46.23***	41.01***	46.01***

*** $p < 0.001$; ** $p < 0.01$; * $p < 0.05$; two-tailed tests; robust standard errors are in parentheses

[a] Transposed to log scale

[b] Standardized

Table 4 Regression results for explorative R&D based on patent classes

Dependent variable Explorative R&D (classes)	Model 1	Model 2	Model 3	Model 4	Model 5	Model 6
Control variables						
R&D intensity	−0.351 (0.393)	−0.203 (0.402)	−0.271 (0.391)	−0.234 (0.388)	−0.248 (0.404)	−0.214 (0.408)
Firm size[a]	0.0979* (0.0577)	0.0953* (0.0561)	0.0939* (0.0570)	0.0954* (0.0551)	0.0938 (0.0572)	0.0891 (0.0566)
Firm innovation experience[a]	−0.517*** (0.0413)	−0.507*** (0.0426)	−0.509*** (0.0424)	−0.511*** (0.0439)	−0.513*** (0.0436)	−0.508*** (0.0455)
Technological diversity	2.826*** (0.562)	2.721*** (0.539)	2.785*** (0.555)	2.752*** (0.545)	2.765*** (0.564)	2.709*** (0.551)
TMT average age[b]	0.139* (0.0725)	0.147** (0.0718)	0.138* (0.0735)	0.144** (0.0728)	0.127* (0.0743)	0.150** (0.0729)
Educational heterogeneity	0.349 (0.754)	0.248 (0.759)	0.303 (0.767)	0.286 (0.771)	0.231 (0.767)	0.266 (0.767)
Functional heterogeneity	0.856 (1.108)	1.650 (1.138)	0.865 (1.115)	1.615 (1.137)	0.805 (1.133)	1.350 (1.165)
_Cons	−2.541** (1.067)	−2.810*** (1.032)	−2.389** (1.054)	−2.796*** (1.032)	−2.564** (1.101)	−2.714** (1.099)
Independent variables						
TMT R&D experience (R&D Exp)		1.002** (0.391)		1.459* (1.112)		2.144* (1.272)
TMT Sci/Eng education (S&E Edu)			0.349* (0.318)		0.248* (0.879)	1.100* (0.888)
TMT average tenure (Tenure)				0.0455 (0.0495)	0.0533 (0.0573)	0.0294 (0.0589)
R&D Exp × Tenure				0.0868* (0.163)		0.207* (0.192)
S&E Edu × Tenure					0.106* (0.135)	0.190* (0.150)
Observations	356	356	356	356	356	356
Wald Chi-square	207.06***	189.33***	214.26***	209.90***	218.69***	199.31***

*** $p < 0.001$; ** $p < 0.01$; * $p < 0.05$; two-tailed tests; robust standard errors are in parentheses

[a] Transposed to log scale

[b] Standardized

technological diversity of the firms increase. The results of Model 2 show a positive and significant (coefficient: 1.030, $p < 0.01$) relationship between TMT members' R&D-related functional experience and the firm's explorative R&D. Model 4 also show a similar positive and significant relationship (coefficient: 2.479, $p < 0.01$). These results support our Hypothesis 1, which stated that an increasing proportion of TMT members with R&D-related functional experience leads firms to engage more in explorative R&D activities. Model 3 tests the proposed relationship between the TMT members' science or engineering oriented academic background and the firm's explorative activity and finds a positive and significant relationship (coefficient: 0.229, $p < 0.05$). These results are further

Table 5 Regression results for explorative R&D based on non-patent references (NPRs)

