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Organizing For Developing Radically Innovative Product: Application of "Quantum Evolution" Theory in Bioecology

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Abstract

Developing radically innovative products is an important issue for many firms. This study addresses how to organize and manage new product development teams to develop radically innovative products. We hypothesize that there exists the optimal combination of conditions to develop radically innovative products through the use of quantum evolution theory found in bioecology and test empirically using the joint covariations approach. Our results show that radically innovative product can be developed in the new product development teams with

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the combination of high diversity, high integration, and high autonomy.

Keywords: radical innovation, quantum evolution, diversity-integration-autonomy

INTRODUCTION

Product innovativeness is one of the critical factors not only for new product success (Cooper 1993; Kleinschmidt and Cooper 1991; Zirger and Maidique 1990), but for firm's competitive advantage (Danneels and Kleinschmidt 2001). Therefore developing a radically innovative product is an important issue for many firms (Chandy and Tellis 2000; Wind and Mahajan 1997). Regarding the development of innovative products, how to organize and manage new product development (NPD) teams has been a critical decision (Brown and Eisenhardt 1995; Krishnan and Ulrich 2001; Shane and Ulrich 2004). There has been some research to examine the project team-level factors that affect new product innovativeness (Lovelace, Shapiro, and Weingart 2001; Sethi, Smith, and Park 2001; Stringer 2000; Wind and Mahajan 1997; Woodman, Sawyer, and Griffin 1993). Sethi, Smith, and Park (2001) identified six key conditions likely to affect new product innovativeness — diversity of input, discovery of novel linkage, motivation to innovate, challenging traditional perspective, promoting risk taking, and resource availability.

Despite the previous efforts to find and test the team-level factors that enhance product innovativeness, the important question has remained unsolved. That is, if the necessary conditions of the continuous innovation are different from those of the discontinuous innovation or not. In other words, what is needed is an explanation as to whether or not the strength of the determinants for the continuous innovation would be increased, the radical innovation should be developed, or if different determinants or conditions should be requested according to the uniqueness of the innovation, namely continuous and discontinuous innovation.

There are two different perspectives and theories about evolution in bioecology. Those are incremental evolution theory and quantum evolution theory. It is said that the enabling forces of the incremental evolution are different from those of quantum (jump) evolution. If these theories are applied to NPD, the continuous innovation is analogized to incremental evolution and the discontinuous innovation is analogized to quantum evolution. In the same vein, according to quantum evolution theory, the occurrence of new species (evolution) is driven by different logic with the change within species (variation). Accordingly, it seems to be said that there are different influential factors within NPD team between the development of radically innovative product and continuous innovative product

The purpose of this study is to determine if there exists an optimal combination of conditions to develop radically innovative products through quantum evolution theory in bioecology and test empirically using the joint covariations approach. Van de Ven and Drazin (1985) suggest that we should consider the joint covariations among sun, water, and soil nutrients to improve crop yields. Sun, rain, and soil nutrients are necessary factors to improve crop yields. To get high crop yields, the three key factors (sun, water, and soil nutrients) should exist at the same time. If any one of those factors is missing, we cannot increase crop yields. If there is sun but not water, we cannot expect high crop yields. Likewise this study hypothesizes and tests that there exists the optimal combination of conditions to develop radically innovative products.

THEORY — OPTIMAL COMBINATION OF CONDITIONS TO DEVELOP RADICALLY INNOVATIVE PRODUCTS

Quantum Evolution in Bioecology and Radically Innovative Product

Goldschmidt and Eldredge suggests quantum evolution theory in 1940s for the purpose of making up incremental evolution theory, the traditional evolution theory by Darwin (Goldschmidt 2002). In the similar perspective, Gould (1980) suggests that the species in nature would be created into new species without mid-shaped species and that the evolution would have a dormant state for a while and stage another species in a specific time. Accordingly, quantum evolution theory is also called “salutatory (jump) evolution” theory. Gould succeeded to develop this theory (Eldredge and Gould 1972).

Goldschmidt (2002) suggests in his book “The Material Basis of Evolution” that microevolution (the change within species) and macroevolution (the occurrence of new species) have a different producing mechanism from each other. He also mentions that macroevolution is driven by the compositional change of chromosome and represented by mutation. Gould (1980) also suggests that macroevolution does not happen in the course of continuous change within a group but is created by the emergence of mutation.

