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# 내생적 선택 환경에서의 조직 진화
# Organizational Evolution Under Endogenously Dynamic Selection Environment

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## ABSTRACT

We consider organizational evolution in an endogenously changing selection environment. Following the majority of research on evolution in the biological realm, organizational scholars predominantly modeled selection environment as being exogenously endowed. We introduce a selection environment that can be shaped and modified by organizations themselves. In this endogenously dynamic environment, we examine the efficacy of two most representative evolutionary operators - mutation and imitation - in both exogenously and endogenously changing selection environment. We find that imitation fares quite differently depending on the type of selection environment while mutation is robust regardless of the environment. We further show that there is a complementary effect between mutation and imitation under the exogenously changing environment while there is no such effect under the endogenous setting. Overall, our study suggests that understanding the nature of evolutionary strategies for different selection regime is critical for organizational evolution.

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Key Words: organizational evolution, exogenous selection, endogenous selection, simulation, computational model

## 요 약

조직의 진화과정에서 선택 (selection) 환경은 생물학의 영역에서 연구되어온 대부분의 진화 이론을 따라 외생적으로 주어지는 것으로 여겨져 왔다. 즉, 개별 개체가 선택의 환경에 영향을 줄 수 없다는 것이었다. 본 연구에서는 기존의 전산 모델 (computational model)을 계승하여, 내생적인 요인으로 인해 변화되는 선택 환경 아래서의 조직의 진화를 살펴본다. 개별 조직이 스스로 변화시킬 수 있는 선택 환경의 가능성을 도입하고, 각각의 선택 환경에서 가장 대표적인 조직 진화 방식인 돌연변이(mutation)와 모방(imitation)이 진화적 성과에 주는 영향을 살펴본다. 돌연변이와 모방은 각각 자체적, 모방적 혁신에 대응될 수 있는 조직 진화의 기재들이다. 돌연변이의 경우 선택 환경에 따라 각 기재의 진화적 성과가 상이하게 나타났으며, 모방의 경우 선택 환경에 상관없이 비슷한 정도의 성과를 보였다. 더 나아가 외생적인 선택 환경에서는 돌연변이와 모방의 상호 보완적 시너지 효과가 나타났으며, 내생적 선택 환경에서는 그러한 시너지 효과를 찾아내지 못했다. 본 연구는 조직의 진화와 그로 인한 성과를 연구하는 데에 있어 선택적 환경의 속성을 고려하는 것이 중요함을 주장한다.

한글색인어: 조직진화, 외생적 선택, 내생적 선택, 시뮬레이션, 전산모델

# Ⅰ. Introduction

Scholars in strategic management and organizational theories consider adaptation in a changing environment one of the most important determinants of organizational long-term survival (e.g., Davis et al., 2009, Eisenhardt, 1989; March, 1991). A frequently examined question in this regard is how much exploration versus exploitation an organization needs to conduct to stay viable in a turbulent environment. While scholars have paid sufficient attention to the balancing part of exploration and exploitation, understanding the characteristics of the environmental changes received scant attention. It is a crucial issue in completing the model of organizational evolution because it eventually determines the selection criteria (Gavetti et al., 2017). Because of the difficulties in conducting an empirical study - e.g., longevity of available data set, operationalization and measures for environmental changes - scholars often examined this question in a computational setting. A striking fact is that in most computational studies, selection environment changes have been assumed to be exogenous - i.e., neither firms nor other industry participants can influence the selection criteria (Miller & Lin, 2010) is a notable exception whereby they examined an interaction between a single firm and the environment).

In fact, we have ample evidence on how firms can actually change the logic of the industry they belong to: the criteria as to which firms to survive while others do not. For example, Shimano, a Japanese bicycle component manufacture, introduced an integrated bicycle drivetrain during the 1980s and it subsequently changed the structure of the bicycle industry (Colfer & Baldwin, 2016, Fixson & Park, 2008). Recently, Gavetti et al. (2017) introduced the possibility for firms to “shape” the selection criteria and examined the comparative advantage between “searchers” and “shapers”. Because their findings suggest qualitatively different outcomes under the changing selection environment being “shaped” by firms, we have to renew some of the conventional views on organizational adaptation under changing selection environment.

This begs an important question as to the relationship between sources of selection environment changes and firms’ ability to adapt to the changing environment. Do environmental changes due to endogenous versus exogenous sources require different adaptation strategies from the firm? In particular, we consider two representative evolutionary operators for firm’s adaptation: mutation (i.e., hill-climbing search) and imitation. We examine whether there is a better performing adaptation strategy between mutation and imitation depending on whether the sources of selection environment changes are exogenous or endogenous. We find that there is an important contingency upon which an adaptation strategy can be based. Beyond this baseline question, we further ask whether there is a complementary effect between mutation and imitation depending on the types of selection environment changes. Although the potentially complementary effect between the two has been analyzed under varying degree of problem complexity (Ethiraj, Levinthal, & Roy, 2008), the contingency effect under varying selection regimes has not been explored. Given the important, yet less explored effect of selection regime, we see this question theoretically valuable. We find that there is a strong complementary effect under the exogenously changing environment while there is no such effect under the endogenously changing environment. Our model and results call for further understanding on the types of selection environment changes and firms’ adaptation strategy.