Dependent variable Explorative R&D (NPRs)	Model 1	Model 2	Model 3	Model 4	Model 5	Model 6
Control variables						
R&D intensity	−0.0264* (0.160)	−0.00981* (0.160)	−0.00293* (0.165)	−0.00080* (0.156)	−0.0664* (0.162)	−0.00534* (0.159)
Firm size[a]	−0.103** (0.0807)	−0.105** (0.0805)	−0.0919** (0.0745)	−0.114** (0.0806)	−0.102** (0.0728)	−0.106** (0.0744)
Firm innovation experience[a]	−0.0548 (0.0469)	−0.0566 (0.0468)	−0.0688 (0.0442)	−0.0657 (0.0442)	−0.0730* (0.0426)	−0.0735* (0.0427)
Technological diversity	−0.411 (0.441)	−0.385 (0.442)	−0.399 (0.435)	−0.299 (0.459)	−0.350 (0.448)	−0.321 (0.451)
TMT average age[b]	−0.00343 (0.0622)	−0.00319 (0.0627)	−0.00150 (0.0613)	−0.0195 (0.0630)	−0.0130 (0.0619)	−0.0166 (0.0624)
Educational heterogeneity	0.554 (0.281)	0.642 (0.275)	0.737 (0.319)	0.638 (0.283)	0.765 (0.326)	0.769 (0.322)
Functional heterogeneity	1.356 (0.994)	1.132 (1.032)	1.275 (0.961)	1.144 (1.005)	1.135 (0.950)	1.070 (1.034)
_Cons	−0.852 (0.981)	−0.834 (0.979)	−1.118 (0.958)	−1.100 (0.953)	−1.319 (0.952)	−1.335 (0.988)
Independent variables						
TMT R&D experience (R&D Exp)		0.425 (0.229)		1.001 (0.445)		0.497 (0.434)
TMT Sci/Eng education (S&E Edu)			0.526** (0.213)		1.152** (0.450)	0.966** (0.472)
TMT average tenure (Tenure)				0.0538** (0.0265)	0.0655** (0.0318)	0.0732** (0.0321)
R&D Exp × Tenure				0.0979** (0.0599)		0.0430* (0.0753)
S&E Edu × Tenure					0.116* (0.0642)	0.0991* (0.0810)
Observations	356	356	356	356	356	356
Wald Chi-square	16.50**	20.06**	22.66***	24.93***	26.39***	29.24***

*** $p < 0.001$; ** $p < 0.01$; * $p < 0.05$; two-tailed tests; robust standard errors are in parentheses

[a] Transposed to log scale

[b] Standardized

supported by Model 5 (coefficient: 0.808, $p < 0.05$), lending further support for our Hypothesis 2. To test the moderation effect of the average tenure of TMT members with R&D-related functional experience or education, interaction terms of both R&D functional experiences and science or engineering academic experiences with the tenure variable were included in Model 4 and Model 5. Both models show positive significant interaction effects (coefficients: 0.246 and 0.101, both with $p < 0.05$). Model 6, the full model, shows consistent results as well. Fig. 1a, b show how both the effects of R&D experiences and science or engineering academic experience on explorative R&D were positively moderated by the TMT tenure. These results support both Hypotheses 3a and 3b.

Next, Table 4 contains the results of the empirical test using a definition of explorative R&D activities based on patent class data. Similar to the results presented in Table 3, it can

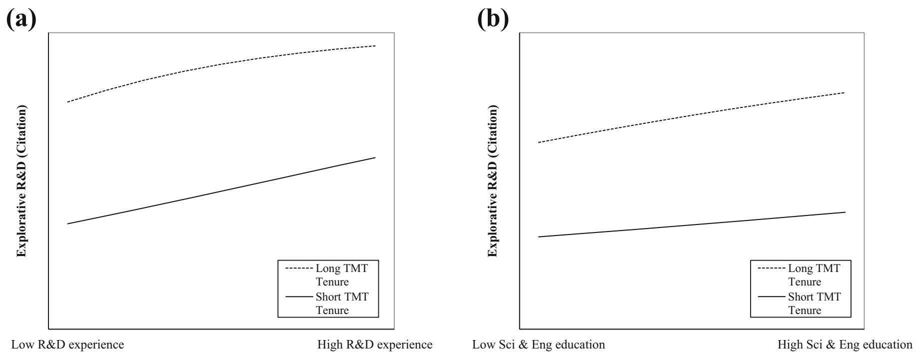

Fig. 1 The moderation effect of average tenure on the relationship between a firm's explorative R&D (calculated using patent citations) and the TMT's (**a**) R&D-related functional experiences, (**b**) science or engineering oriented academic background. Low (*short*) and high (*long*) are one standard deviation below/ above the mean value

