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Competition and Pharmaceutical Innovation: The Moderating Role of Size and Age of Leading Companies in the Market

Ye Lim Jung and Hyoung Sun Yoo

Abstract—**Despite a long period of research on the relationship between competition and innovation, contradictory observations about their relationship have been reported and there is yet no consensus on this relationship. Moreover, there have been few studies on how this relationship is affected by the characteristics of companies participating in the market. In this article, we aim to examine the relationship between competition and innovation activities, particularly in the pharmaceutical industry, and investigate how this relationship is moderated by the size and age of leading companies. By analyzing 8243 reported drug development activities and the competitive intensity of the global pharmaceutical market for 234 drug classes, we found that there is a positive linear relationship between the 1-Herfindal–Hershman Index or the number of competitors and the number of drug development projects. In addition, it was found that this relationship is negatively moderated by the size and age of the leading participating companies. Based on these findings, we discussed several implications for stimulating pharmaceutical innovations.**

Index Terms—**Drug development, innovation activities, market competition, pharmaceutical industry, pharmaceutical innovation.**

I. Introduction

COMPETITION in the market is considered to have both positive and negative aspects, simultaneously. On the positive side, competition can be the best method of allocating resources in a free competitive market [1]. It enables market participants to provide better products and services to consumers at a lower cost, with greater variety and opportunities for choice. In addition, companies pursue high efficiency and productivity in a competitive environment and such competition becomes the basis for the enrichment of technological and managerial knowledge by encouraging more innovations [2]. However, competition is not always beneficial for participating companies in the market [1], [3]. It is inevitable that certain participants will fall behind the competition, and it is often difficult for them to recover because the winners already occupy dominant positions. Such market preemption can even break the fair rules of the market and cause inequality of opportunities.

In this regard, researchers have investigated for a long period of time that how such pros and cons of market competition affect the innovation activities of companies. While competition may fuel innovation to survive in the market, excessive competition among market participants may sometimes be costly and counterproductive and, consequently, inhibit innovation. Since the fundamental discussion about the relationship between competition and innovation was initiated by Schumpeter in 1942 [4], several hypotheses have been proposed to explain this relationship, advancing from a focus on the negative effects to the positive effects of competition on innovation, and finally on a quadratic (an inverted U-shaped) relation that merges both effects [5]. To date, the studies on the relationship between competition and innovation continue, and this has become one of the most important subjects of innovation research. Numerous empirical studies that support different hypotheses on this relation have been reported, varying by the areas of industry [6], [7], [8], countries or regions on which they are focused [5], [9], [10] and also varying by the type of applied metrics [11], [12], [13]. Consequently, the debate on the theory that can best explain the relationship is still ongoing and a consensus has not yet emerged.

Furthermore, although several studies investigated the relationship between competition and innovation in the pharmaceutical industry [14], [15], [16], [17], examinations of the relationship depending on the detailed therapeutic class of the drug have been scarce. The pharmaceutical industry has unique characteristics that distinguish it from other industries: this industry is characterized by one of the highest research and development (R&D) intensity among all industry sectors, the long period and low success rate of product (drug) development, strict regulations on approval for market launch, and restrictions on flexible pricing due to issues related to medical insurance [18], [19]. Due to these particularities, it is necessary to closely examine the relationship between competition and innovation in the pharmaceutical industry. Moreover, how this relationship is moderated by other factors has been rarely investigated. Specifically, there has been a lack of research on how the effects

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Ye Lim Jung is with the Division of Data Analysis, Korea Institute of Science and Technology Information, Seoul 02456, South Korea (e-mail: yelima@kisti.re.kr).

Hyoung Sun Yoo is with the Division of Data Analysis, Korea Institute of Science and Technology Information, Seoul 02456, South Korea, and also with the Department of Science and Technology Management Policy, University of Science and Technology, Daejeon 34113, South Korea (e-mail: hsyoo@kisti.re.kr).

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of competition on innovation may vary depending on the size and age of the participating companies, in spite of the fact that they are one of the most important indicators reflecting the market environment, along with the competitive intensity of the market. This study tries to shed light on these subjects that have been inadequately explored.

We address the following research questions. What kind of relationship exists between competition and pharmaceutical innovation and how is the relationship moderated by the size and age of the leading companies in the market? To answer these questions, we analyzed the relationship between competition and innovation activities in the global pharmaceutical industry. Specifically, we investigated the recently reported drug development pipelines of pharmaceutical companies as an indicator of innovation activities, and market concentration as an indicator of the competitive intensities in each therapeutic drug class. We analyzed the relationship by applying a negative binomial regression method with a total of 8243 innovation activities and market competitive intensity in terms of 234 drug classes. Thereafter, we examined the moderating role played by the size and age of the leading companies on the relationship between competition and innovation activities. Based on these analyses, we identified the positive relation between competition and pharmaceutical innovation as well as the impact of the interaction between competition and the size or age of the leading companies on innovation activities. Finally, we discussed several contributions made by this study and its policy implications.