# Ⅱ. Evolution Under Dynamic Selection Environment

## 2.1 Organizational Evolutionary Operators: Imitation and Mutation

In theory of evolution, evolutionary operators are the functions that actually enable evolution by injecting variation. The most representative of them are crossover and mutation (Holland 1975: 91 and 97). In this section, we suggest how these two general evolutionary operators can be mapped to familiar sources of variation in an organizational setting.

*Crossover* is a process by which the next generation's variations of solutions to the problem of interest are produced from parent solutions. In a typical model of evolution (e.g., genetic algorithms), a problem is defined and a set of potential answers or solutions to the problem is created. Then, a pair of parent solutions is chosen from a mating pool of solutions and "mate" with each other by exchanging parts of their solutions. The offspring - the results of mating - creates variation. In an organizational setting, M&A's between firms and the resulting entity resembles the outcome from crossover. By recombining two parental firms (or one firm acquiring another), the post M&A entity can be understood as an offspring. The other event that serves the role of crossover in an organizational setting is inter-organizational learning or imitation (Hauschild & Miner, 1997). Although there is no explicit "mating" or recombination in an imitation process, it is similar to crossover in that an imitator (the imitating firm) injects some traits of the imitatee (the imitated firm) and create a new firm having traits of both firms. In an evolutionary setting, the effectiveness of imitation has been examined extensively (e.g., Rivkin, 2000; Posen et al., 2016).

Understanding mutation from organizational evolution is rather straightforward. From a theory of evolution, mutation is a process wherein "one allele of a gene is randomly replaced by (or modified to) another to yield a new structure" (Holland, p.109). This is similar to an image of "search" in organizational evolution. For example, in adaptation on an NK landscape (e.g., Levinthal, 1997), one of the N decision variables is flipped from one of the binary values to the other in the case of local search. This local search process is exactly identical to mutation. When the number of flipped decision variables increases, we call it a "long-jump"[1] or "distant search".

1) It is also possible to view imitation as "long-jump" when the degree of changes is high (e.g., Ethiraj, Levinthal, & Roy, 2008).

Of the two evolutionary operators, comparing efficacy of one over the other is an important question. Oftentimes the comparison is an overlooked question of interest for organizational theorists (Ethiraj & Levinthal 2004 is a notable exception.). In a model of evolution, one often asks how extensively one has to engage in one type of the operators. For example, with regard to imitation, scholars asked how much to copy when engaging in imitation (Csaszar & Siggelkow, 2010) or how many firms to include when choosing a firm to imitate (Posen et al., 2016). One the side of mutation, comparing whether one type of mutation (e.g., local search) is superior to the other (e.g., long-jump) and whether these two types are complementary or not has been an important question to ask (e.g., Levinthal 1997; Ethiraj, Levinthal and Roy 2008). Given the limited resources a firm can put in for change and the potential hazardous effects of performing extensive change (Hannan & Freeman 1984), it is important to compare the efficacy of one operator over the other.

This comparison becomes even more critical when we take into account the potentially varying selection contexts. In most biological evolution, selection forces exist independently from the entities to be selected (Levinthal & Marino 2015). This is a form of exogenous selection. However, scholars start giving attention to the endogenous nature of selection. That is, some firms are modeled to be able to actually "shape" the environment and produce a new form of selection rule (Gavetti et al., 2017). Given this possible endogenous nature of selection, the role of each operator needs to be reexamined under the endogenously changing selection environment.

## 2.2 Endogenously Dynamic Selection Environment

*Selection* is a process by which a certain proportion of the existing set of solutions (or organizations) is chosen to produce the next generation of solutions. In a Darwinian sense, the natural environment (or what we call "selection regime") intervenes and determines which organisms to be selected whose genes fit the environment better for future survival. While it is frequently assumed that the organisms cannot change the selection environment, scholars both in a biological realm and a business context are paying more attention to the possibility of organisms actively altering the environment in which they reside. In the theory of niche construction in biology, scholars examine the cases in which organisms actively define and modify their own niches through activities and behaviors of their own (Gavetti et al., 2017; Laland et al., 2000). We believe this proactive view of changing selection environment by firms is a frequent phenomenon that deserve more attention. Business firms like Apple or Shimano changed the industry landscape and many other firms residing in the same industry had to be evaluated by the new selection regime. Testing how the two evolutionary operators can fare well against each other in different types of selection environment changes is a natural question to ask. In the current study, we model the selection environment as the criteria against which a firm's set of choices is evaluated. While it is possible to model the actual selection process (e.g., death of an organization), we report performance changes over time in order to track long-term performance changes. In what follows, we describe the model and report the computational results.