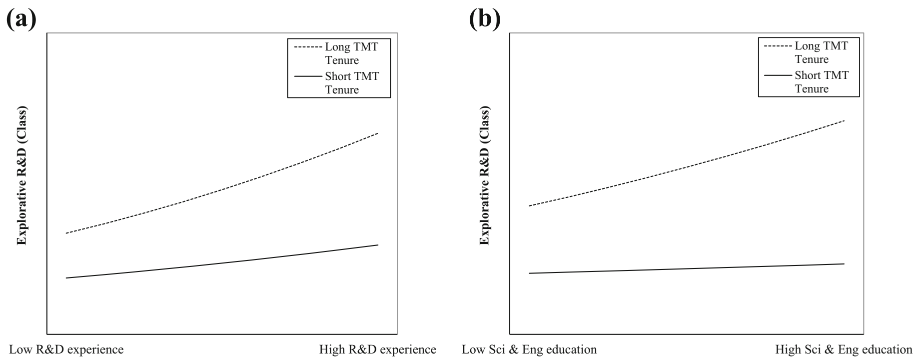

Fig. 2 The moderation effect of average tenure on the relationship between a firm's explorative R&D (calculated using patent classes) and the TMT's (**a**) R&D-related functional experiences, (**b**) science or engineering oriented academic background. Low (*short*) and high (*long*) are one standard deviation below/ above the mean value

be seen that the firm's innovation experience negatively influences its explorative R&D activities while the technological diversity of the firms and TMT's age increase the proportion of explorative R&D. The coefficient of TMT's R&D experience in Model 2 and Model 4 were 1.002 ($p < 0.01$) and 1.459 ($p < 0.05$), respectively, supporting our Hypothesis 1. The coefficients for the TMT members' science or engineering related academic experience were positive and significant in both Model 3 (coefficient: 0.349, $p < 0.05$) and Model 5 (coefficient: 0.248, $p < 0.05$). These results support Hypothesis 2. Moreover, the positive and significant interaction terms in Model 4 (coefficient: 0.0868, $p < 0.05$) and Model 5 (coefficient: 0.106, $p < 0.05$) confirm the proposed moderation effects of the average tenure of TMT members with R&D-related functional or education experience on the relationship between TMT characteristics and the firm's pioneering activities in new technological fields. Those results were supported by the results of the full model, Model 6. The moderation effect is also clearly visible in Fig. 2a, b.

Last, Table 5 contains the results of the empirical tests using a definition of explorative R&D activities based on non-patent references (NPRs). Model 1 indicates negative influences of R&D intensity and firm size on the firm's explorative R&D activities. Another difference the between previous analysis based on patent citation and class data and the models based on NPRs is that the effect of R&D-related functional experience of TMT members on the firm's explorative activities was statistically insignificant, not supporting Hypothesis 1. However, in support of Hypothesis 2, the influence of educational background in science or engineering was positive and significant in Model 3 (coefficient: 0.526, $p < 0.01$) and Model 5 (coefficient: 1.152, $p < 0.01$). These results imply that TMT members which are educated in science or technology lead to firm's R&D being more focused on basic science. The moderation effects of average tenure were positive and significant in both Model 4 (coefficient: 0.0979, $p < 0.01$) and Model 5 (coefficient: 0.116, $p < 0.05$). Above results were also statistically supported in the full model, Model 6. Fig. 3a, b show this positive interaction effect of average tenure on both relationships and support our Hypotheses 3a and 3b.

Additional analysis

Additional analysis was conducted to increase the robustness of the research, address potential effects of the diversity among the TMT, and investigate the link between explorative R&D and firm growth. First, one of the dependent variables of this research, the share of scientific references among all cited references in the firm's patents, captures the firm's explorative R&D activities through the relative level of scientific and technological knowledge in the R&D process (Van Vianen et al. 1990; Subramanian and Soh 2010). To strengthen the robustness of our approach, we performed analysis using another proxy for the level of firm's scientific engagement. The firm's scientific intensity, which is measured by the average number of scientific references per patent in the firm's patent portfolio, can be seen as directly reflecting the firm's efforts to apply scientific knowledge into their R&D (Van Vianen et al. 1990; Subramanian and Soh 2010). The results of the empirical analysis of the effects on scientific intensity, based on an ordinary least square (OLS) model, are shown in Table 6. Compared with the main analysis, both R&D intensity