If this theory is applied to NPD, product innovation can be analogized to evolution in bioecology (Astley 1985; Mensch 1979). Radically innovative product can be thought of as the counterpart to ‘quantum evolution’ in bioecology (Astley 1985). By investigating the process through which quantum evolution happens, we can explain how radically innovative product can be developed. For quantum evolution to occur, a combination of two evolutionary forces is necessary — (1) production of special new variability as variation-producing forces and (2) isolation as variation-fixing forces (Grant 1963). Production of special new variability can arise by hybridization (Grant 1963).

Analogy to the Process through Which Radically Innovative Products Emerge

A combination of two conditions, hybridization and isolation, is necessary for quantum evolution to occur. If we analogize the combination of conditions to the process through which radically innovative products emerge, hybridization, which means the process of mixing different species, can be analogized to ‘integration of diversity’ and isolation, which means the separation of two population of a species, can be analogized to ‘autonomy’.

Diversity, Integration, and Autonomy in NPD

First, the question whether team diversity is positively related to product innovativeness has not been solved yet, although much research has been arguing that team diversity is one of the critical factors to improve product innovativeness. The previous research has suggested contradictory findings on the relationship between team diversity and innovativeness (See (Williams and O'Reilly III 1998), for review). The researchers who support the positive relationship argue that team diversity brings a broader range of perspective and knowledge and the diverse knowledge can have a positive impact on innovativeness (Hoffman and Maier 1961; Jackson 1992). The researchers who support the negative relationship argue that individuals having diverse backgrounds or perspectives were cognitively dissimilar (Triandis 1959), teams with such individuals have difficulty in communicating or collaborating, and, in turn, reduce creativity; therefore, team diversity reduces creativity (Smith, Smith, Olian, Sims, O'Bannon, and Scully 1994; Zeleny 1955; Zenger and Lawrence 1989). Some researchers have tried to solve the problem by hypothesizing invert-U shape relationship which means that new product innovativeness is highest at a moderate level of team diversity (Sethi, Smith, and Park 2001), but did not have a significant result.

Second, the studies on the relationship between team integration and product innovativeness have shown mixed results. Lovelace, Shapiro, and Weingart (2001) show that intrateam task agreement is positively associated with innovativeness, but Sethi, Smith, and Park (2001) show the negative relationship. They argue that beyond a moderate level, team integration may incur groupthink (Janis 1982), which refers to a high level of conformance by members of the group. Groupthink behavior negatively affects the innovativeness. In addition, Nystrom (1979) try to solve the relationship between team integration and product innovativeness by hypothesizing invert-U shape relationship.

Third, several researchers have suggested that allowing a considerable degree of autonomy can foster innovation (Amabile, Conti, Coon, Lazenby, and Herron 1996; Bailyn 1985; Olson, Walker Jr., and Ruekert 1995; Pelz 1956). Olson, Walker, and Ruekert (1995) note that a high level of autonomy is positively related to radical product innovation. Amabile (1988), however, argues that autonomy may hurt creativity. But research on autonomy has mainly focused on the autonomy of NPD team from company (Gem?nden et al. 2005), it seems to be said that the affect of the autonomy of members within NPD team has not been examined.

Hypothesis about Necessary Conditions for Radically Innovative Products

Integration of Diversity as Analogy of Hybridization. Hybridization is analogous to integration of diversity — what Eisenberg (1984) has termed “unified diversity”. Diversity means diversity of knowledge (Sethi, Smith, and Park 2001). Interactions across individuals who each possess diverse and different knowledge structures will augment the organization’s capacity for innovating (Cohen and Levinthal 1990). A radical research solution within a particular arena requires a diversity of competencies that are strongly connected (Hage and Rogers 2000). Hage and Rogers (2000) suggest that the greater the diversity of competencies or knowledge that is connected with frequent and intense communication within an arena, the greater the likelihood that radical innovations will emerge.