# Ⅲ. The Model

## 3.1 Selection Environment and Firm Performance

Following prior computational modeling studies (e.g., March, 1991; Posen et al., 2013), our model is comprised of three parts. The first is reality. It is modeled as an n-dimensional vector $R = \{r_1, r_2, ..., r_n\}$ and each element $r_i$ takes on either 1 or 0. The reality can be interpreted as customer preferences. The second one is the firm modeled as an *n*-dimensional vector $X = \{x_1, x_2, ..., x_n\}$ with each attribute having one of binary numbers. Modeled as a composition of attributes, a firm handles an *n* decision problems corresponding to the element of the reality. For instance, a firm holds beliefs about *n*-characteristics of a specific merchandise in order to satisfy consumer needs. Lastly, an industry consists of *F* firms searching for configurations of attributes which can lead to better performance.

Following the performance payoff function from Posen at al. (2013), we define performance as the function of the number of corresponding attributes between a firm, X and the reality, R. The more matches they have, the better performance the firm gets. The payoff function incorporates interdependencies between attributes by including an adjustable parameter *k*. More formally, following Posen et al. (2013), we define performance as follows:

$$\mathrm{Y(X)} = \mathrm{f(R, X)} = \begin{cases} \frac{1}{n}\sum_{i=1}^{n} (\delta_i \cdot \prod_{j=1}^{k} \theta_j^i), & if\ 1 \le k \le n-1 \\ \frac{1}{n}\sum_{i=1}^{n} \delta_i, & if\ k = 0 \end{cases}$$

*Y*(*X*) stands for the performance of a firm with attribute vector *X*. $\delta_i = 1$ if the $i$-th element of attribute vector $X$ correctly matches the $i$-th element of the reality vector $R$, ; otherwise $\delta_i = 0$. Interdependence plays a vital role in determining the level of performance. When interdependence is absent ($k$ = 0), the performance equals the ratio of attributes that correctly match the reality. When $k > 0$, however, the performance equals the sum of partial payoffs each attribute gets when it and all its subset of $k$ other attributes correspond to reality. To be specific about the interdependence pattern, each attribute randomly tied with $k$ other attributes from $X$ precluding $i$ itself. $\theta_j^i = 1$ if the $j$-th element of the subset matches the corresponding element of reality; otherwise $\theta_j^i = 0$.

In an exogenously given environment, firms are unilaterally affected by the environment because their performance relies on attributes that correctly match the reality. Therefore, a useless attribute, such as one's old knowledge, is discarded and can be substituted by a useful attribute right away. To examine the case under endogenously dynamic selection environment, we first describe each type of selection environment change.

## 3.2 Selection Environment Changes

### 3.2.1 Exogenous Selection Environment Change

Exogenous selection environment changes proceed in the following steps: partial elements are randomly chosen and the chosen elements change their values with certain probability. Following these changes, firms undertake imitation or mutation to adapt to the changed environment. For example, when the number of changing attributes (denoted by $b_a$) is five ($b_a = 5$) and the probability of change (denoted by $p_{exo}$) is 0.2 ($p_{exo} = 0.2$), five are randomly selected among one-hundred attributes and each of them changes with the probability of 0.2 in each round. Consequently, as the elements of the reality changes, previously correct attributes held by a firm and all its k other interdependent attributes may turn into wrong attributes. Thus, each firm's performance can possibly drop dramatically.

### 3.2.2 Endogenous Selection Environment Change

In the endogenous environment, on the other hand, firms are able to shape their environment in addition to adapting to the given reality. The reality is not objectively determined, but, instead, firms exercise their forces over the selection environment conducive to their performance. Environmental changes of the endogenous world are different from that of exogenous world:

number of firms are chosen and each firm chooses attributes randomly to change with certain probability. Same with the case above, this process also occurs in each round. For instance, when the number of chosen firms (denoted by $b_f$) is five $(b_f = 5)$ and the probability of endogenous change (denoted by $p_{endo}$) is $0.2(p_{endo} = 0.2)$, five firms are randomly selected in the industry and each firm switch one random attribute $(b_a = 1)$ with the probability of 0.2. Note that our endogenous selection environment change is, in spirit, similar to Gavetti et al. (2017)'s environment "shaping". However, the modeling details are different: whereas Gavetti et al. (2017) based their modeling strategy on the NK landscape platform, we modified and extended March (1991)'s model of exploration and exploitation. Posen et al. (2013)'s model of (imperfect) imitation - the model we built upon - is another extension of March's model.

## 3.3 Search Strategy

Firm behavior consists of two search strategies: imitation and mutation. Firms employing imitation make decisions as simply copying the market leader's configuration of attributes. Firms engaging in mutation make decisions based on their own knowledge in an attempt to enhance their performance.

### 3.3.1 Imitation

Our imitation is built upon Posen et al. (2013)'s model. The definition of perfect imitation is that firms can 1) easily target the leading firm and 2) accurately imitate its whole attributes. Imperfect imitation is defined by softening these two assumptions. First, a firm might not process information about all other firms in the industry due to bounded rationality. Thus, instead of choosing the best firm, it may search firms with the highest outcome in the subsample of industry. The size of subsample is denoted by *b*. Therefore, $b \leq F$. That is, if the search scope is significantly big, it is possible to find the market leader fortunately or at least comparably superior one with higher performance. In the same context, a firm might also have the probability of imitating an inferior firm when *b* is a small number. Secondly, a firm is boundedly rational in judging whether attributes imitated from other firms is correct or not. The imitating firm does not know the benefit of copying a specific attribute. We presume that a firm indiscriminately reproduces a target firm's partial attributes without predicting its effect. The probability of imitating the target firm's single attribute is denoted by *p*. Thus, in our setting, *p* represents the imitation rate.