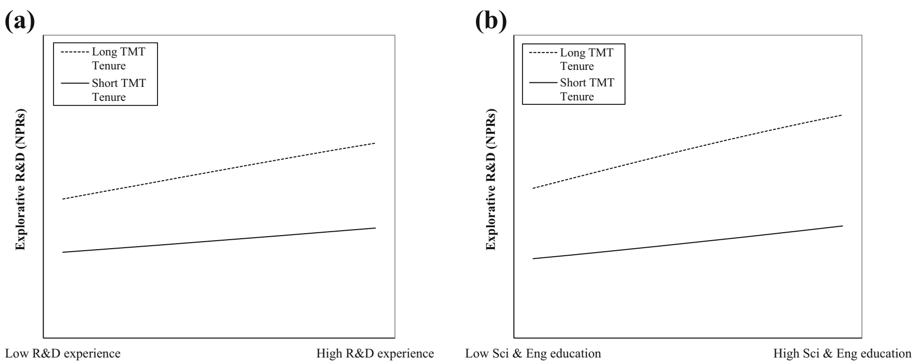

Fig. 3 The moderation effect of average tenure on the relationship between a firm's explorative R&D (calculated using non-patent references) and the TMT's (**a**) R&D-related functional experiences, (**b**) science or engineering oriented academic background. Low (*short*) and high (*long*) are one standard deviation below/above the mean value

Table 6 Regression results for explorative R&D based on scientific intensity

Dependent variable Explorative R&D (scientific intensity)	Model 1	Model 2	Model 3	Model 4	Model 5	Model 6
Control variables						
R&D intensity	27.60*** (4.459)	27.76*** (4.474)	27.87*** (4.464)	27.85*** (4.488)	28.08*** (4.467)	28.08*** (4.489)
Firm size[a]	6.061*** (1.925)	6.231*** (1.951)	6.026*** (1.925)	6.193*** (1.977)	6.170*** (1.941)	6.199*** (1.992)
Firm innovation experience[a]	−3.416** (1.663)	−3.467** (1.667)	−3.395** (1.662)	−3.557** (1.677)	−3.421** (1.664)	−3.409** (1.679)
Technological diversity	0.144 (0.111)	0.156 (0.113)	0.156 (0.111)	0.157 (0.113)	0.175 (0.112)	0.176 (0.114)
TMT average age[b]	0.0297 (1.439)	0.0392 (1.441)	−0.0166 (1.439)	−0.0145 (1.452)	−0.0592 (1.444)	−0.0499 (1.452)
Educational heterogeneity	−0.0625 (0.100)	−0.0662 (0.101)	−0.0694 (0.100)	−0.0595 (0.101)	−0.0728 (0.101)	−0.0741 (0.102)
Functional heterogeneity	0.253 (0.214)	0.262 (0.215)	0.262 (0.214)	0.273 (0.216)	0.262 (0.214)	0.261 (0.216)
_Cons	48.82** (24.71)	50.43** (24.91)	47.50** (24.73)	53.44** (25.25)	55.24** (25.35)	55.27** (25.73)
Independent variables						
TMT R&D experience (R&D Exp)		0.0439 (0.0774)		0.0564 (0.148)		0.0186 (0.170)
TMT Sci/Eng education (S&E Edu)			0.0716* (0.0645)		0.0753* (0.124)	0.0828** (0.142)
TMT average tenure (Tenure)				0.459 (0.786)	0.975 (0.839)	0.942 (0.893)
R&D Exp × Tenure				0.0182** (0.0225)		0.00287** (0.0276)
S&E Edu × Tenure					0.0271** (0.0194)	0.0285** (0.0238)
Observations	356	356	356	356	356	356
Adjusted R-squared	0.143	0.144	0.147	0.146	0.154	0.154

*** $p < 0.001$; ** $p < 0.01$; * $p < 0.05$; two-tailed tests. Standard errors are in parentheses

[a] Transposed to log scale

[b] Standardized

and firm size positively and significantly affect the firm's scientific intensity. Moreover, the firm's past innovation experience, which was measured by the number of the firm's granted patent, was negatively significant. In other words, the firm's increasing use of scientific knowledge in its R&D increased with increasing focus being placed on R&D and the size of the organization. Meanwhile, the firm's accumulated innovation experience based on patenting activity, which is more closely related with technology-based R&D, lowers the amount of scientific knowledge used in the firm's R&D processes. Similar to the previous analysis, we find that there is no relationship between the R&D functional experiences of TMT member and the firm's scientific intensity whereas increasing the proportion of TMT members with an educational background in either science or engineering is positively related with scientific intensity. We also investigated the moderation effects of the TMT members' tenure and conclude that our research model shows consistent results with the models based on other aspects of explorative R&D.