II. Theoretical Background and Hypothesis

A. Relationship Between Competition and Innovation

According to Schumpeter's hypothesis [4], which initiated the theoretical discussion on the relationship between competition and innovation, a monopolistic market structure is more efficient than a competitive structure in inducing innovation activities from a dynamic point of view (this is called the "Schumpeterian effect."). The study argued that the excess profits that firms obtained from competition are the substantial incentives that stimulate innovation activities. That is, when there is less competition in the market, there is a greater margin (room) that induces companies to conduct R&D, one of the typical innovation activities. Following Schumpeter's hypothesis, many studies have empirically demonstrated the Schumpeterian effect [20], [21], [22], [23].

However, the theory of competition and innovation reached a new phase with the publication of Arrow's study in 1962 [24]. This study hypothesized and demonstrated that, as opposed to the Schumpeterian effect, the incentives for innovation are greater when the market structure is competitive rather than monopolistic. In other words, competition is a good catalyst for innovations. The study explained the reasons for this positive effect as follows: the companies with market dominance in monopoly or oligopoly markets are already relishing excessive profits and bureaucracy may be rampant in these companies, leading to a decline in innovation activities, whereas in a highly competitive market, companies have no choice but to continuously pursue innovations to survive (this is called the "escape-competition effect."). Although many subsequent studies supported Arrow's hypothesis [25], [26], [27], there have also been many studies reporting mutually contradictory results, either supporting the Schumpeterian effect or the escape-competition effect.

More recently, Aghion et al. [28] incorporated these incompatible effects and demonstrated that there is a nonlinear relationship between competition and innovation that forms an inverted-U shape. They found strong evidence that the degree of each effect changes depending on the level of competition, resulting in an inverted-U shape relation. It was observed in the study that the distribution of the Lerner index and the number of patents showed the form of a quadratic function. Their interpretation of this balance was that when the competition level is low, the escape-competition effect is more dominant because competition increases incremental profits from innovating, whereas when the competition level is high, the Schumpeterian effect is more dominant because the initial profits from the innovations driven by laggard firms are low. Although it is a widely accepted theory that explains the relationship between competition and innovation, it remains controversial because other studies have continually reported observations of different results depending on the analysis target and conditions [29], [30], [31], [32].

In the pharmaceutical industry, few studies have examined the relationship between competition and innovation, and the results are also mixed (see Table I) [14], [15], [16], [17]. The results differed somewhat depending on data, samples, and measures of competition or innovation. Briefly, it has been empirically demonstrated that R&D investments by biopharmaceutical companies increase as competition increases [16]. In addition, the number of clinical trials initiation has increased as competition increases in a situation where the market power of the incumbent firms cannot be guaranteed by legal protections due to the antitrust enforcement [17]. On the other hand, it was found that increase in generic competition reduces innovation activities of incumbent firms or early stage innovation [15]. Although the relationship between competition and innovation in the pharmaceutical industry is unclear and depends on the scope of analysis, we expect a positive relationship in global setting because the pharmaceutical industry typically has characteristics that favor competition than concentration to promote innovations: the majority of innovations are product innovations rather than process innovations, and it possesses high technological opportunities and high appropriability [14]. All of these characteristics make competition play an important role in innovation. Moreover, we argue that the escape-competition effect would be more pronounced than the Schumpeterian effect because the pharmaceutical industry has a highly concentrated market structure; that is, the average competitive intensity of the market is low [33]. Therefore, we established our hypothesis as follows:

> *H1. The relationship between competition and innovation activities is positive in the pharmaceutical industry, such that when the market is more competitive, there are more drug development projects.*

B. Impact of the Participating Companies' Size and Age on the Relationship Between Competition and Innovation

The characteristics of the companies participating in an industry, such as sales, age, and number of employees, are known

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TABLE I
PREVIOUS STUDIES ON THE RELATIONSHIP BETWEEN COMPETITION AND INNOVATION (ACTIVITIES) IN THE PHARMACEUTICAL INDUSTRY