In our model, imitation works in a sequential process: firms search the industry, find the leading firm, choose its attributes, and reproduce them. Controlling the degree of bounded rationality by varying value of search scope, *b*, and imitation rate, *p*, Posen et al. (2013) introduced four cases of imitation process: perfect imitation, near-perfect imitation, imperfect imitation and random imitation. Under imperfect imitation, the industry's long-run overall performance is highest despite the bounded search scope and imitation rate $(b=5,\ p=0.3)$. In the case of perfect imitation, a firm can search the market leader in the entire industry and reproduce all attributes of the target firm $(b=50,\ p=1)$. Rather than comparing various imitation cases across the different levels of bounded rationality, we mainly focus on the case of imperfect imitation $(b=5,\ p=0.3)$ in an effort to check whether the long-run performance of the imperfect imitation is still valid in different types of environments. To distinguish the parameters used in mutation, *b* and *p* in the imitation process is denoted by $b_f$ and $p_i$.

3.3.2 Mutation

We assume a firm in our model attempts to adapt to a changing environment. Instead of assuming blind mutation, following prior studies on organizational search, we endow a moderate level of intelligence by allowing firms to mutate selectively. That is, after firms undertake mutation, they do performance check and decide whether to adopt the new alternative or to go back to the status quo. Performance check is done by comparing the status quo performance with the expected performance calculated by counting the number of attributes that match the elements of reality. A firm maintains its status quo attributes if the previous performance is higher than the expected performance; otherwise it adopts the new attributes. We denote the degree of mutation by $b_a$. That is, $b_a$ represents the number of attributes chosen by each firm to be changed. Note that we used the same notation for the degree of exogenous environmental change to denote the number of attribute changes. Mutation rate, $p_m$ means the probability of changing an attribute. If the set of changed attributes brings a higher performance than the status quo performance, the firm decides to adopt the new set of attributes.

## 3.4 Simulation

To observe the effect of imperfect imitation and mutation, we design two experiments. In experiment 1, we examine the efficacy of imitation and mutation under different types of environment.

In experiment 2, we explore the complementary effect of imitation and mutation.

All simulation results are calculated from 500 x 160 matrix containing longitudinal industry level performance. Specifically, to ensure the steady state of the performance in each run, 500 simulated industry runs until $t=160$. Reality consists of 100 attributes $(n=100)$, and each attribute is interdependent with five others $(k=5)$. 50 firms are contained in each simulated industry $(F=50)$ but there is no any entry or exit. Each firm is endowed with random attributes in the initial period. On average, half of the attributes correctly corresponds with the reality in the initial state. Firms conduct imperfect imitation ($b_f=5, p_i=0.3$) or mutation ($b_a=5,\ p_m=1$) in each type of environment. In the case of exogenous selection environment change, five randomly chosen attributes from the reality change with the probability of 0.2 $(b_a=5,\ p_{exo}=0.2)$ in each time step. In the case of endogenous changes, five attributes from the reality change by reflecting the attributes of the influencing firms with the probability of 0.2 $(b_f=5,\ b_a=1,\ p_{endo}=0.2)$. Therefore, the average rate of change between the two types of changes is the same. <Table 1> summarizes parameters and figures used in two experiments.

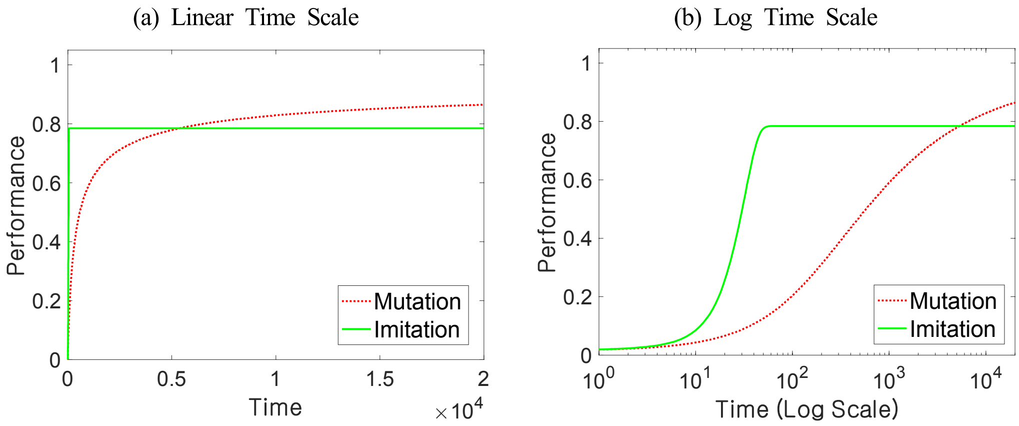
〈Table 1〉 Parameters Used in the Presented Results