Previous studies from the fields of organizational and strategic management also have emphasized the important role of diversity on strategic decision making as well as organizational performance (Talke et al. 2010; Qian et al. 2013). As we mentioned, heterogeneity increases the potential for conflict among the TMT members, however, some streams of literature argue that high heterogeneity among the TMT members can help them to develop their strategic decisions based on various viewpoints (Talke et al. 2010). Consequently, we conducted additional empirical tests to investigate how the heterogeneity of the firm's TMT members influences their R&D decisions. Adding to our empirical analysis which included the TMT's functional and educational heterogeneity as control variables, we included interaction terms to address potential effects of both heterogeneity variables on the relationships between our explanatory variables and the firm's explorative R&D. However, the results of these empirical tests indicated that the interaction effects of heterogeneity of the TMT members were not statistically significant. Despite prior studies mentioning the central role of heterogeneity in organizational behavior (Talke et al. 2010; Qian et al. 2013), we find no empirical evidence for an influence of the diversity of TMT members on the R&D decision making. We assume that these results could be related to the data sample used in the analysis. For analyzing the R&D activities of firms which are facing high technological uncertainties, our sample is comprised of firms operating in a series of high-tech industries. Because firms in high-tech industries usually focus on their R&D activities, there is a potential bias in case our sample firms specifically selected TMT members with innovation-related experiences, which might not be the case for firms in other industries.

Last, many innovation studies indicate the role of innovation as a driver for firm growth (Del Monte and Papagni 2003). Especially, it is argued that explorative innovation is related to long-term performance as well as the organization's survival (March 1991; Uotila et al. 2009; Piao 2010; Vagnani 2015). In this respect, we additionally tested whether the different kinds of firm's explorative R&D activities stimulate firm growth. For measuring firm growth, we calculated the rate of sales growth of the sample firms using the following formula:

$$\text{Firm Growth}_{\text{it}} = \left(\frac{\log \text{SALES}_{\text{it}+3} - \log \text{SALES}_{\text{it}+1}}{2} \right) \times 100$$

where SALES_{it} denotes firm *i*'s total sales in million dollar in year *t* (Kim et al. 2016). As we assumed a one-year time lag to account for the effects of TMT's decisions on the firm's R&D activity to manifest, we similarly use a one-year time lag for firm growth as well. Moreover, a two-year time lag is considered when proxying the rate of sales growth to avoid volatility (Kim et al. 2016). To investigate the linkage of the three different kinds of explorative R&D, which are influenced by the TMT's innovation-related characteristics, and firm growth, this research employed empirical models testing for mediation effects. By conducting stepwise tests, we can verify the mediation effects of the explorative R&D on the relationships between TMT members' characteristics and firm growth (Baron and Kenny 1986). We employed ordinary lease square (OLS) models and Table 7 contains the simplified results for testing the possible mediation effects. In Step 1, both independent variables positively affect the rate of the firms' sales growth. Excluding the effects of R&D functional experience on firm's explorative R&D measured by NPRs, the results show that

Table 7 Results of the mediation effects of Explorative R&D (Citation, Class, NPRs) on the relationships between TMT's innovation-related experiences (R&D Experience and Science and Engineering Education) and Firm growth

Independent variables	Mediators	Dependent variable	Sobel test	Step 1 (IV–DV)	Step 2 (IV–mediator)	Step 3 (mediator–DV)	Step 4 (mediator controlled IV–DV)
R&D Exp	Explorative R&D (Citation)	Firm growth (rate of sales growth)	2.006* (0.006)	0.143* (0.107)	0.140** (0.0152)	0.0890** (0.0433)	0.0901 (0.118)
S&E Edu			2.029* (0.007)	0.161* (0.0890)	0.0251** (0.0127)	0.0890** (0.0433)	0.126 (0.0983)
R&D Exp	Explorative R&D (Class)		2.955** (0.001)	0.143* (0.107)	0.158** (0.0115)	0.0239* (0.0079)	0.0782 (0.119)
S&E Edu			1.799†	0.161* (0.0890)	0.0215** (0.0096)	0.0239* (0.0079)	0.133 (0.0991)
R&D Exp	Explorative R&D (NPRs)		1.252 (0.002)	0.143* (0.107)	0.0364 (0.0284)	0.0587** (0.0100)	0.0749 (0.119)
S&E Edu			1.988* (0.001)	0.161* (0.0890)	0.0243** (0.0115)	0.0587** (0.0100)	0.135 (0.0990)

