New Perspective of Radical Innovation based on Upper Echelon Theory

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This study examines how experience diversity of chief technology officer (CTO) drives radical innovation of the firm, and the moderation effect of group attributes of top management team. Using data of 148 firms in U.S. manufacturing industries, this study finds that a CTO' s diverse functional experience increases a firm radicalness, and diverse industrial experience also increases the radicalness. This study also examined the moderating effect of top management team (TMT) characteristics such as TMT size, TMT tenure, and gender composition in TMT. The positive relationship of CTO knowledge diversity and firm radicalness is weakened as TMT size or TMT tenure increased while the relationship is strengthened as gender diversity in TMT increased. These results of the analysis of firm-level radicalness provide implications for both academics and practitioners.

Keywords : radical innovation; chief technology officer; experience diversity; top management team

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I. INTRODUCTION

The capability to constantly develop new technologies in a rapidly changing environment ensures a firm's survival and competitive advantage (Christensen, Suárez, & Utterback, 1988; Cooper & Schendel, 1976). Accordingly, many scholars highlight the importance of radical innovation which indicates those foundational innovations that serve as the basis for many subsequent technological developments (Ahuja & Lampert, 2001). Radical innovation is a long-term growth engine for firms (Leifer, O'Connor, & Rice, 2001) and the foundation for subsequent technological developments (Datta & Jessup, 2013), and provides subsequent generation of economic rents (Nijssen, Hillebrand, & Vermeulen, 2005; Song, Van, & Weggeman, 2005).

Several studies have emphasized that radical innovation is driven by the initiative of top managers (Leifer et al., 2001; O'Connor & Ayers, 2005). The first reason is that radical innovation cannot be pursued spontaneously by organization itself. While radical innovation requires new routines that is quite different from the existing ones that have been implemented (Leifer et al., 2001), organizations tend to stay in existing routines due to path dependence (Sydow, Schreyögg, & Koch, 2009). Organizations do not change their routines to pursue radical innovation by themselves (Nelson & Winter, 1982), the role of the top manager, who aggressively leads the development of new trajectories, is crucial. Second, radical innovation is risky, costly, and requires a lengthy process (Abernathy & Clark, 1985; Utterback, 1994). Because of these natures, strong willingness and commitment of leadership are essential to implement radical projects. For this reason, unlike the incremental innovation that takes place under a horizontal decision-making structure, radical innovation is generally pursues in a centralized decision structure (Moon, 2006). Therefore, top managers are key triggers for radical innovation.

While the importance of top managers is emphasized in studies of radical innovation, however, there are few empirical evidences. To build a theoretical foundation on this issue, it is necessary to develop a more sophisticated logic based on empirical evidence. The purpose of this study is to empirically specify the mechanism of radical innovation from the perspective of upper echelon theory.

Many studies in the upper echelon theory have examined the impact of the

CEO or TMT on firm innovation (e.g., Chung, Kang, & Cho, 2014; Finkelstein & Hambrick, 1996). There is no doubt that these are important decision-making individuals or groups in innovation activities of firms. However, it is hard to conclude that CEOs or TMTs are the most critical player since it is yet ambiguous that they have a direct impact on performance of innovation, especially radical innovation. On the other hand, there are relatively few studies on the impact of the chief technology officer (CTO) on innovation even though they are executives who handle overall technology development including radical technologies with technological expertise. In order to understand the mechanism of radical innovation, it is necessary to examine the role of the technological executive such as a CTO in more detail.

In this paper, the prime decision maker in radical innovation is expected to be the CTO, considering the "technology push" nature of most radical innovations (Benedetto, DeSarbo, & Song, 2008), the importance of technological expertise in decision-making on radical projects (Leifer et al., 2001; O'Connor & Ayers, 2005) and the CTO's budget authority for R&D (Herstatt, Tietze, Nagahira, & Probert, 2007). Therefore, this paper examines the relationship between the characteristics of the CTO and radical innovation. We pay particular attention to the experience diversity of CTOs. Cognitive diversity based on prior experiences is an important variable on the decision-making of firm innovation (Smith, 1994; Tushman& Nadler, 1978). Based on the existing studies of the cognitive base of executives (Cyert & March, 1963; March & Simon, 1958), we examine how the functional and industrial experience diversity of the CTO affects the decision on radical innovation of firms.

Even though the basic premise of this study is that the CTO is the most crucial decision maker in radical innovation, the CTO's decisions should be considered within the context of TMT. The CTO cannot make all the decisions apart from the TMT. CTO's decision on radical innovation and its implementation can be influenced by the social interactions and information processing within the TMT. Top managers assess the problem and find solutions through group discussion, trial and error, and sounding out (Huber & Daft, 1987). In this process, if the preference of the CTO is well aligned with the collective tendency of the TMT, pursuing radical innovation will be synergistic; otherwise, they will produce inconsistencies and inefficiencies. Therefore, we believe that the collective nature of the TMT will have an indirect impact on the decision-making of the CTO. To prove this, we will examine how collective characteristics such as size, average tenure, and gender diversity of the TMT moderate the relationship between the

CTO’s experience diversity and radical innovation.

The study has several contributions. Until now, the upper echelon theory-based research has focused on TMT and CEO oriented variables, but the CTO who has a direct influence on technology development and innovation activities has been overlooked. This study found that cognitive characteristics of CTOs are critical variables for predicting important outcomes such as radical innovation. We expect that this study would add new evidence to the argument in upper echelon theory that individual top managers do matter for innovation performance. Another important contribution of this study is our consideration of industry variable in examining knowledge diversity of executives. This concept has received much less attention than by functional diversity (e.g., Cohen & Bailey, 1997; Monge & Eisenberg, 1987), educational background diversity (e.g., Carpenter & Fredrickson, 2001; Wiersema & Bantel, 1992) in upper echelon theory. However, our finding results show that the diversity based on the prior industrial experiences of an executive has a critical impact on firm-level innovation. This expands the breadth of a perspective on the characteristics of firm executives. This study also provides important implications in the area of technological innovation theory. While a number of studies in innovation theory have conceptually suggested the importance of leaders in radical innovation (Benedetto et al., 2008; Herstatt et al., 2007), there was no empirical evidence that examined how the executives affect the radical innovation. In particular, this study traces the cognitive base of the CTO, which is the foundation of the current decision, to prove that it drives radical innovation. We also attempt to show how social interaction and information processing in TMT context affect this relationship. To our knowledge, this is the first study to examine the role of the interplay between the technological executive (CTO)’s cognitive base and social interaction context of decision-making group (TMT) to investigate the origin of radical innovation.