Autonomy as analogy of isolation. Isolation is analogous to autonomy. The reason isolation is needed for quantum evolution is as follows. Astley (1985, p.232) wrote:

> Certain factors suspend the forces that normally limit change to the gradualistic pattern produced by phyletic evolution. One such force is population gene flow, which retards evolutionary change by suppressing the emergence of radical mutations. Though genetic mutations occur all the time within species, they typically do not take hold, since they are outnumbered in the population gene pool and rapidly dissipate through the normal intermixing process. However, if by accident a geographic barrier happens to isolate physically a few mutant individuals, they may escape homogenizing pressures in their parent population, interbreed among themselves, and eventually become reproductively isolated to form a new and quite different species.

Isolation helps to avoid the homogenizing pressures. In NPD teams, an individual’s creative idea should be protected from other individuals’ homogenizing pressure. By giving autonomy to individuals, the individual’s creative idea may be protected. Ancona and Caldwell (1992) suggest that a R&D team be located in a remote place. Strong routines inhibit any actions outside of pre-existing patterns. The organizational routines are ineffective at developing radical product innovations, because the latter are based on a substantially different technology (Henderson 1993). Stringer (2000) suggests that the radical innovators should be completely separate from the traditionalists. Tushman and O'Reilly (1997) suggest that the management team must not only protect and legitimize the entrepreneurial units, but also keep them physically, culturally, and structurally separate from the rest of the organization.

Therefore, radical innovations can occur only in the combination of three conditions: (1) diversity, (2) integration and (3) autonomy.

Therefore, we hypothesize that:

> **H1:** The optimal combination of conditions for radically innovative product development is high diversity, high integration and high autonomy.

METHODS

Sample

The population was composed of Korean manufacturing firms stratified by technological excellence (i.e., received excellent technology marks or did not) as rated by agencies of the Korean Government, the Korea Industrial Technology Institution and the Korean Agency for Technology and Standards. In 1999, we judgmentally sampled from the excellent firm strata based on a sampling frame constructed by listing those firms that received a KT (Excellent Korean Technology) mark or IR-52 (Industrial Research) mark from the Korea Industrial Technology Institution and the firms that received an NT (New Technology) mark or EM (Excellent Machine, Material) mark from the Korean Agency for Technology and Standards. We included all firms that had been rated (i.e., received a KT, IR-52, NT, or EM mark) as "excellent" from 1998, 1997, and 1996. The total list of excellent firms was 849. Beginning with the most recently rated (e.g., 1998) we called all the firms on the list for their willingness to participate out of the total of 849. Out of the total, 321 were willing to participate, which represents a 37.8% judgmental sample from the 849 excellent companies in the sampling frame.

Using the list of excellent firms, we personally interviewed 76 project managers within the Seoul metropolitan area. We faxed the interview questions to 245 project managers from firms outside the Seoul metropolitan area because of travel cost considerations. A reminder was sent to those who had not responded within two weeks and callbacks were made to fill in missing data when the questionnaires were returned. This procedure yielded 99 usable responses for a 40.4% response rate to the faxed survey and a usable response rate of 55% including both the faxed questionnaires and personal interviews. The overall response of usable response rate was 21% of the total of 849 firms. The industries in the sample consisted of electronics, electricity, machinery, chemical, textile, computer, software, and information technology. The average team had 7.1 members (s.d. = 6.2) and had an average product development time of 22.9 months (s.d. = 13.7). The firms responding were not significantly different from those not responding in industry representation. Therefore, even though the sample was not selected probabilistically, we believe that it was representative of the population of 849 excellent Korean manufacturing firms.

Measures

Diversity. The diversity is operationalized as the width of relevant knowledge of NPD team members among various aspects of diversity in organizational literature (Van Knippenberg et al. 2004). This is because we consider innovativeness as a performance variable. While the functional diversity has been selected and examined in the existing research, this study measures a four item-scale (alpha = 0.6028) in terms of relevant experience of team members (Bonner and Walker Jr. 2004). A seven-point Likert scale ranging from ‘strongly disagree’ to ‘strongly agree’ was used to assess this construct. The questions are like these: (1) Our team consists of members with very various academic majors, (2) Our team consists of members with very various functional experiences, (3) Our team consists of members with very various backgrounds, and (4) Our team consists of members with very various job experiences. These items were formed into a single scale by factor score.