*** $p < 0.001$; ** $p < 0.01$; * $p < 0.05$; † $p < 0.1$; two-tailed tests; robust standard errors are in parentheses. Results of control variables and moderator are not shown here

the effects of the independent variables on the mediators, three different measures of explorative R&D, were statistically significant in Step 2. Next, Step 3 indicates that explorative R&D significantly and positively influences firm growth. Last, we confirmed that all of our independent variables were not statistically significant with firm growth under three different mediators in Step 4. By following Baron and Kenny (1986), these results support that the relationships between TMT member's innovation-related experiences and firm growth were partially mediated by firm's explorative R&D activities. An additional Sobel test, which is employed to assess whether the mediation effects are significant, also confirms our results.

Conclusion

This research analyzed the effects of TMT's innovative experiences and backgrounds as well as their average tenure on the firm's explorative R&D activities. We hypothesized that either functional experiences in R&D or academic backgrounds in engineering or science among the observable characteristics of the TMT affect the extent to which firms engage in explorative R&D projects. Also, we proposed that the relationship between the proportion of TMT members with R&D-related experience or educational background and the firm's explorative R&D is moderated by the average tenure of these TMT members. The hypotheses were tested on a sample of TMTs biographic information, financial, and patent data of 89 firms in US high-tech industries from 2006 to 2009. All suggested hypotheses were supported and allow us to draw the following conclusions:

The innovation-related experiences of TMT members affect the firm's R&D activities. In other words, R&D activities were more focused on exploration in firms in which a larger proportion of TMT members have innovative experiences such as R&D-related

employment experience or majoring in engineering or sciences. Specifically, this research analyzed three different aspects of explorative R&D in terms of applying new technological knowledge (patent citations) as well as scientific knowledge (non-patent references), and exploring new technological fields (patent classes), to address the effects of TMT member's decision on the firm's R&D activity. Our empirical results show that there are positive influences of TMT members with R&D functional experiences on firms' explorative R&D when explorative R&D is defined focusing on technological, rather than science aspects. If an organization's decision makers have more work experiences related to R&D, the organization's R&D tends to apply new technological knowledge as well as knowledge from new technological fields. Nonetheless, we were unable to find evidence for a relationship between the R&D functional experience of the TMT members and the firm's explorative R&D in terms of adopting scientific knowledge (non-patent references). For TMT members with an academic background in science or engineering, on the other hand, we find positive effects on the firm's explorative R&D activity in terms of both technological and science aspects. Specifically, increasing the proportion of science and engineering educated TMT members in an organization leads to the organization actively applying new technological knowledge, knowledge from new technological fields, and scientific knowledge in their R&D. It seems that these different results are due to the different way of achieving objectives and methods when developing the individual's cognitive bases through experiences in R&D functions or through science or engineering education. Individuals with functional experiences in R&D usually tend to accomplish their R&D objectives in technological ways due to their unfamiliarity with scientific knowledge. Moreover, scientific knowledge also requires considerable time to understand and is difficult to directly apply in the development process. Meanwhile, individuals with science or engineering education usually emphasize problem solving based on technological knowledge as well as scientific knowledge. During their higher education, students are encouraged to solve fundamental problems which require an approach from the scientific perspective.

Based on the upper echelon theory suggested by Hambrick and Mason (1984), our results confirm that past experiences of individuals affect organizational behavior such as the direction of the innovation activities. R&D departments and science or engineering subjects put strong emphasis on innovation, and TMT members with such experiences have R&D-favoring cognitive bases and strive to enhance the organization's competitiveness through R&D and innovation. Therefore, increasing proportions of members with innovative experiences in TMTs lead to firms investing more resources into explorative R&D projects.

Next, we demonstrated how the average tenure of these TMT members affects the decision making process of and moderates the relationship between innovative experiences and explorative R&D activities. Even if TMT members with innovative experiences are willing to conduct explorative projects, in case of being junior members with a short tenure, their weak influence in the TMT can make it more difficult for them to lend support to high-risk R&D. TMTs with a large proportion of members experienced in innovation, who also hold more power due to a long tenure in the TMT can allow them to better manage and deploy large amounts of resources to support explorative R&D. The empirical results of this study demonstrate the positive moderating effect of the average tenure of TMT members with innovation-related experiences on the relationship between innovation-related TMT characteristics and the explorative activities of the firm.