II. THEORY DEVELOPMENT AND HYPOTHESES

1. Radical Innovation and Chief Technology Officer

Inupper echelon theory, Hambrick and Mason (1984) argued that a firm’s outcome can be viewed as both a reflection of the values and the cognitive base of primary top managers in their organization. Likewise, a firm’s innovation outcome is largely influenced by top managers. For this reason, a number of

studies have focused on the correlation between top managers and firm innovation (Bantel & Jackson, 1989; Jehn, Northcraft & Neale, 1999; Pegels, Song & Yang, 2000; Wirersema & Bantel, 1992). The TMT has significant authority over control of corporate strategy, innovation spending, and ownership structure (Baker & Mueller, 2002; Zahra & Pearce, 1989).

Recently, there has been growing interest in radical innovation, which is the development of novel and unique technologies that have an impact on future technologies (Dahlin & Behrens, 2005). It has a long life cycle and is unpredictable, sporadic (with stops and starts, deaths and revivals), non-linear, and stochastic (with unpredictable exogenous events) (Leifer et al., 2001). Many studies in this theme emphasize that radical innovation is largely determined by the initiative of top managers (Leifer et al., 2001; O'Connor & Ayers, 2005). Leifer, O'Connor, and Rice (2001) conducted a longitudinal study of 12 radical innovation projects of ten large and mature companies over the course of six years. In 90 percent of companies, executives played an active role in driving radical innovation by issuing a call to arms that stimulated innovation. Such research emphasizes that the success of radical innovation ultimately lies with the strong will, effective decision-making, and driving force of top managers (Abernathy & Clark, 1985; Utterback, 1994).

However, the issue of which player exerts the most critical influence on radical innovation has not yet been sufficiently discussed. Until now, much of the studies based on upper echelon theory have dealt with the relationship between the attributes of top managers and innovation (Bantel & Jackson, 1989; Jehn et al., 1999; Pegels et al., 2000; Wirersema & Bantel, 1992). And most of the studies found a relationship between the individual characteristics of the CEO or the collective characteristics of TMT and firm innovation. For example, Baker and Mueller (2000) posited that the direction of decision-making regarding R&D spending changes depending on the tenure, education, and functional experiences of the CEO. Finkelstein and Hambrick (1996) stated that the compositional heterogeneity of the TMT influences strategic choice. Chung, Kang and Cho (2014) demonstrated that a firm's patent-based innovation performance changes according to the diversity of the TMT's industrial knowledge.

However, whether the CEO or TMT plays the most decisive role in influencing a firm's technological innovation is still questionable. The CEO does not engage in detailed process of projects in organization even though the CEO is the final decision maker within a firm (Boyd, 1995). New technologies are directly influenced by the effort of the R&D or product departments, and the CEO's role

is more of an approving body or gatekeeper for the firm's information processing (Cao, Simsek, &, Zhang, 2010).

Considering the mechanism of radical innovation, it is easy to deduce that the CTO who is directly responsible for technological development is the prime decision maker. First, due to the "technology push" nature of most radical innovations, the capabilities of a technology-related leader are important (Benedetto et al., 2008). Radical innovation re-establishes the marketplace economy, replaces pre-existing technology, and generates a completely new product category (Leifer et al., 2001). Harpaz and Meshoulman (1997) stated that as the strategic significance of technology becomes more important, the role of the key individual who effectively handles technology contingencies such as the CTO becomes extremely decisive. In addition, the future plan for technological development is managed by the top leader of the R&D unit (Leifer et al., 2001; O'Connor & Ayers, 2005), and CTOs, in particular, have full budget and approval authority over R&D (Herstatt et al., 2007). Therefore, the CTO is the most critical decision maker that leads radical innovation.

Many scholars specified the activities of the CTO to highlight the importance of the role. Smith (2003) identified that CTOs affect firm innovation through specific activities as follows: monitoring new technologies; assessing the potential of new technologies; explaining firm's technologies and future strategic plans to the trade media; technological evaluation of potential mergers and acquisitions; and promoting the firm's technological reputation and capturing valuable data by participating in government, academic, and industry groups. On the other hand, Adler and Ferdows (1990) underlined that the CTO's most important role is to foster positive interaction between technological capabilities in various parts in the firm. This activity involves the transfer of new technology developed in the firm's central labs to divisions for incorporation into other products or processes.

In sum, the CTO is involved in the whole process from the beginning until the achievement of radical innovation. Thus, the characteristics and decision-making style of the CTO, who is the trigger of radical innovation, determines the pattern of strategic guidance for radical technology development and the creation of synergy among the firm's disparate resources. In the case of radical innovations, totally different characteristics of CTO are required because radical innovations take a completely new path and require a different style of decision-making (Herstatt et al., 2007). This paper focuses on the cognitive base of the CTO and studies its effects on decision-making and performance regarding radical innovations.

2. CTO's Cognitive Base

The theoretical roots regarding the CTO's decision-making trace back to March and Simon's behavioral theory of firms (Cyert & March, 1963; March & Simon, 1958). According to this theory, decision makers process information and make choices based on their cognitive base. Executives make un-rational decisions because of their limited information processing capabilities, the complexities of decision-making, incomplete information, etc. Decision makers cannot see all of the issues regarding the organization and the environment and their perception is limited by their field of vision. In particular, they can only perceive phenomena, which further limit their perception. And even this information that is acquired through limited perception is interpreted differently depending on the executive's cognitive base (Hambrick & Mason, 1984). Executives recognize the situation based on their own values or interests and based on these factors, they make their strategic decision (Hambrick & Mason, 1984). Therefore, the cognitive base is the foundation that determines the decision-making tendencies and capabilities of decision makers (Souitaris & Maestro, 2010).