Reference	Variables (Measures)	Sample	Findings
[14]	-	· Previous literature analysis and case studies	· Competition is more beneficial for innovation than monopoly in the pharmaceutical industry. · The pharmaceutical industry is characterized by product innovation (rather than process innovation), high appropriability, and high technological opportunities, which makes that the competition is important for innovation.
[15]	· Competition: Incidence of generic competition (Ratio of generic sales to sum of focal firm and generic sales in therapeutic area) · Innovation: Early stage innovation (New compounds in preclinical or Phase 1 clinical trials)	· Country: U.S. · Period: from 1998 to 2010 · N: 29 514 observations for firm-market-year level	· Increase in generic competition reduces early-stage innovation. · Increasing generic competition drives companies to shift their R&D from chemically based products to biologically based products.
[16]	· Competition: Number of competitors in the industry · Innovation: R&D investment (R&D expenditures/total assets), Number of patents, and Market values of the patents	· Country: Global · Period: from 1950 to 2016 · N: 1489 biopharma firms (13 816 firm-year observations)	· When competition intensifies, companies increase their R&D investments, carry more cash, and reduce their net debt. · As competition increases, the number of patents issued by firms decreases, while the economic value of these patents increases.
[17]	· Competition: Number of generic entries · Innovation: Initiation of clinical trials for drug development	· Country: U.S. · Period: from 2005 to 2016 · N: 572 biopharma firms (3543 firm-year observations)	· The relationship is subject to regulatory and antitrust laws for incumbent firms. · Before the legal ruling that induces antitrust enforcement (the Federal Trade Commission versus Actavis Ruling), the relationship is negative, but it reverses to positive after the ruling.

to be the main factors that influence innovations in the industry [5], [34], [35]. Although the impact of firm size and age on innovation has been studied extensively in the previous literature, the direction of their effects is still controversial. Regarding firm size, previous studies have found positive, negative, and nonlinear or statistically insignificant relationships [36], [37], [38]. In many studies, including Schumpeter's study, it was pointed out that there is a scale of economy in innovation activities in which only large firms can exploit because of the high fixed cost and resource requirements [39], [40]. On the other hand, there have also been evidence of the negative effect of firm size on innovation activities. It has been suggested that as firms get larger, the R&D efficiency decrease with the managerial control loss and the innovation incentives of researchers and entrepreneurs are weakened by bureaucracy that reduces the ability to capture the profits from their endeavors [27]. Thus, the findings on the relationship between firm size and innovation remain inconclusive. The effect of firm size may vary by industry, and the evidence is contradictory particularly in the pharmaceutical industry because preceding studies have found diverse and often conflicting results [41].

With respect to firm age, the relationship between firm age and innovation has been long debated over the past decades. Previous studies have argued that new firms are more active in learning new technologies or products and have a higher degree of creativity than mature firms, making them more advantageous for innovation [42], [43], [44]. In addition, older firms may become less able to cope with new challenges due to organizational inertia and rigidity [45], [46]. On the other hand, other studies indicated that younger firms lack complementary resources [47] and lack the ability to absorb and utilize external knowledge, making it difficult to make the most of these inputs into innovation [48]. In this regard, the evidence on the relationship between firm age and innovation is also mixed.

Unlike their direct effects on innovation, there has been little research on how firm size and age moderate the relationship between competition and innovation. A study by Acs and Audretsch [49] reported that the effect of the size of a company on innovation is not identical in all industries; the effect differs depending on the competitive situation of the industry. It was identified from the study that large firms have an innovative advantage over small firms in highly concentrated industries, whereas small firms have the relative innovative advantage in less concentrated industries. However, there has not yet been adequate, detailed research on how the competitive environment and firm size interact to influence innovation.

In this context, we propose that the degree of innovation may vary depending on the interaction between competitive intensity and the size of companies participating in the market. Specifically, we expect that the positive relationship between competition and innovation, whereby innovation increases as competition increases, will be strengthened in a market where smaller companies participate as the main players because small companies have more innovative advantages in a competitive

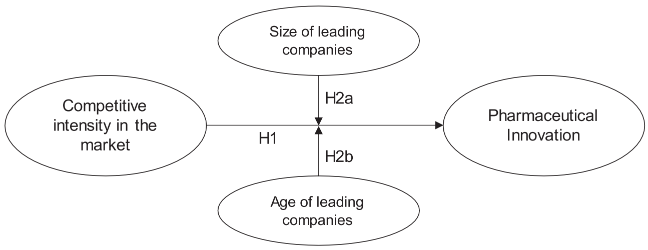

Fig. 1. Framework of the research hypotheses tested in this study.

market. Similarly, we assume that the positive impact of competition on innovation will be intensified in a market where younger companies participate as the main players because firm age is likely to coincide with firm size [50]. They need to be explored as important characteristics that influence not only innovation directly but also the relationship between competition and innovation. We focused on top ten companies by revenue in each drug class because these are the leading companies that have attracted the practical interest of many entrepreneurs in the field.