Discussion

Firms within high-tech industries, which mainly concern themselves with highly complicated technology, run the risk of overly focusing on exploiting existing or familiar knowledge which can have negative impacts on their competitiveness (March 1991). To achieve breakthrough innovation earlier than its competitors, a firm is forced to pioneer new technologies and test experimental alternatives (Ahuja and Lampert 2001; Mudambi and Swift 2014). This research shows that the extent to which a firm pursues explorative R&D is a result of the characteristics of its top management. The presented results highlight the role TMT members with innovative experiences play in shaping the direction of a firm's R&D strategy, especially towards explorative R&D. In terms of managerial implications, we suggest firms to hire TMT members with innovative experiences to examine firm's R&D projects and establish firm's R&D policies more comprehensively. Generally, having researchers and engineers with superior ability is considered a key factor of success in individual R&D projects. But, as competitiveness in high-tech industries mainly depends on technologies, the TMT setting the direction of the R&D is equally important. Traditionally, the role of TMT was limited to approving investments in innovation without examining the details of R&D projects, as TMT often consist of members with backgrounds in business, financial, accounting and law. However, considering the increasing importance of R&D for the growth of organizations, this research suggests that increasing the proportion of TMT members with innovative experiences allows firms to direct their R&D strategies towards exploration which opens the opportunity to the a first-mover and capture future-opportunities in advance. Also, this research fills a gap in the existing literature by investigating the factors which affect the organization's R&D strategy. Most existing ambidexterity literature highlights the importance of implementing an ambidexterity strategy rather than addressing the determinants that impact the relative proportions of exploitation and exploration (March 1991; He and Wong 2004; Gupta et al. 2006). By investigating the organization's internal factors in terms of TMT and their R&D behaviors, therefore, we state that firms can enhance their ambidexterity strategy by appointing innovation-experienced individuals to the TMT, which results in increasing explorative R&D.

Along with the relationship between TMT characteristics and R&D strategies, we also provide evidence for the positive link between firm's explorative R&D and firm growth. Although considerable innovation literature argued on the close relationship between R&D and firm growth, only a few studies investigated the link from a comprehensive perspective. By testing mediation effects of explorative R&D on the relationship between firm's internal factors in terms of top manager's characteristics and organizational performance, this research suggests that organizations are required to appoint innovation-experienced top managers to increase innovation performance as well as financial performance. Moreover, as our results show that there is a time lag between firm's explorative R&D activity and firm growth, we highlight the important role of explorative R&D to avoid myopic ways to firm's long-term performance (Uotila et al. 2009). While the limited resources of firms induce their top managers to deploy R&D resources into exploitative R&D projects to seek short-term performance, we argue that firms are required to increase the proportion of explorative R&D for the long-term survival (Piao 2010).

Contributing to the literature on empirical research on innovation, this research shows how firms' R&D activities can be analyzed in detail through patent analysis. So far, previous research only focused on patent citations or patent classes for analyzing firms' innovation activities. Though non-patent references are known to represent the basicness or scientific characteristics of patented innovation (Trajtenberg et al. 1997; Callaert et al. 2014), most prior research did not apply them to study innovation in firms. Also, the results of this research show the consistency of measuring firm's R&D activity using various patent-based indexes. The additional analysis shows the robustness of the patent indexes in dealing with scientific aspect of patent data using both proportions and average values.

While providing valuable insights into factors influencing the direction of organizational R&D, this study has several limitations, which we hope can be overcome by future research. In defining scientific non-patent references, we considered journal papers, conference proceedings and books. However, we considered citations to all published journal papers, rather than only considering papers published in Science Citation Index (SCI) listed journal. Even though journal papers are considered to be dealing with more basic and fundamental phenomena, some research argued that journal papers from SCI-listed journals have a higher impact among the non-patent references (Callaert et al. 2006). Future research can further distinguish types of non-patent references by further looking into their characteristics to select references with the highest likelihood of affecting R&D outcomes. There are also some limitations in measuring and defining the biographical information of the TMT members. While we collected TMT data from various sources to cross-check available information, data on the background of some individuals was partially missing. Moreover, this research was unable to find evidence for the role of TMT heterogeneity in R&D decision making due to possible sampling issue. Future research can overcome the above-mentioned limitations on collecting biographical information by using other sources such as direct interviews with the TMT members to capture their innovation-related characteristics in more detail. Also, we believe that the sample firms from various industries would contribute to address the effects of the heterogeneities on the organizational behaviors.

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