| Parameter | Values | Meaning |
|---|---|---|
| $n$ | 100 | Number of elements of the reality |
| $F$ | 50 | Number of firms in an industry |
| $k$ | 5 | Level of Interdependence |
| $b_f$ | 5 | Search scope (Number of firms) |
| $b_a$ | 5, 1 | Search scope and Degree of Environmental Change (Number of attributes) |
| $p_i$ | 0.3 | Imitation rate |
| $p_m$ | 1 | Mutation rate |
| $p_{exo}$ | 0.2 | Environmental change rate in exogenous environment |
| $p_{endo}$ | 0.2 | Environmental change rate in endogenous environment |

# Ⅳ. RESULTS

## 4.1 The Efficacy of Imitation vs. Mutation Under Varying Selection Environments

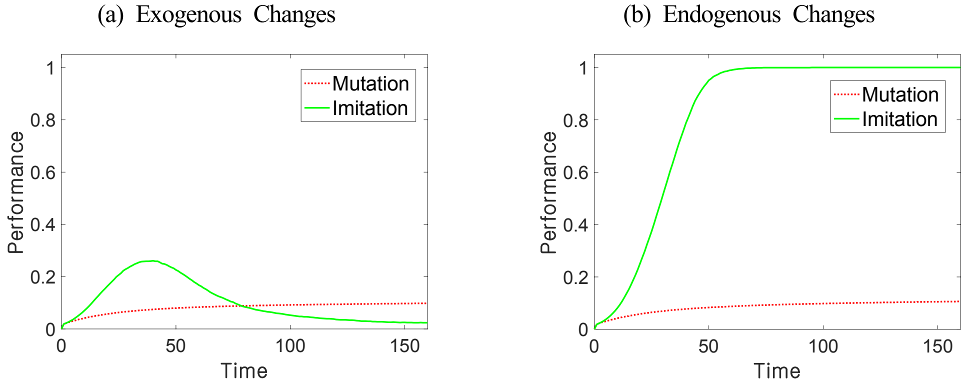
In this section, we examine the efficacy of (imperfect) imitation versus mutation under different types of selection environment changes. Before we do so, it is helpful to set a baseline. In Figure 1, we report the efficacy of imitation versus mutation under no selection environment changes. We use a linear time scale and a log time scale for the horizontal axes in [Figure 1(a)] and [Figure 1(b)], respectively. The log scale figure helps us see the performance evolution pattern in early periods.




[Figure 1] Mutation vs. Imitation Under Stable Selection Environment

The case of imitation exhibits fast early performance improvement. At around $t$ = 5,000, however, mutation catches up with imitation and eventually outperforms it. It is clear that in a long-run, mutation is a better evolutionary strategy under a stable environment. The reason behind this conclusion is rather straightforward. Although mutation may be slow in finding the most fit set of attributes, it gives more variety in experimenting with diverse possibilities of combinations. It is the random nature of mutation that increases such possibilities. On the other hand, the degree of possibility in experimenting diverse combinations in imitation is limited. The extent to which each firm can experiment with cannot exceed the degree of diversity endowed in the beginning. These baseline results and the intuition are useful in understanding the results of our main interests. This intuition may seem diverge from the results from prior studies such as Ethiraj, Levinthal, and Roy (2008) where they argue imitation is the key for overcome exploitation trap. The difference is due to the nature of the landscape (i.e., payoff function). The rugged nature of the NK landscape in Ethiraj et al. (2008) is the key to understanding the diverging performance implication. Our payoff function has a single peak with a step-function-like gradient.

[Figure 2] presents the main results. In a nutshell, there are three major observations. First, [Figure 2(a)] shows the long-run performance of imperfect imitation and of mutation under exogenous selection environment changes. The simulation result shows that the performance of imperfect imitation increases at a faster rate in the beginning. But in a longer-run, it approaches to zero. Second, [Figure 2(b)] shows that the performance of imitation increases continuously and nearly reaches 1, the maximum performance level. Third, regardless of environment type, mutation shows robust performance patterns.

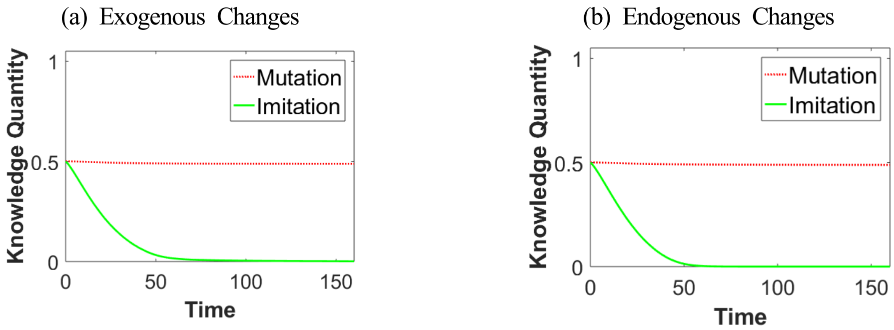



[Figure 2] Mutation vs. Imitation Under Changing Selection Environment

In the case of imperfect imitation, firms fail in adapting to the changing exogenous environment as in [Figure 2(a)] whereas they realize a much higher performance under the endogenously changing environment as in [Figure 2(b)]. Why do we observe poor imitation performance under the exogenous selection environment changes? And why does the performance in the endogenously changing selection environment grow so rapidly? To answer these questions, we analyzed the quantity of knowledge diversity and the quality of knowledge following Posen et al. (2013).