As a result, in order to investigate the moderating role of the size or age of leading companies in an industry on the relationship between competition and innovation activities, we established the following hypotheses.

H2a. The size of leading companies in the market negatively moderates the positive relation between competition and innovation such that the smaller the major participating companies, the greater the impact of competition on pharmaceutical innovation.

H2b. The age of leading companies in the market negatively moderates the positive relation between competition and innovation such that the younger the major participating companies, the greater the impact of competition on pharmaceutical innovation.

The research framework for the hypotheses tested in this study is illustrated in Fig. 1.

III. Methods

A. Data Collection and Processing

Information on the drug development projects of pharmaceutical companies was obtained from IQVIA pipeline intelligence. The 8243 reported activities in drug development from January 2018 to April 2020 were collected and classified according to the European Pharmaceutical Market Research Association's anatomical classification of the drug [51]. Market information, including the market size and market share of the companies in each drug class in 2018, was obtained from IQVIA therapeutic class profiles. It provides annual pharmaceuticals sales, market share, and market share rankings by therapeutic area (drug class). In addition, the information on the top ten companies based on market share by drug class was further collected from Standard & Poor's Capital IQ.

B. Defining Variables

1) *Innovation Activities:* The innovation activities were measured by the number of reported drug development projects of the pharmaceutical companies by drug class. These included drugs in developmental stages, including the discovery, preclinical, and clinical (phase 1, 2, 3) stages, but did not include registered or marketed drugs. That is, we only considered drugs under development to avoid the endogeneity problem, whereby innovation activities again affect market competition. When counting the number of drug development projects, if two or more drug classes were tagged in a single drug, multiple counting was allowed.

2) *Competition:* The Herfindahl–Hirschman Index (HHI) and the number of competitors by drug class were utilized as indicators of competition. The HHI is a widely used measure of market concentration and is calculated by summing the squared market share of each company competing in a market [52]. Thus, a smaller HHI value indicates a more competitive market. In our analysis, since only the market shares of the top ten companies and the total number of participating companies were available in the collected data, the HHI values were calculated approximately as the sum of the squares of the market share of the top ten companies and the squares of the average market share of the remaining companies

$$\text{Approximate HHI} = \sum_{i=1}^{10} S_i^2 + \frac{\left(1 - \sum_{i=1}^{10} S_i\right)^2}{n - 10} \quad (1)$$

where S_i is the market share of company i, and n is the total number of companies participating in each drug class' global market. 1-Approximate HHI was used to ensure that the value increases as competition increases.

3) *Control Variables:* The variables controlled in the analyses were the market size of a drug class and the size and age of the leading companies in a drug class. With respect to market size, it is already known that market size positively affects innovations in the pharmaceutical industry [53]. Specifically, the authors found that a 1% increase in the market size of a drug category increases the number of new drugs launched by 4%. Many subsequent studies have corroborated these findings [18], [54], [55], [56]. Extensive and various preceding studies strongly demonstrated that market size positively affects pharmaceutical innovation. Accordingly, we controlled market size in our analysis investigating the relationship between competition and pharmaceutical innovation. The market size was largely skewed to zero and showed a long-tailed distribution, so it was transformed by applying the natural logarithm.

In addition, firm size and age are important factors that influence innovation activities, as we reviewed in Section II-B. In this regard, we added the size and age of companies participating in the industry as control variables in our analysis of the relationship between competition and innovation. Particularly, we considered the top ten companies by revenue in each drug class because it would have been difficult to collect information on all participating companies in the world by class. We focused on only the top ten companies in sales for each class equally so that a relative comparison would be attainable. The size

TABLE II
OPERATIONAL DEFINITIONS OF THE VARIABLES CONSIDERED IN THIS STUDY

Category		Metrics[a]	Definition	Period
Innovation activities		Drug development	The number of drugs (reported to be) under development	January, 2018 –April, 2020
Competition		1-HHI	One minus the sum of the squares of the market shares of participating companies	2018
		Number of competitors	Total number of participating companies in the market	2018
Control variables		Market size	Size of the global pharmaceutical market (Unit: million USD)	2018
	Moderating variables	Size of companies	Average number of employees in the top ten companies by revenue (Unit: thousand employees)	2018
		Age of companies	Average age of the top ten companies by revenue (Unit: year)	2018

[a]All metrics were measured by drug class.

of the company was measured by the number of employees in the company, and the age of the company was calculated by the number of years since the company's establishment. Finally, the average size and age of the top ten leading companies were used for analyses. Table II summarizes the operational definitions of the variables used in this study.