Integration. A four item-scale (alpha = 0.8658) of integration is developed based on Kratzer's (2004) scales on communication among team members and Swink's (1999) scales on cooperative environments of NPD team. A seven-point Likert scale ranging from 'strongly disagree' to 'strongly agree' was used to assess this construct. The questions are like these: (1) Team members shared information well, (2) Communication among members was active, (3) Team members worked cooperatively, and (4) Team members solved problems collaboratively. These items were formed into a single scale by factor score.

Autonomy. While related research has measured the autonomy of NPD team from company, the autonomy of this study is as operationalized as the autonomy of members within NPD team. Among the various aspects of the autonomy (Gem?nden 2005), we selected items in terms of goal-defining autonomy and structural autonomy. A final four-item scale (alpha = 0.8571) was used to measure the construct "autonomy". A seven-point Likert scale ranging from 'strongly disagree' to 'strongly agree' was used to assess this construct. The questions are like these: (1) Team members planned their own task by themselves, (2) Team members set the goal of their own task by themselves, (3) Team members set how to do their own task by themselves, and (4) Management in the team was autonomous. These items were formed into a single scale by factor score.

To ensure the discriminant validity of these three types of independent variables — diversity, integration, and autonomy, we conducted a common factor analysis. Table 1 shows the results of this analysis.

Dependent variable: Innovativeness. A two-item scale (alpha = 0.7896) was used to measure innovativeness. Innovativeness is measured in terms of both technology and market (Kleinschmidt and Cooper 1991). A seven-point Likert scale ranging from 'strongly disagree' to 'strongly agree' was used to assess this construct. The questions are like these: (1) How innovative in terms of technology the new product is compared with the goal when the project started, (2) How innovative in terms of market the new product is compared with the goal when the project started. The mean and standard deviation of the first dependent variable are 4.93 and 1.12 and those of the second dependent

Table 1. Discriminant Validity among Independent Variables: Factor Analysis Results.

	Factor 1 **Autonomy**	Factor 2 **Integration**	Factor 3 **Diversity**
Team members set the goal of their own task by themselves	**.868**	.194	5.173E-02
Team members set how to do their own task by themselves	**.806**	.156	.103
Management in the team was autonomous	**.801**	8.107E-02	.160
Team members planned their own task by themselves	**.789**	.166	8.331E-02
Team members worked cooperatively	7.153E-02	**.851**	-2.614E-02
Team members sharedl information wel	.230	**.831**	4.176E-02
Team members solved problems collaboratively	5.621E-02	**.826**	.138
Communication among members were active	.356	**.777**	1.876E-02
Our team consists of members with very various job experience	.105	-6.511E-02	**.777**
Our team consists of members with very various academic majors	7.440E-02	.151	**.663**
Our team consists of members with very various functional experience	.139	.185	**.612**
Our team consists of members with very various background	1.703E-02	-9.526E-02	**.608**

Extraction Method: Principal Component Analysis.
Rotation Method: Varimax with Kaiser Normalization.
Three factors selected based on Scree test and eigenvalues > 1.0

variable are 5.21 and 1.19 respectively. And the correlation of those two variables is 0.65 ($p < 0.01$). We use average value of the two variables as a final dependent variable.

Grouping

We divided our sample into the eight groups using diversity (high vs. low) X integration (high vs. low) X autonomy (high vs. low). For example, if the diversity score is greater than mean, the

Table 2. 8 Groups using Diversity, Integration, Autonomy

		Autonomy (L) Diversity L	Autonomy (L) Diversity H			Autonomy (H) Diversity L	Autonomy (H) Diversity H
Integration	L	Group 1 (n=20)	Group 2 (n=18)	Integration	L	Group 5 (n=21)	Group 6 (n=17)
	H	Group 3 (n=31)	Group 4 (n=17)		H	Group 7 (n=23)	Group 8 (n=28)

team is grouped into high diversity group. We compared the mean of the dependant variables across the groups.

RESULTS

We used a one-way analysis of variance (ANOVA) to test the hypothesis that there exists the optimal combination of conditions for radically innovative product development. As table 2 shows, the analysis of variance for innovativeness was significant ($p < .05$).

In order to explore the relationships further, we conducted a multiple comparisons analysis using the method of least significant difference (LSD) (Saville 1990).