The cognitive base of top managers is formed through the accumulated knowledge of their education, experience and technical background (Smith, 1994; Tushman& Nadler, 1978). Top managers' knowledge acquired from past experiences is an especially important cognitive base that greatly influences decision-making. A number of studies suggest that the past experiences of top managers influence their decision-making, as well as the scope of their activity in the present firm (Baty & Evan, 1971; Srensen, 1999). This study focuses on the experience diversity of CTOs. Depending on managers' industrial background or the diversity of their past experiences, the scope of their ability to recognize technological opportunities is determined (Shane, 2000), and depending on their cognitive diversity, their ability to generate new values by adding new knowledge to pre-existing knowledge is also determined (Talke, Salomo, & Kock, 2011). Therefore, the experience diversity of CTOs becomes an important variable in predicting the radicalness of a firm. This paper will study the influence that a CTO's experience diversity has on radical innovation, focusing on CTOs' industrial and functional experiences.

3. Two Types of CTO Experience Diversity

Following a rich history of research on top managers, this paper will first assess the functional experience diversity of CTOs (which is defined as the heterogeneity of functional experiences of the CTO), followed by the CTO's industrial knowledge diversity (which is defined as the heterogeneity of industrial experiences of the CTO) in order to analyze the relationship with a firm's radical innovation.

*Functional experience diversity of the CTO.*If the histories of functional experiences of top managers differ, their attitudes, knowledge, and perspectives will also differ (Dearborn & Simon, 1958; Hambrick & Mason, 1984). No matter what kind of information or knowledge managers come across, they will perceive and interpret it according to their functional training (Dearborn & Simon, 1958). And this will influence how manager behave throughout each of the stages of the innovation process (Baker & Mueller, 2002).

Because executives who are specialized in a particular function and those with general function experiences have different decision-making patterns (Geletkanycz & Black, 2001), their influence on radical innovation will also differ. We expect that CTO's functional experience diversity will affect radical innovation in several ways.

First, radical innovation requires knowledge regarding not only R&D and technology engineering but also the firm's overall strategies including analyzing emerging markets and deciding on appropriate acquisition deals (Leifer et al., 2001). Various experiences regarding diverse functions will provide advantageous in pursuing radical innovation. For example, knowledge regarding marketing or sales can provide synergistic effects. If a firm has great capabilities to recognize the future consumers who will form a new market, and to capture their potential needs, the success rate of its technology development will increase (Christensen, 1997; Leonard-Barton, 1995; Lynn, Morone, & Paulson, 1996). HR experiences will also play a complementary role because the maturity of radical innovation is dependent on organizational attributes such as a culture supporting new changes, and a rewarding system for novel achievement (Leifer et al., 2001). Generalists with diverse functional experiences have expertise of greater strategic relevance than specialists with specific functional expertise (Finkelstein & Hambrick, 1989). As such, CTO with diverse functional experiences will take into consideration various comprehensive strategies in order to effectively develop radical technology.

Second, top executives with deep expertise in a functional area have a tendency to adhere to existing strategies, are characterized by a narrowing of perspective, and are less flexible decision-making (Beyer et al., 1997). Chandy and

Tellis (1998) stated that firms that have a greater willingness to cannibalize on their existing technology have a higher potential for radical innovation. The willingness to cannibalize refers to the extent to which a firm is prepared to reduce the actual or potential value of its own former investments. In this respect, a functional specialist will likely see radical innovation as burdensome. Conversely, top managers with high functional diversity are less likely to be narrowly parochial. They will also be more flexible when it comes to moving to a different trajectory of technology (Raskas & Hambrick, 1992).

Lastly, CTOs with high functional diversity come to have both larger and more structurally sparse networks (Monge & Eisenberg, 1987). A diverse network is generally an important precursor to novel innovation (Rothwell & Zegveld, 1985; Shrivastava & Souder, 1985). This is because various information and knowledge inflows through a diverse network, creating a rich knowledge pool in which innovative ideas are created through a combination or recombination of various knowledge (Swan, Jacky, Newell, Scarbrough, & Hislop, 1999). With the use of diverse networks, therefore, a functional generalist will increase the novelty of radical innovation.

*Industrialknowledge diversityof the CTO.*The industrial experience of top executives influences the preference for and evaluation of new technology domains (Shane, 2000). We expect this industrial experience to also influence the attitude and decision-making of the CTO regarding radical innovation as further explained below.

Radical innovation is achieved through the smooth recombination of new or emergent knowledge (Schoenmarkers & Duysters, 2010). This emergent knowledge provides the valuable new components that can lead to radical innovation (Ahuja & Lampert, 2001), but if the CTO' s knowledge is limited to a particular industry, the CTO will not be able to fully recognize the real properties and latent potential of emerging technologies outside of particular industry domain (Nerkar, 2003). Bantel and Jackson (1989) argue that if domain knowledge is homogeneous, the executives will not be able to recognize the importance of external opportunities and will not embrace them. And even if superiors or subordinates propose new and innovative items, there is a high possibility that the CTO will reject these proposals. This limits the development of promising technology. As a result, the higher the CTO' s industrial diversity, the more likely the CTO will pursue radical innovation.

Also, during the process of assimilating and utilizing new technology, knowledge diversity increases the relative novelty of the technology that is being

developed (Adler, 1988). Technological novelty becomes possible when new knowledge from diverse industrial domains is sourced to acquire a distinct technology (Datta & Jessup, 2013). If a CTO has knowledge regarding diverse technology domains, the CTO will be more adept at leading the cross fertilization of multiple technologies, which will enhance the novelty of the technology.

Furthermore, given the nature of radical innovations, it is imperative for project leaders to be able to deal with highly complex knowledge combination (O'Connor & Ayers, 2005). If firms come across diverse technologies, it is generally very difficult for CTOs to lead technological development in various domains (Adler, 1988). However, if the CTO has knowledge regarding diverse domains, the CTO possesses excellent capability in solving complex problems such as combining or re-combining various knowledges (Talke et al., 2011).

Therefore, we predict that the CTO's industrial and functional experience diversity will have a positive association with radical innovation. Therefore, we propose the following hypotheses:

Hypothesis 1a: The functional experience diversity of the CTO will be positively associated with a firm's radical innovation.

Hypothesis 1b: The industrial experience diversity of the CTO will be positively associated with a firm's radical innovation.

4. Characteristics of top management team

Even if the CTO is the ultimate decision maker, the CTO's decisions regarding radical innovation must be considered within the context of the TMT. This is because the CTO cannot make decisions independent of the TMT and because the direction of decision can be influenced by the social interaction of the TMT. Ng and Burke (2005) stated that in order to increase the effectiveness of a firm's overall decision-making, the individual executives' needs and values must align with the attributes of the group. In order to more accurately understand the decision-making mechanism of radical innovation, it is valuable to investigate how the TMT's collective attributes potentially interact with CTO's individual knowledge base to influence firm innovation.