C. Data Linkage

As for the indices for competition (independent variables), annual data for 2018 were used for the estimation of 1-HHI and number of competitors. For innovation activities (a dependent variable), the number of drug development projects reported during the period from January 2018 to April 2020 was counted, as presented in Table II. That is, by linking the independent and dependent variables for the above periods, a time lag was considered so that the competitive environment of the market could be sufficiently reflected in the innovation activities. In addition, all the data were linked based on the drug class. The data on a total of 234 classes were available after the linkage and this constituted the target dataset analyzed in this study.

D. Methodology

To test our hypotheses, we estimate the following equation (control variables omitted):

$$\text{Innovation activities} = \beta_0 + \beta_1 X_1 + \beta_2 X_2 + \beta_3 X_1 X_2 + \varepsilon \quad (2)$$

where X_1 represents the competition (i.e., 1-HHI or number of competitors) and X_2 represents the size or age of the leading companies. When investigating the quadratic relation of the competition and innovation activities, ${X_1}^2$ term was added to the equation.

It was observed that the distribution of innovation activities (drug development projects) is skewed to zero and their frequency values are greater than or equal to zero. The results of an overvariance test using the likelihood ratio (LR $= -2$(Log Likelihood $(\text{LL})_{\text{poisson}} - \text{LL}_{\text{negative binomial}}$)) showed that the negative binomial regression analysis was more suitable than the Poisson regression analysis [57]. In addition, the Akaike Information Criterion and Bayes Information Criterion values were also lower in the negative binomial regression analysis. Consequently, a negative binomial regression method was applied for the analysis. All the analyses were conducted with the statistical package for the social sciences (SPSS) version 20.0.

IV. RESULTS

Table III presents the descriptive statistics and the correlations between the variables analyzed in this study. The number of drug development projects ranged from 0 to 283 drugs by drug class and the average of drug development was 11.4 drugs per each drug class. The drug class with the most reported drug development project was A16A class (other alimentary tract and metabolism products). Regarding the competitive conditions, the averages of 1-HHI and the number of competitors were 0.75 and 393.92, respectively. The class with the largest number of competitors was D11A (other dermatologicial preparations), and the class with the largest 1-HHI was A2B1 (H2 antagonists). In terms of market size, A10C (human insulins and analogues) showed the largest market size (41 245 million USD) and B2A9 (other antifibrinolytics) was the smallest (32 000 USD). As a result of the correlation analysis, although the size and age of the companies had the highest correlation coefficient (*R*) of 0.54, the variance of the inflation factor (VIF) of the variables showed a maximum of 1.60, indicating that there is no multicollinearity between the variables [58].

Table IV presents the results of our analysis of the effect of competition (1-HHI) on drug development using negative binomial regression and the results of our analysis of the moderating effect of the size and age of leading companies on the relationship between 1-HHI and innovation activities. In Model 1, market size and the size and age of the leading companies were controlled. It was found that 1-HHI has a statistically significant positive effect on drug development activities ($B = 1.40$ and $p < 0.001$). That is, the higher the competitive intensity, the more innovation activities occurred. This result supports our hypothesis H1 in which the relationship between competition and innovation activities is positive in the pharmaceutical industry. Regarding the control variables, only market size had a positive effect on innovation activities. Size and age of leading participating companies did not have significant effects on innovation activities (Models 1–4 in Table IV).

Model 2 includes the quadratic term of 1-HHI to examine the quadratic relationship between competition and innovation activities. It was not statistically significant, indicating there is no quadratic (inverted U-shaped) relation. It suggests that the pharmaceutical industry is likely not to fit into the characteristics

TABLE III
DESCRIPTIVE STATISTICS AND CORRELATIONS BETWEEN THE VARIABLES

	Mean	S.D.	Min.	Max.	Skewness	Kurtosis	VIF
1. Drug development	11.40	33.38	0.00	283.00	4.96	28.31	-
2. 1-HHI	0.75	0.23	0.00	0.98	−1.34	1.31	1.32
3. Number of competitors	393.92	522.70	1	2,801	2.19	5.05	1.60
4. ln(Market size)	6.48	1.90	−3.44	10.63	−1.15	3.15	1.37
5. Size of companies	31.34	15.59	0.86	80.68	0.27	−0.26	1.53
6. Age of companies	82.19	26.87	25.33	151.13	0.29	−0.39	1.48
	1	2	3	4	5	6	
1. Drug development	1						
2. 1-HHI	0.08	1					
3. Number of competitors	0.15*	0.48**	1				
4. ln(Market size)	0.14*	0.20**	0.41**	1			
5. Size of companies	−0.01	0.04	0.28**	0.37**	1		
6. Age of companies	−0.06	0.01	0.22**	0.35**	0.54**	1	

$^*p < 0.05$, $^{**}p < 0.01$.