Quantity of diversity in firm attributes can explain the performance of the imperfect imitation (Campbell, 1965; March, 1991; Kauffman, 1993; Fang et al., 2010). Quantity of diversity in knowledge is measured by comparing all firms in a pairwise manner. We compare all corresponding attributes between two firms and calculate diversity by averaging the sum of squared differences (See Fang et al., 2010 for details).

[Figure 3] presents changes in the quantity of knowledge (i.e., knowledge quantity) over time. What is most striking in [Figure 3(a)] and [Figure 3(b)] is that the longitudinal patterns in knowledge quantity are the same regardless of the type of selection environment change. The pattern for mutation starts at around 0.5 and remains at the similar level towards the end; the pattern for imitation starts at the same level and, over time, the knowledge quantity approaches to zero. From the same pattern between [Figure 3(a)] and [Figure 3(b)], one might conclude that knowledge quantity does not explain the performance differences between two imitation cases in [Figure 2]. However, there are more to speculate from the two imitation patterns in [Figure 3]. In the process of interfirm imitation, diversity reduces over time and all firms come to have almost same attributes. In the end, firms have nothing to imitate from each other and diversity approaches to zero. Although the two imitation cases indicate the degree of knowledge diversity approaches to zero over time, the converging points may be two very different points.

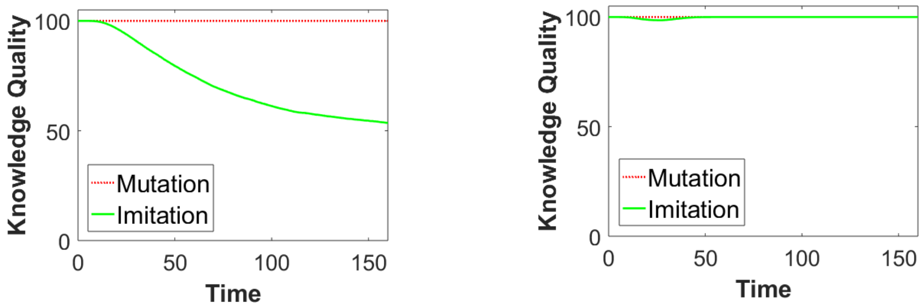



[Figure 3] Quantity of Knowledge Under Changing Selection Environment

In [Figure 3(a)] even after industry-level diversity is completely driven out, the selection environment keeps changing and the sources of change are independent of the firms' existing attributes. Thus, as the degree of diversity among the firms' attributes gets lower, there is a less chance of matching the exogenously changing selection environment. As once-correct-attributes are likely to be wrong with exogenous changes, the performance of the industry starts falling and gets close to zero due to near-identical attributes among firms. In [Figure 3(b)], quantity of diversity in knowledge for imitation also decreases to the level of zero over time. However, unlike the case of imitation in [Figure 3(a)], firms are able to shape the selection environment. As the degree of knowledge diversity becomes smaller over time, there is a higher likelihood of matching between the newly constructed selection environment and the existing firms' attributes. Furthermore, changed elements of the reality diffuse within the industry and the homogenization process continues. Hence, the higher level of homogenization through imitation, the higher performance the industry as a whole can acquire.

To demonstrate the above points further, we simulate the quality of knowledge. Quality of knowledge reflects the level of preservation of useful attributes about the reality at the industry level. Quality is computed by counting the number of correct attributes matching reality. For example, the industry has one correct attribute if at least one firm has the attribute that matches the world.

(a) Exogenous Changes (b) Endogenous Changes




[Figure 4] Quality of Knowledge Under Changing Selection Environment

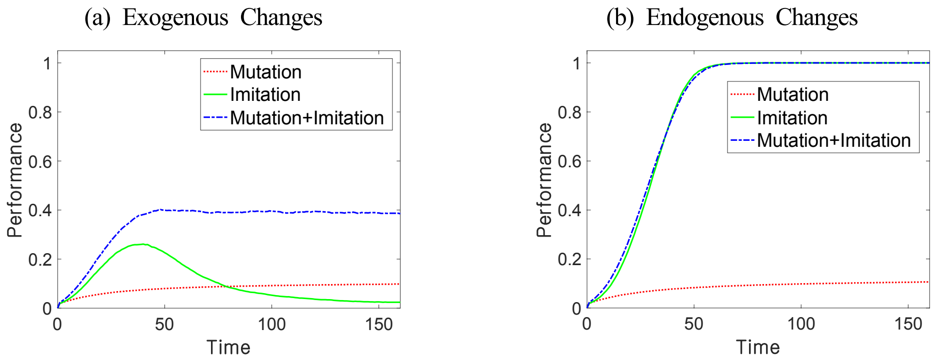
[Figure 4(a)] shows that the quality of knowledge for the case of imitation drops over time. After a series of imitation processes, all firms become homogenous and the selection environment keeps changing independently. Thus once-correct-attributes turn into useless ones. Firms keep preserving worthless attributes and imitate these attributes from each other. This is why quality of knowledge declines as time goes by. On the other hand, according to [Figure 4(b)], quality of knowledge stays at the highest level in the case of endogenous selection environment changes. There are periods with slight quality decrease between $t = 20$ and $t = 50$.