Within the TMT, different sets of people form unique collective attributes (Graen & Uhl-Bien, 1995; Lord, Brown, Harvey, & Hall, 2001) and this determines the pattern of interaction between executive members, including how they socialize and communicate (Bantel & Jackson, 1989; Pelled, Eisenhardt, & Xin, 1999). These patterns of social interaction in the TMT group shape the way

decision makers understand and interact with their environment (Maitlis, 2005). Executives define problems and find meaning through discussions, trial and error and sounding out with other executives (Huber & Daft, 1987). During this process, if the CTO's individual tendencies are compatible with the collective attributes of the TMT, decisions regarding radical innovation will have a synergistic effect, but if the two are incompatible, this will give rise to inefficiencies. Therefore, within the context of finding the most appropriate fit for radical innovation, we will assess how the impact of the CTO's experience diversity on radical innovation is moderated by the collective attributes of the TMT.

TMT tenure. Tenure is an important determinant of the communication patterns of the members of the group (Allen & Cohen, 1969; Camella, Park, & Lee, 2008). Prior literature suggested the influence of group members' average tenure on the firm's interaction and information processing patterns.

Many scholars argued that group tenure limits constructive communication (Pelz & Andrews, 1966; Staw, 1977). People who have worked together for a long time tend to develop standardized ways of communicating (Katz, 1982; Nielson & Nielson, 2013). As the average tenure is longer, group members can anticipate the viewpoints of the other members, which hamper the level of overall communication (Katz, 1982; Tihanyiet al., 2000). Long tenured members usually avoid communication that breaks the pattern of behavior that they have grown accustomed to (Staw, 1977). This leads to isolation from new sources of information (Pelz & Andrews, 1966). For this reason, firms with long tenure become increasingly resistant to changes in their familiar trajectory.

Moreover, we posit that long tenure decreases creativity and the desire to generate novel initiatives. Continued interaction between the same team members over time diminishes the cognitive diversity of the TMT which in turn decreases the possibility of developing novel technologies. The more time members spend with each other, their perspective, knowledge, and values may assimilate (Van Maanen & Schein, 1979). In addition, long tenure tends to focus on consensus building rather than team members' search for novel ideas (Jehn, 1995). Even if members propose new viewpoints or ideas, long-tenured teams have a lower tendency to carry out in-depth discussions regarding new ideas, ask external advisors for their counsel, or pursue new initiatives. This leads to groupthink, rigidity, and strategic inertia (Katz, 1982).

These attributes of long-tenured TMTs restrict the positive relation that a CTO's experience diversity has on radical innovation. Therefore, we propose the following hypothesis:

Hypothesis 2: Average tenure of TMT negatively moderates the effect of the CTO's experience diversity on firm-level innovation, such that the positive effect of the CTO's (a) functional and (b) industrial experience diversity on firm-level radicalness is weakened as TMT tenure increases.

TMT size.We also expect that the TMT size will affect the CTO's decision and radical innovation. Hannan and Freeman (1984) stated that as the TMT size increases, group inertia also increases, which increases the tendency of the group to stick to the status quo. A TMT with inertia impedes organizational creativity by preventing the organization from exploring a new trajectory. Also, the larger the TMT, the less the freedom or flexibility for particular members, such as the CTO, to freely made decisions or exert their authority (Yoon, Kim, & Song, 2015). Therefore, the larger the TMT size, the more difficult it will become to set challenging goals such as cannibalizing existing technology and generating a completely new category.

Also, larger TMTs have a lower communication quality among its members. Zenger and Lawrence (1989) stated that as the number of decision makers increase, the quantity of communication among members decreases, and as a result, this decreases the quality of the information changing. Insufficient information changing, less communication, and insufficient sharing of opinions make it impossible to facilitate and develop creative ideas. Ultimately, the conditions that are created are not conducive to promoting or developing novel ideas.

In addition, decisions in large TMTs are made more slowly. The larger the organization, the less the opportunity for members to interact (Thornburg, 1991; Zenger & Lawrence, 1989). It is not easy to come to a consensus regarding a particular issue due to conflicts of opinions, the process of all members reaching agreement, and the possibility of delays in judgment. Especially, because radical innovation is unpredictable, sporadic, and stochastic, it requires companywide approval (Leifer et al., 2001). As a result, as the number of TMT members increases, it will be much more difficult to reach agreement.

These characteristics will moderate the relationship between the CTO's experience diversity and corporate radical innovation. Hence, we suggest the following hypothesis:

Hypothesis 3. TMT size negatively moderates the effect of the CTO's experience diversity on firm-level innovation, such that the positive effect of the CTO's (a) functional and (b) industrial experience diversity on firm-level

radicalness is weakened as TMT size increases.

TMT gender composition.A number of studies suggest that gender diversity in TMTs influences firm's innovative activity (Benner & Tushman, 2003; Dezso & Ross, 2012). In particular, female executives exert great influence on the social interaction and communication climates of TMT groups (Sandberg, 2003). We predict that decision-making regarding radical innovation will be different contingent upon the proportion of female executives in TMT.

Increasing gender diversity as the proportion of female executives increase fosters active interaction among TMT members. Female executives lead TMT members to have open communication (Rosener, 1995), and contribute to creating a flexible environment where ideas and knowledge are actively exchanged (Sandberg, 2003). The greater the gender diversity, the greater the interaction compared to homogeneous groups, enabling high-quality decision-making and generating more innovative solutions (Torchia et al., 2011).

Moreover, the higher the proportion of women, the greater the knowledge diversity of the group. Female executives generally bring different distinctive viewpoints, experiences and working styles compared to those of their male counterparts (Nielsen & Huse, 2010). Therefore, gender diversity generates certain dynamics that foster diverse solutions leading to innovation. In addition, women tend to try and understand new ideas and are more accepting of diverse viewpoints (Miller & Triana, 2009). The higher the proportion of female executives in a firm, the easier it becomes to preserve new innovative opportunities and novel ideas. It means that the presence of female executives contributes to incubate diverse radical ideas.