The table 3 shows that Group 8's performance is significantly higher than Group 1's, Group 2's, Group 3's, Group 5's, and Group 6's. Group 8's performance is higher than Group 4's (mean difference=.16) and Group 7's (mean difference = .31), even though the difference is not significant. Therefore, the

Table 3. ANOVA Table

	Sum of Squares	d.f.	Mean Square	F	Sig.
Between Groups	17.488	7	2.498	2.388	.024
Within Groups	174.690	167	1.046		
Total	192.177	174			

Table 4. Multiple Comparisons between Groups in Innovativeness

i \ j	Group 1	Group 2	Group 3	Group 4	Group 5	Group 6	Group 7	Group 8
Group 1	–							
Group 2		–						
Group 3			–					
Group 4		80*		–				
Group 5					–			
Group 6						–		
Group 7		.65*					–	
Group 8	.80**	.96**	.60*		.60*	.81*		–

*p < 0.05, **p<0.01

1) Only significant differences are shown.

2) The number in cell is mean difference (i — j)

quantum theory is well applied to organization for radical innovation. The group with high diversity, high integration, and high autonomy is the team that achieves radical innovation.

CONCLUSION

We found that there exists an optimal combination of conditions to develop radically innovative product. The optimal combination of conditions for NPD teams is high diversity, high integration, and high autonomy.

The interesting group is Group 2. The characteristics of Group 2 are high diversity, low integration, and low autonomy. This shows that although the team consists of diverse members, if there's low integration and low autonomy, the team's performance is the lowest within the eight groups studied. Therefore, even though NPD teams consist of highly diverse members, if there is low integration and low autonomy, the teams cannot develop radically innovative products.

This research represents three necessary factors — diversity, integration and autonomy — in NPD team for developing radical innovative product and supports empirically the necessary condition of these factors. We apply quantum evolution theory to induce these factors and extend the existing research on the determinants of innovative product to argue that NPD team should have three necessary factors for developing radical innovative product.

The theoretical implication of this study is as follows. First, this study extends existing research on the determinants for NPD to explain that there are necessary conditions for developing radical innovative product different from those for incremental innovative product. Second, we suggest three necessary conditions — high diversity, high integration and high autonomy — for developing radical innovative product based on quantum evolution theory in bioecology, which will be basis for future casual relationship research on NPD. Third, we suggest the importance of knowledge diversity of NPD team as well as functional diversity in term of cross-function (Lovelace et al. 2001). In addition, we suggest the importance of team members' autonomy within NPD team different from NPD team's autonomy from company.

It has been said that NPD, especially radical innovative product, is critical factor for sustaining firm's advantage and surviving competitive environments. The practical implication of this study is as follows. First, diversity, integration, and autonomy in NPD team are key factors to develop radically innovative products. To develop radically innovative products, the three key factors should exist at the same time. If any one of those factors is missing, radically innovative products cannot be developed. Second, it needs to be considered that NPD team should be organized for enhancing the level of knowledge diversity, NPD team leader should increase the level of integration through making active communication and cooperative environments among team members, NPD team leader should manage not to make collective learning through keeping autonomous thinking.

The limitation and future research of this study is as follows. First, the sampling issues might be suggested. This study defined operationally radical innovative product as the product which has the higher level of innovativeness and measured this performance variable through the same innovativeness scales as incremental innovative product. But radical innovative product might need to be measured by scales different from incremental innovative product. Accordingly, future research needs to have measurement and sampling to overcome this limitation.

Second, the measurement issues of independent variables could be suggested. This study measures three necessary factors by perceptual evaluation with measurement errors. Especially, diversity can be measured by mathematical index to each characteristic (Teachman 1980, Ancona and Caldwell 1992) such as the number of job experience of NPD team. Future research needs to consider various methods of each variable in this study.

Third, this study makes an empirical test with just two groups due to the problem of the number of sample and does not consider the causal relationship among three necessary factors. If three groups and more are considered, a curvilinear relationship within each factor can be examined. Moreover, extensive causal relationships including three factors, other mediating and moderating variables (Gebert 2006) needs to be examined to explain the development of radical innovative product. In that case, it should be interesting issue to include time efficiency as dependent variable.

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