But soon after the quality level returns to the original level because of the characteristics of endogenous environment. The high quality of knowledge and the homogenization process among firms make the high-performance level by imitation in [Figure 2(b)] possible.

### 4.2 The Complementary Effect of Mutation and Imitation

In this section, we explore whether there is a complementary effect between imitation and mutation under the two environment changes. To examine the interaction between a firm's search strategies, we combine imitation and mutation in a single adaptation process. Firms undertake imitation and then mutation in each round with the following parameter setting: $b_f = 5$, $p_i = 0.3$; $b_a = 5$, $p_m = 1$. The degree of selection environment changes remains the same as well with the following parameters: $b_a = 5$, $p_{exo} = 0.2$; $b_f = 5$, $b_a = 1$, $p_{endo} = 0.2$.

[Figure 5(a)] shows the long-run performance of mutation and imitation as well as the combined the combined case under exogenous selection environment changes. Compared to the performance of imitation alone, the combined case shows a strong complementary effect by reaching a performance level near 0.4 and it does not exhibit a sign of decline. On the contrary, we find similar results between imitation and the combined case in [Figure 5(b)]. Why do we observe the complementary effect between mutation and imitation under the exogenous selection environment changes only? It is because mutation 'defends' the homogenization process and introduces a moderate level of randomness to the industry. According to our analysis on the quantity of knowledge (not reported here), the knowledge diversity level does not drop to zero. This means mutation helps overcome the effect of negative homogenization by increasing diversity of knowledge and thereby diffuse valuable knowledge through imitation into the industry.




[Figure 5] The Complementary Effect of Mutation and Imitation

## 4.3 Sensitivity Analysis

We examine the robustness of our results in the regards to the following two issues: (1) the extent and the method of causing endogenous change and (2) the order of imitation and mutation. First, in terms of the endogenous change, we increase the number of changing attributes at every specific time period, which is similar to the concept of environmental turbulence of March (1991). We switch thirty attributes ($b_a = 30$) of ten leading firms ($b_f$= 10)[2] with the probability of successful change ($p_{endo}$ = 0.2) at the specific time period ($t$ = 10). The results show that, in case of doing imitation and mutation, after the slight decrease in the firm performance when there are significant changes in the attributes of leading firms, firm performance starts to increase immediately. That is, with a general tendency to increase in performance, there was a minor decrease in every tenth interval ($t$ = 10, 20, 30, ⋯). In addition, we alter the probability of changing attributes to 0.8 ($p_{endo}$ = 0.8). In this case, there are no substantial differences in results, except that the degree of the decrease in performance in every tenth interval is greater than that with the probability of 0.2. Second, we change the order of imitation and mutation in experiment 2 by making firms undertake imitation after the mutation. In spite of the change in the order of imitation and mutation, the results remain robust across the cases. Although there are minor differences in the timing and the degree of the increase in performance, these differences do not influence the results in a qualitatively different way.

## Ⅴ. Discussion and Conclusion

In this study we modeled organizational evolution in an endogenously changing selection environment and considered performance implications. Until recently, most of the models in organizational evolution assumed exogenously given selection environment whereby the selection regime is independent of influences from organizations. This is rather surprising when we take the ample examples of more active images of firms influencing the industry settings into consideration. Thus, we introduced a selection environment that can be shaped and modified by organizations themselves. In this endogenously dynamic environment, we examined the efficacy of two most representative evolutionary operators - mutation and imitation - in both exogenously and endogenously changing selection environment. We find that imitation fares quite differently depending on the type of selection environment while mutation is robust regardless of the environment. While imitation reached a zero performance level over time under an exogenously changing selection environment, it fared quite well under an endogenously changing environment. We further show that there is a complementary effect between mutation and imitation under the exogenously changing environment while there is no such effect under the endogenous setting.