TABLE IV
RESULTS OF THE NEGATIVE BINOMIAL REGRESSION ANALYSIS ON THE RELATIONSHIP BETWEEN COMPETITION (1-HHI) AND INNOVATION ACTIVITIES (DRUG DEVELOPMENT), AND THE MODERATING EFFECT OF THE SIZE AND AGE OF LEADING COMPANIES ON THE RELATIONSHIP

Drug development	Model 1	Model 2	Model 3	Model 4
ln(Market size)	0.33*** (0.04)	0.34*** (0.04)	0.34*** (0.04)	0.33*** (0.04)
1-HHI	1.40*** (0.33)	3.42* (1.47)	2.83*** (0.72)	3.57*** (1.00)
$(1\text{-HHI})^2$		−1.64 (1.17)		
Size of companies	−0.01 (0.01)	−0.01 (0.01)	0.02 (0.02)	−0.01 (0.01)
Age of companies	−0.004 (0.003)	−0.004 (0.003)	−0.01 (0.003)	0.01 (0.01)
Size of companies*(1-HHI)			−0.04* (0.02)	
Age of companies*(1-HHI)				−0.02* (0.01)
Constant	−0.30 (0.46)	−0.86 (0.57)	−1.38* (0.63)	−1.90* (0.80)
χ^2	76.81***	78.74***	81.61***	82.11***
Log likelihood	−775.74	−774.78	−773.34	−773.10
deviance/df	3.31	3.32	3.31	3.30
Number of observations	234	234	234	234

$^*p < 0.05$, $^{**}p < 0.01$, $^{***}p < 0.001$.

TABLE V
RESULTS OF THE NEGATIVE BINOMIAL REGRESSION ANALYSIS ON THE RELATIONSHIP BETWEEN COMPETITION (NUMBER OF COMPETITORS) AND INNOVATION ACTIVITIES (DRUG DEVELOPMENT), AND THE MODERATING EFFECT OF THE SIZE AND AGE OF LEADING COMPANIES ON THE RELATIONSHIP

Drug development	Model 5	Model 6	Model 7	Model 8
ln(Market size)	0.30*** (0.05)	0.30*** (0.47)	0.27*** (0.05)	0.26*** (0.05)
Number of competitors	0.0004*** (0.0001)	0.0003 (0.0004)	0.001*** (0.0004)	0.003*** (0.001)
$(\text{Number of competitors})^2$		$5.68*10^{-8}$ $(1.56*10^{-7})$		
Size of companies	−0.01* (0.01)	−0.01* (0.01)	−0.001 (0.01)	−0.01 (0.10)
Age of companies	−0.004 (0.003)	−0.004 (0.003)	−0.01 (0.003)	0.003 (0.003)
Size of companies*(Number of competitors)			−0.00002* (0.000009)	
Age of companies*(Number of competitors)				−0.00002*** (0.000006)
Constant	0.88** (0.31)	0.90** (0.31)	0.73* (0.31)	0.39 (0.33)
χ^2	73.72***	73.85***	80.05***	90.76***
Log likelihood	−777.29	−777.22	−774.12	−768.77
deviance/df	3.33	3.34	3.31	3.27
Number of observations	234	234	234	234

$^*p < 0.05$, $^{**}p < 0.01$, $^{***}p < 0.001$.

of the typical manufacturing industry regarding the relationship between competitive environment and innovation.

Model 3 analyzed the moderating effect of the leading companies' size on the relationship between competition and innovation activities. The coefficient of the interaction term is negative and significant ($B = -0.04$ and $p < 0.05$). It, thus, supports our hypothesis H2a, the size of leading companies in the market negatively moderates the positive relationship between competition and innovation activities. Likewise, Model 4 analyzed the moderating effect of the leading companies' age on the relationship between competition and innovation activities. The coefficient of the interaction term is negative and significant ($B = -0.02$ and $p < 0.05$), thus supporting hypothesis H2b: The age of leading companies in the market negatively moderates the positive relationship between competition and innovation activities.