As a result, with a higher proportion of women, gender diversity will be enhanced, which will foster an atmosphere that will evaluate and accept the CTO's initiative regarding radical innovation with an open mindset. Also, through active communication, the effectiveness of decision-making will be strengthened. Therefore, we suggest the following hypothesis:

Hypothesis 4. Gender diversity of TMT positively moderates the effect of the CTO's experience diversity on firm-level innovation, such that the positive effect of the CTO's (a) functional and (b) industrial experience diversity on firm-level radicalness is strengthened as gender diversity of TMT increases.

III. METHODS

1. Data and Sample

This research uses U.S. manufacturing sector in SIC codes 2011 – 3999 data, including data regarding firm executives, firm asset status, and patents. Data and information on executives were obtained from Dun and Bradstreet's Reference Book of Corporate Managements as well as the 10K (Annual Report) of each firm. Asset status and patent data were extracted from the COMPUSTAT business segment file and the US Patent and Trademark Office (USPTO) patent citation data file, respectively.

We gathered data using 2006 as the focal year. This is because this study uses patent citations to measure firm radicalness, and according to the Triadic Patent Families of the OECD, 2006 was the year when the most patents were applied for after 2000. Firm radicalness was measured according to the attributes of the patents that were applied for during the focal year. For the CTO data, we gathered information about the chief officer in charge of R&D and engineering function in the focal year who had the title of Chief Technology Officer, Chief Science Officer, or Chief Engineering Manager. The data for the TMT was compiled from information regarding the executives of each firm who had a position above that of the vice president in the focal year. However, we excluded CTOs and top managers who had joined the firm in the focal year because if the term in office is too short, executives' influence on innovative activity is minimal. We used data from four years preceding the focal year in order to measure absorptive capability. With the exception of this variable, the rest of the control variables were from data measured in the focal year.

We randomly selected 2,000 manufacturing firms which existed during our research window in order to test our hypotheses. Then, we filtered the sample according to the following steps. First, we matched Compustat financial data to USPTO patent data using CUSIP numbers. Thus, firms that had both financial and patent data remained. Through this process, we were left with 312 samples. Second, in measuring the characteristics of executives, we excluded data that was unavailable from our sample. Through this process, we gathered a total of 148 samples.

2. Measurement

*Dependent variable.*Our dependent variable of firm's radical innovation output indicates innovation that is original and forms the foundation for future innovation outcomes. To measure firm radical innovation output, we use Datta and Jessup (2013)'s formula based on patent citations, which represents a ratio of forward looking over backward facing. This formula implies that it will have few backward citations if an innovation is original, and will be a foundation for future innovations if it is forwardly cited numerous times by future patents.

R represents the radicalness of each patents that focal firm applied for during the focal year. F is the number of forward citations during a four-year period starting from the focal year (2006~2009). f represents the number of forward citation classes that match with the focal patents. B is the number of backward citations for a four-year period prior to the focal year (2002~2005) and b is the number of backward citations classes that match with the focal patent. In order to avoid division by zero and ensure mathematical stability during the calculation process, 1 was added to both the numerator and the denominator. Firm radicalness was calculated as the average of the radicalness of n number of patents applied for during the focal year by firms.

Just as most of the distribution of ranking data is skewed, we discovered that our sample is skewed, as well. In order to ensure the normality of our distribution properties, we used the log transformation (Datta & Jessup, 2013).

*Independent variables.*The first independent variable is CTO functional diversity. As Gunz and Jalland (1996) maintained that the work experience of executives is the foundation for their knowledge base, this study regards their functional background as their knowledge base. We modified the approach used by Bunderson and Sutcliffe (2002) to measure the functional diversity of CTOs. First, we classified all of the functional backgrounds that each CTO experienced into seven tracks: production-operations; R&D and engineering; accounting and finance; management and administration; marketing and sales; personnel and labor relations; other. Then, we used a version of the Herfindal-Hirschman index (Bantel & Jackson, 1989; Blau, 1977; Michel & Hambrick, 1992) to capture CTO functional diversity. This index was calculated as follows:

Pi is the proportion of each function i during the years of the CTO's career. In this index, the more diverse the CTO's experiences in various functions, the closer the index is to 1 and the more homogeneous the functional experiences, the closer the index is to 0.

The second independent variable is the CTO's industrial diversity and in order to measure this variable, we analyzed the SIC industry code of all of the firms that each CTO had worked at. We also assessed the number of years that the CTO had worked in each industry and calculated industrial diversity by using the Herfindahl-Hirschman index. Pj is the proportion of the CTO's career spent in each industry. Like the CTO's functional diversity, the closer the index is to 1, the higher the CTO's industry diversity and the closer the index is to 0, the lower the diversity.

The moderators of TMT characteristics are TMT tenure and TMT size. TMT tenure is the average of the number of years that each TMT member worked for the focal firm. TMT tenure has a significant influence on innovation (Barkema & Shvyrkov, 2007). For TMT size, we used the number of TMT members, which is also positively associated with innovation outcome (Alexiev & Jansen, 2010). To determine TMT gender diversity, we examined the gender of the TMT members and measured the variable using the Herfindahl-Hirschman index.

*Control variables.*In order to test our model, we controlled for variables that could affect radical innovation, including firm size, R&D expenditure, CTO tenure, CTO education level, CTO age, TMT gender diversity, and firm age. Firm size is a typical control variable in studies of innovation because larger firms have greater ability and more strategic freedom than smaller firms (Hagedoorn & Duysters, 2002). Firm size was measured by calculating the log of the total number of employees in the focal year. R&D expenditure is measured by calculating the log of accumulated R&D expenses for the four-year period prior to the focal year. R&D expenditure could potentially improve innovation performance, since it allows a firm to initiate new R&D projects and expand the support of existing project (Kim et al., 2013). CTO tenure was measured as the number of years since entering the focal firm. CTO education level was measured to assess the educational background's influence on firm's radicalness. According to Daellenbach et al. (1999), a four-point Likert scale reflecting the highest level of education that the CTO attained was adopted (0 = no college degree, 1 = undergraduate degree, 2 = master's degree or JD, 3 = Ph.D. degree). CTO age was controlled because it tends to influence the CTO's decision-making. Prendergast and Stole (1996) insisted that younger managers tend to invest in risky

projects more aggressively regardless of tenure. Lastly, we included firm age in the control variables because it affects innovation performance (Kelly & Amburgey, 1991; Van de Ven, Polley, Garud, & Venkataraman, 1999).