Since there is no clear-cut distinction between exogenous and endogenous selection regimes,

2) Leading firms are determined in the order based on their performance in every ten periods.

it is important to establish a real-world correspondence. One way to interpret each category is by considering industry concentration level. As an industry becomes more concentrated - e.g., oligopoly or duopoly - environment changes are more likely due to changes made by a small number of firms. As the industry becomes more competitive (i.e., less concentrated), the industry logic would be less dependent on a particular set of firms. An analogy of “price-maker” versus “price-taker” would be an adequate image here. In our results, the case of endogenous changes generates much higher performance than the exogenous case does. On average, individual firms generate more profit in a more concentrated industry. Our model roughly captures this tendency, too. Using this industry concentration background, we can reach a conclusion about whether imitation versus own innovation is more rewarding. Our result suggests that, in a highly concentrated industry, imitation efforts fares better than its own innovation efforts. Since imitation performs as good as the combination case under endogenously changing environment, imitation is a weakly dominant strategy under the endogenous case. On the other hand, in an exogenously changing environment, the combination of imitation and own innovation effort produces the best outcome, thus, a strictly dominant strategy.

This conclusion should be taken with caveat. Our results can take a different form under other assumptions. First, in modeling the exogenously changing environment, we assigned the influencing firms randomly. This picture corresponds to a highly dynamic industry, not an industry with a few powerful players. In a future study, an industry situation that more closely resembles a highly concentrated case can be modeled. Second, it is important to note that there are several existing studies using different performance landscape models. The NK performance landscape is a notable example (e.g., Levinthal, 1997; Rivkin, 2000). Although modeling an endogenously changing environment with the NK model in the way consistent with ours may be difficult, it would be a fruitful way for future research. Our results may be dependent on the landscape assumption.

Overall, our results suggest there are strong needs for further understanding on the relationship between the selection environment and the selected firms. As our results indicate, firms’ adaptation strategies need to be selected and used after considering the logics of the selection environment. This seemingly obvious insight has been mostly overlooked until very recently. We hope our attempt to better understand the interaction between adaptation strategies and endogeneity of selection environment can further our understanding on organizational evolution beyond the wisdom diffused from the biological realm.

## References

Campbell, D. T. (1965). Variation and selective retention in socio-cultural evolution. In: H. R. Barringer, G. I. Blanksten, & R. Mack (Eds.). *Social change in developing areas: A reinterpretation of evolutionary theory*: 19-49. Cambridge, Mass.: Schenkman.

Colfer, L., & Baldwin, C. Y. (2016). The mirroring hypothesis: Theory, evidence and exceptions. *Industrial Corporate Change*, 25, 709-738.

Csaszar, F. A., & Siggelkow, N. (2009). How much to copy? Determinants of effective imitation breadth. *Organization Science*, 21, 661-676.

Davis, J. P., Eisenhardt, K. M., & Bingham, C. B. (2009). Optimal structure, market dynamism, and the strategy of simple rules. *Administrative Science Quarterly*, 54, 413-452.

Eisenhardt, K. M. (1989). Making fast strategic decisions in high-velocity environments. *Academy of Management Journal*, 32, 543-576.

Ethiraj, S. K., & Levinthal, D. (2004). Modularity and innovation in complex systems. *Management Science*, 50(2): 159-173.

Ethiraj, S. K., Levinthal, D., & Roy, R. R. (2008). The dual role of modularity: Innovation and imitation. *Management Science*, 54(5): 939-955.

Fang, C., Lee, J., & Schilling, M. A. (2010). Balancing exploration and exploitation through structural design: The isolation of subgroups and organizational learning. *Organization Science*, 21, 625-642

Fixson, S. K., & Park, J. K. (2008). The power of integrality: Linkages between product architecture, innovation and industry structure. *Research Policy*, 37, 1296-1316.

Gavetti, G., Helfat, C., & Marengo, L. (2017). Searching, shaping, and the quest for superior performance. *Strategy Science*, 2, 194-209.

Haunschild, P. R., & Miner, A. S. (1997). Modes of interorganizational imitation: The effects of outcome salience and uncertainty. *Administrative Science Quarterly*, 42(3): 472-500.

Holland, J. H. (1975). *Adaptation in Natural and Artificial Systems*. University of Michigan Press, Ann Arbor.

Kauffman, S. A. (1993). *The Origins of Order: Self-Organization and Selection in Evolution*.

New York: Oxford University Press.

Laland, K. N., Odling-Smee, J., & Feldman, M. W. (2000). Niche construction, biological evolution, and cultural change. *Behavioral and Brain Sciences*, 23, 131-146.

Levinthal, D. A. (1997). Adaptation on rugged land scapes. *Management Science*, 43, 934-950.

Levinthal, D. A., & Marino, A. (2015). Three facets of organizational adaptation. Selection, variety, and plasticity. *Organization Science*, 26, 743-755.

March, J. G. (1991). Exploration and exploitation in organizational learning. *Organization Science*, 2, 71-87.

Miller, K. D., & Lin, S. (2010). Different truths in different worlds. *Organization Science*, 21, 97-114.

Posen, H. E., Lee, J., & Yi, S. (2013). The Power of Imperfect Imitation. *Strategic Management Journal*, 34, 149-164.

Posen, H. E., Leiblein, M. J., & Chen, J. S. (2016). A behavioral theory of real options. *Academy of Management Proceedings*, vol. 2016, No. 1: 12346. Briarcliff Manor, NY: Academy of Management.

Rivkin, J. W. (2000). Imitation of complex strategies. *Management Science*, 46, 824-84.