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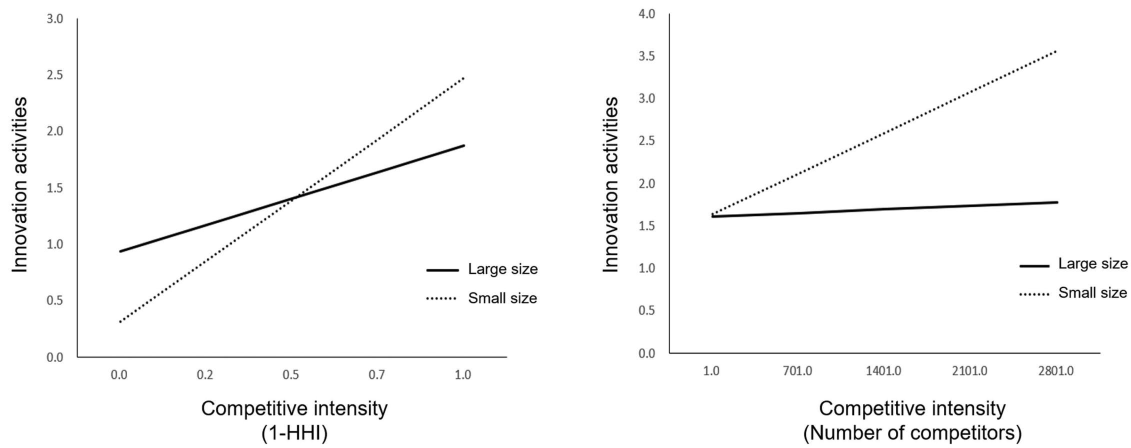
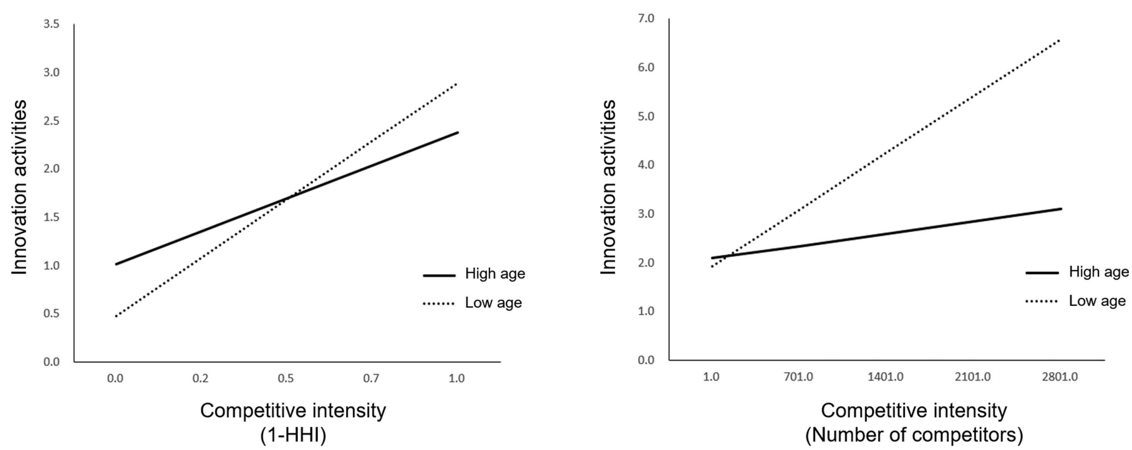


(a) (b)

Fig. 2. Moderating effect of the size of leading companies on the relationship between competition and innovation activities. (a) 1-HHI is used as an indicator of competitive intensity, (b) the number of competitors is used as an indicator of competitive intensity.



(a) (b)

Fig. 3. Moderating effect of the age of leading companies on the relationship between competition and innovation activities. (a) 1-HHI is used as an indicator of competitive intensity, (b) the number of competitors is used as an indicator of competitive intensity.

Table V presents the results of the negative binomial regression analysis using the number of competitors as a measure of competitive intensity, instead of 1-HHI. The results obtained from Model 5 to Model 8 were consistent with the results from Model 1 to Model 4, respectively. It suggests that as competition in the market intensifies, the innovation activities tend to increase as well. These results confirmed the robustness of the analysis.

Fig. 2 depicts the moderating effect of the leading companies' size on the relationship between competition measured by 1-HHI or the number of competitors and innovation activities measured by the number of drugs under development. The slope of 1-HHI or the number of competitors on innovation activities of the smaller leading companies (dotted line) is steeper than that of the larger companies (solid line) (see Fig. 2(a) and 2(b)). It implies that the positive relationship between the competition and innovation activities was further strengthened in a market in which smaller companies are ranked as the top sales companies compared with a market in which larger companies are the main players.

Fig. 3 shows the moderating effect of the leading companies' age on the relationship. In both cases, where 1-HHI or number of competitors were applied as the indicators of competitive intensity, the slope of the competitive intensity on innovation activities was greater for younger companies (dotted line) than for older companies (solid line). It indicates that the positive relationship between competition and innovation activities is more intensified in a market in which younger companies are participating as the main companies, rather than older companies.