IV. ANALYSES AND RESULTS

1. Main analyses

The unit of analysis in this study is at a firm level. Ordinary least squares regression was adopted for the analysis. Table 1 provides descriptive statistics and correlations among variables. To check multicollinearity among independent variables, variance inflation factor (VIF) for each variable was calculated. VIF values ranges between 1.11 and 4.75, which is well below the recommended cutoff value of 10.0 (Chatterjee, Hadi, & Price, 2000; Neter, Kutner, Nachtsheim, & Wasserman, 1996). Thus, the multicollinearity issue is not serious in this study.

InsertTable1abouthere

Table 2 shows the results of the seven different regression models. Model 1 includes all of the control variables. Model 2 adds cognitive characteristics of CTO, such as functional experience diversity and industrial experience diversity. Model 3 includes TMT attributes such as tenure, size and gender diversity. Model 4 to Model 6 adds interaction terms of TMT attributes and CTO's experience diversities respectively.

InsertTable2abouthere

Hypothesis 1 predicts the direct effect of CTO's experience diversity on radical innovation output. More specifically, Hypothesis 1a predicts that CTO's functional experience diversity is positively associated with a firm's radical innovation, while Hypothesis 1b predicts that CTO's industrial experience diversity is positively associated with a firm's radical innovation. In Model 2, the coefficient for CTO's functional diversity is positive and strongly significant (β = 2.23, $p < .001$), as well as CTO's industrial diversity is also positive and significant (β = 1.94, $p < .001$). Thus, Hypothesis 1 is supported.

We next tested Hypothesis 2, which stated that average tenure of TMT

negatively moderates the effect of CTO's experience diversity on radical innovation output. As seen in Model 4, the interaction of TMT tenure and CTO's functional diversity is negative and marginally significant (β = -.19, p <.1) as well as the interaction of TMT tenure and CTO's industrial diversity is also negative and marginally significant (β = -.26, p < .05). Adjusted R-squared of Model 4 (0.3876) was higher than that of Model 2 (0.2274) or Model 3 (0.3361).Thus, the evidence in Model 4 supports Hypothesis 2.

In Hypothesis 3a, we proposed TMT size negatively moderates the effect of CTO's functional diversity on firm radicalness. As seen in Model 5, the interaction effect between CTO's functional diversity and TMT size was not significant. Thus, Hypothesis 3a is not supported. This result indicates that the larger size of TMT does not moderate the impact on the CTO's functional diversity. Given that a large TMT is likely to consist of executives from more various functions, the CTO with various functional experience and knowledge can communicate and communicate smoothly with the executives of other functions. Thus, it is interpreted that the large size of TMT does not constraint the CTO with various functional experience to pursue radical innovation.Hypothesis 3b predicts that TMT size negatively moderates the effect of CTO's industrial diversity on firm radicalness. In Model 5, the interaction term is negative and marginally significant (β = -.22, p< .05). Thus, Hypothesis 3b is supported.

Hypothesis 4 predicts that gender diversity of TMT positively moderates the effect of CTO's experience diversity on firm level innovation. As seen in Model 6, we found no significant relationship between CTO's functional and industrial diversity and radical innovation. Thus, there is no support for Hypothesis 4. Although prior studies argued that gender diversity affects organizational communication and creativity, this result shows that those effects may not be found in the case of radical innovation. We will discuss this issue in the next section.

Model7 is a full model that includes all variables simultaneously. The main effects and interactions that were significant in the individual models were also significant in this full model. Thus, this result further supports what we have concluded.

2. Sensitivity analyses

To improvethe robustness of our test results, we conducted additional analyses with multiple test settings. We tested our model using two measurements for the

dependent variable, based on different methods of measuring radical innovation.

First, we conducted the analysis using the ‘citation-weighted patent count’ as an indicator of radical innovation performance. Trajtenberg (1990) demonstrates that citation-weighted patent count can serve as a valid measure of radicalness of innovation. Several succeeding studies also use the citation-weighted number of patents to calculate the radicalness of a firm (Katila, 2000; Rao, 2010). To analyze the sensitivity using this approach, we measured our dependent variable with the number of patents that were applied in the focal year, weighted by the number of citations that they subsequently received. While the original analysis was tested by the ordinary least squares (OLS) method, this sensitivity analysis was tested by negative binomial regression (NBR) since the citation-weighted count of patents is a discrete variable which does not satisfy the assumption of homoscedasticity required by classical linear regression models(Hausman, Hall, & Griliches, 1984). Negative binomial regression is also adopted in the majority of existing studies that use the number of patents as a dependent variable (Song, Almeida, & Wu, 2003).

Second, we used information of backward patent citations as another method of measuring radicalness. Dahlin and Behrens (2005) argue that radical inventions tend to cite from other patent classes other than the category they belong to. For these reason, many studies adopt backward citation to measure radical innovation (Rosenkopf & Nerkar, 2001; shane, 2001). We measured the radicalness through the ratio of patents belonging to other classes in backward citations.This analysis was tested by ordinary least squares (OLS).

InsertTable3abouthere

Table 3 presents our test results for the two different settings. Model 8 shows the results with radical innovation being measured by the citation-weighted number of patents, Model 9 by the ratio of category references in backward citations. Model 7 is the full model from the original analysis. The results from the robustness tests are similar to the outcome of the initial analysis, thus providing additional support for our original conclusion.

V. DISCUSSION

In this study, we offer a new perspective on the linkage between the technological executives and radical innovation of the firm by examining factors

reflecting social interaction context in TMT. Our result shows that diverse experience of CTO drives radical innovation. In particular, this study investigated how the CTO's cognitive background and the interaction with the attributes of TMT affect the firm's radical innovation. We found that there is a significant relationship between the CTO's experience diversity and a firm's radical innovation. More importantly, we confirmed that the more diverse the CTO's functional experience, the higher the firm's radicalness. In other words, a generalist who has a wide array of diverse knowledge is more suited to radical innovation than specialists in technology and science engineering. In addition, our findings showed that the more diverse the CTO's industry domains experience, the higher the radicalness of the firm. This is because if the CTO has more knowledge regarding diverse industry domains, the CTO will undertake more cross fertilization of multiple technologies, which will, in turn, enhance novelty and radicalness (Adler & Ferdows, 1990).

Because the executive's decision-making must be considered within the context of the TMT, we also investigated how the collective characteristics of the TMT, including team size and average tenure, affect the impact of the CTO's experience diversity on radical innovation. Our findings showed that as a TMT has longer tenure, its tendency for groupthink, rigidity, and strategic inertia become stronger (Katz, 1982) and that these characteristics negatively moderate the relationship between the diversity of the CTO's work experience and radical innovation. In other words, while the wide range of different experiences the CTO has can be a driving factor behind radical innovation, the impact can be diminished by long tenure of the top team.

It is conventionally assumed that the size of a TMT is inversely associated with the communication quality and the speed of decision-making in the firm, eventually limiting the active development of radical ideas in the organization. In this study, however, we found that the size of the firm partially moderates the CTO's work experience diversity. The positive impact of industrial diversity in the CTO was diluted as the TMT became larger, while the firm size did not affect the functional diversity of the CTO. The large size of the top team generally indicates executives with many different functions. If the CTOs have a wide diversity of functional knowledge, they can facilitate communication and information processing among his fellow executives from other departments, as a result mitigating the constraint by the large size of the TMT.

We anticipated that gender diversity in TMT would have a positive moderation effect on the CTO's cognitive influence on radical innovation.

However, the empirical test showed that there is no significance, which indicates that gender composition is not an important attribute in the hypothesized relationship. Contrary to our hypothesis, some studies suggest that TMT with a high proportion of female executives avoids moving to a new trajectory and that it is due to the general tendency of risk aversion in women (Huang & Kisgen, 2013; Powell & Ansic, 1997). Therefore, it may be difficult to predict certain effects of the gender diversity on firm radicalness because it has both of positive and negative natures on pursuing innovation.

1. Contributions and Implications

This study has a number of contributions. Until now, upper echelon theory-based research has focused primarily on TMT and CEO-related variables. Despite the fact that the CTO is the top manager that exerts the most direct influence on technological development and innovation, the CTO has been largely overlooked in previous research. This study discovered that the CTO's cognitive characteristics are a critical variable in predicting performance such as radical innovation. Through this new evidence, this paper has expanded the breadth of the discussion prompted by upper echelon theory of "Do top managers matter?"

Another important contribution of this study is our consideration of industry variables in examining knowledge diversity of executives. This concept has received much less attention than functional diversity (e.g., Cohen & Bailey, 1997; Monge & Eisenberg, 1987) and educational background diversity (e.g., Carpenter & Fredrickson, 2001; Wiersema & Bantel, 1992) in upper echelon theory. However, our findings show that the diversity based on the prior industrial experiences of an executive has a critical impact on firm-level innovation. This expands the breadth of a perspective on the characteristics of firm executives.

Third, the findings of this study have important implications for not only upper echelon theory but also technological innovation theory. Until now, there have been a few studies explaining the concept of the importance of leaders on radical innovation (Benedetto et al., 2008; Herstatt et al., 2007), but, from what we know, there has been no empirical study on the effects of the characteristics of the CTO and TMT, specifically, on radical innovation. Especially, this study traced the CTO's cognitive base, which is the foundation of current decisions and proved that it drives a firm's radical innovation. We also showed this relationship can be changed contingent upon the collective characteristics of the TMT. This study contributed to broadening the firm innovation theory by specifically

demonstrating that the cognitive base of the CTO and the mutual interaction of the decision-making body are the origin of radical innovation.

There are also managerial implications, as well. First, this study lays out the characteristics of the CTO that enhances the firm's technological performance. In other words, it proposes the conditions of a CTO that are most conducive to successfully pursuing radical innovation. This can be used as a detailed guideline when selecting a CTO. This will serve as a specific standard and a profile for selecting talent that can enhance the firm's innovative capabilities, whether it is hiring a new CTO or promoting someone in-house.

In particular, this study revealed that the diverse experiences of the CTO are positively associated with radical innovation. This shows that firms that wish to pursue radical innovation must strategically place talented individuals who have experiences in various functions or industries. In addition, from a long-term perspective, this is something that must also be kept in mind when nurturing executives. This illustrates that it is important to help individuals gain various experiences through HR policies such as departmental rotation or dispatching them to work in different industries in order to raise them as talent that can lead the firm's radical strategy in the future. Also, in order to promote technological leadership that can facilitate radical innovation, the TMT, which is a decision-making body, must be slim and must be composed of young executives.

2. Limitations and Future Research Suggestions

First, we conducted a study pertaining narrowly to radical innovation. However, firms pursue not only radical innovation but incremental innovation, as well (Tushman and Romanelli, 1985). This research does not provide insights into the conditions for a CTO that can successfully lead incremental innovation. As such, it does not provide an answer for what kind of CTO is appropriate for firms that are simultaneously pursuing both radical innovation and incremental innovation. As such, there is a need to study the impact of CTOs on incremental innovation, as well as radical innovation.

Second, we took TMT size, TMT tenure, and gender diversity in the TMT into consideration as moderators in the relationship between radical innovation and the CTO's cognitive characteristics. However, because there are other internal and external contexts that are embedded in the firm, there is a need to analyze the interplay between CTOs and TMTs using various other variables. For example, faultlines, which are conceived of as hypothetical dividing lines that split a group

into subgroups based on one or more attributes (Brzrukova, Thatchet, and Jehn, 2001), can affect the CTO's decision-making and the interaction of the TMT. Extant literature reveals that faultlines within the TMT significantly affects firm performance (e.g., Thatcher, 2003). A study on how TMT faultlines moderate the CTO's cognitive effect on radical innovation will also provide interesting insights into innovation research.

Third, this study assumes that the CEO's latitude of action or managerial discretion is consistent in all situations. However, the managers do not always have complete latitude of action, or managerial discretion (Hambrick & Finkelstein, 1987; Lieberson & O' Connors, 1972). The impact of executives on organization is likely to be more prominent in a high-discretion situation (Crossland & Hambrick, 2007; Finkelstein & Boyd, 1998) and this also applies to the impact of the CTO. As such, a study that analyzes the effects of the CTO, taking managerial discretion into consideration, will also provide important findings, given that managerial discretion is different for individuals, organizations, and industries (Hambrick & Finkelstein, 1987).

3. Conclusion

In conclusion, this study is the first to develop a model that connects the CTO's cognitive base and the TMT's characteristics with a firm's radical innovation. The cognitive capability of the CTO is an important resource that greatly leverages a firm's technological core competence. In order for this capability to function properly, it needs to achieve a proper fit with the structure of the top team. We hope that this study that deals with this important topic can serve as a foundation that other studies can derive from.

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Table 1. Descriptive statistics and correlations

Variables	VIF	Mean	s.d.	1	2	3	4	5	6	7	8	9	10	11
Log radical	-	0.24	1.43											
CTO functional diversity	1.20	0.14	0.20	0.31*										
CTO industry diversity	1.68	0.23	0.26	0.18*	0.29*									
TMT tenure	1.46	12.06	4.88	-0.28*	-0.09	-0.31*								
TMT size	1.37	9.26	4.49	-0.31*	-0.21*	-0.20*	0.31*							
TMT gender	1.11	0.17	0.16	-0.01	0.00	0.11	0.06	0.15*						
Firm size (employees)	4.75	7.50	2.46	0.19*	-0.06	-0.33*	0.28*	0.30*	0.01					
Firm age	1.73	43.09	43.54	0.06	-0.13	-0.25*	0.32*	0.40*	0.02	0.56*				
R&D expenditure	4.30	11.86	2.71	0.23*	-0.12	-0.36*	0.16*	0.21*	0.01	0.85*	0.42*			
CTO education level	1.28	2.05	0.88	0.02	-0.23*	-0.19*	-0.07	0.04	-0.10	0.18*	0.10	0.33*		
CTO tenure	1.88	11.12	7.51	0.05	-0.10	-0.35*	0.34*	0.05	-0.20*	0.27*	0.33*	0.19*	-0.05	
CTO age	1.69	46.34	8.52	-0.10	0.15*	0.23*	0.23*	-0.05	-0.01	-0.15*	-0.04	-0.22*	-0.24*	0.39*

*p< .05.

Table 2. Result of the Ordinary Least Squares Regression Predicting Innovation Performance

Model	Model 1	Model 2	Model 3	Model 4	Model 5	Model 6	Model 7
Firm size (employees)	-.01	-.05	.04	.05	.04	.05	.04
	(.10)	(.09)	(.09)	(.08)	(.08)	(.09)	(.08)
Firm age	-.00	-.00	.00	.00	.00	.00	.00
	(.00)	(.00)	(.00)	(.00)	(.00)	(.00)	(.00)
R&D expenditure	.14	.19*	.14†	.13†	.12†	.13†	.11
	(.09)	(.08)	(.07)	(.07)	(.07)	(.08)	(.07)
CTO education level	-.12	.01	-.03	-.04	-.07	-.02	-.07
	(.15)	(.13)	(.12)	(.12)	(.12)	(.13)	(.12)
CTO tenure	.01	.05**	.04*	.03†	.04*	.04*	.02
	(.02)	(.02)	(.02)	(.02)	(.02)	(.02)	(.02)
CTO age	-.02	-.05**	-.03*	-.02	-.03†	-.03†	-.01
	(.02)	(.02)	(.01)	(.01)	(.01)	(.01)	(.01)
CTO functional diversity		2.23***	1.80***	3.81*	2.80*	1.74*	4.12**
		(.56)	(.53)	(1.48)	(1.14)	(.74)	(1.58)
CTO industry diversity		1.94***	1.33**	3.71**	3.02***	1.64*	4.82***
		(.50)	(.48)	(1.36)	(.87)	(.63)	(1.45)
TMT tenure			-.07**	.00	-.06**	-.07**	.00
			(.02)	(.03)	(.02)	(.02)	(.03)
TMT size			-.09***	-.07**	-.01	-.09***	-.02
			(.03)	(.02)	(.04)	(.03)	(.04)
TMT gender diversity			.47	.69	.41	.91	.53
			(.63)	(.61)	(.62)	(.95)	(.92)
CTO functional diversity × TMT tenure				-.19†			-.21†
				(.11)			(.12)
CTO industry diversity × TMT tenure				-.26*			-.21†
				(.12)			(.12)
CTO functional diversity × TMT size					-.13		-.08
					(.12)		(.13)
CTO industry diversity × TMT size					-.22*		-.19*
					(.09)		(.09)
CTO functional diversity × TMT gender diversity						.30	3.22
						(3.16)	(3.21)
CTO industry diversity × TMT gender diversity						-1.92	-1.74
						(2.62)	(2.51)
F	1.68	6.41	7.77	8.16	7.44	6.54	6.67
R-squared	0.0666	0.2694	0.3858	0.4417	0.4191	0.3883	0.4659
Adj R-squared	0.0269	0.2274	0.3361	0.3876	0.3627	0.329	0.3961

N = 148

†p< .10, *p< .05, **p< .01, ***p< .001.

Table 3. Result of the Sensitivity Test

Model (Method)	Model 7 (OLS)	Model 8 (NBR)	Model 9 (OLS)
Firm size (employees)	.04	-.11	.01
	(.08)	(.12)	(.02)
Firm age	.00	.00	-.00
	(.00)	(.00)	(.00)
R&D expenditure	.11	.39***	-.01
	(.07)	(.10)	(.02)
CTO education level	-.07	-.14	.01
	(.12)	(.15)	(.03)
CTO tenure	0.02	-.03	.01†
	(.02)	(.02)	(.00)
CTO age	-.01	.06**	-.00
	(.01)	(.02)	(.00)
CTO functional diversity	4.12**	4.15*	.95**
	(1.58)	(2.09)	(.35)
CTO industry diversity	4.82***	6.66***	.57†
	(1.45)	(1.64)	(.32)
TMT tenure	.00	-.04	.00
	(.03)	(.04)	(.01)
TMT size	-.02	.16**	.01
	(.04)	(.05)	(.01)
TMT gender diversity	.53	-2.11	.13
	(.92)	(1.34)	(.20)
CTO functional diversity ×TMT tenure	-.21†	-.41**	-.05*
	(.12)	(.14)	(.03)
CTO industry diversity ×TMT tenure	-.21†	-.30*	.02
	(.12)	(.14)	(.03)
CTO functional diversity ×TMT size	-.08	.10	-.03
	(.13)	(.18)	(.03)
CTO industry diversity ×TMT size	-.19*	-.52***	-.05*
	(.09)	(.12)	(.02)
CTO functional diversity ×TMT gender diversity	3.22	.32	6.33
	(3.21)	(.71)	(4.29)
CTO industry diversity ×TMT gender diversity	-1.74	-.37	2.17
	(2.51)	(.56)	(3.11)

N = 148

† p< .10, *p< .05, **p< .01, ***p< .001.