V. Discussion and Conclusion

In this article, we explored how competition affects innovation activities in the global pharmaceutical industry. We also investigated how this relationship is moderated by the size and age of the leading companies in the market. The number of drug development projects of pharmaceutical companies and two types of competitive intensity (1-HHI and number of competitors) by drug class were analyzed using the negative binomial regression method.

A. Theoretical Discussion and Methodological Issues

When we examined the relationship between competition and innovation activities, we observed that there is a simple linear positive relationship. That is, when the competition is fiercer, there are more drug development activities. This result supports Arrow's hypothesis rather than the hypotheses of Schumpeter or Aghion. It may be because the pharmaceutical industry has high market concentration (average of concentration ratio of top three companies (CR_3): 0.60 and average of HHI: 0.25, from our dataset), we can observe only the left side of the inverse U-shape, the pattern in which innovation increases as competition increases. In addition, it is known that the escape-competition effect can be more prominent than the Schumpeterian effect in a high-tech industry, which has high appropriability [59]. A high-tech industry refers to an industry with high R&D expenditure relative to its production and high R&D expenditure relative to added values [60]. The pharmaceutical industry is a representative high-tech industry with high R&D intensity. Consequently, in the case of intraindustry analysis within the pharmaceutical industry, which has a high-tech oriented and highly concentrated market, only the positive relationship between competition and innovation can be observed.

In addition, since we analyzed the latest global data mostly obtained from the developed markets, which account for the majority of global pharmaceutical consumption and where antitrust laws are well-established in recent years, an increase in innovation was observed with increasing competition, consistent with the previous finding that competition stimulates the initiation of new drug development projects when the regulations on monopolies are well enforced [17].

With respect to the methodology for the measurement of competition in the market, it is known that concentration ratio or HHI may give a biased view of competition because they are sales-based measures [16]. In the biopharmaceutical sector, even a company with small market sales can be a significant potential competitor. Therefore, we utilized both 1-HHI and the number of competitors in the drug class to capture more accurately the competitive environment of the market.

Regarding the effects of the control variables that were considered, market size showed a statistically significant effect in all models analyzed in this study (see Tables IV and V). This is consistent with a previous finding that market size positively affects pharmaceutical innovation [53]. It implies that there is still a tendency for innovation activities to be directed toward more profitable areas. In other words, the therapeutic classes with small market sizes are being marginalized by pharmaceutical companies in their R&D and innovation activities. This result provides evidence of the need for the public sector to invest more in or support the therapeutic areas that have been neglected by the private sector in their voluntary innovation efforts.

In terms of the size and age of the leading companies, although the preceding literature on their effects on innovation has remained controversial, the results from most of our analyses showed that size or age had no direct effect on innovation activities (only the size of leading companies was significant at a 95% confidence level in Models 5 and 6.). However, it was found that these variables have the role of negatively moderating the effect of competition on innovation activities by interacting with the competitive intensity of the market. This may be because even at the identical competitive intensity, there is a difference in innovation activities between large and small firms [61]. Preceding studies have pointed out that large firms have the relative innovative advantage in markets with imperfect competition, but small firms have the advantage in markets closer to a perfect competition [49]. As shown in Fig. 2(a), this tendency was also observed in our analysis: when 1-HHI was small, the absolute value of the innovation activities of large companies was higher than that of small companies, whereas when 1-HHI was large, the absolute value of innovation activities of small companies was higher than that of large companies. In this regard, our observation can be interpreted that when competitive intensity increases, innovation activities increase more in a market in which small companies, rather than large companies, are the main participants.

In regard to the moderating effect of firm age on the relationship between competition and innovation activities, we found the same tendency as in the case of firm size. Since firm age is likely to be positively correlated with firm size (the correlation coefficient between firm size and firm age is 0.54 in our dataset, as shown in Table III) [50], it can be construed that the moderating effect of firm age on the relationship between competition and innovation is similar to the effect of firm size. In summary, we observed that when the leading companies in the market are smaller and younger, the degree of change in innovation activities according to the competitive intensity was greater. Since most small and young companies are not yet stable, they will inevitably respond more sensitively and proactively to changes in the competitive environment in order to survive in the market.

B. Practical and Managerial Implications

This study makes several contributions to the literature. First, we added new evidence on the relationship between competition and innovation, a subject which has been debated for a long time and has remained at what has been referred to as the "Schumpeter–Arrow stalemate" [14]. We identified the positive linear relationship between competition and innovation in the pharmaceutical industry by examining the global pharmaceutical market by therapeutic drug class. Furthermore, we revealed for the first time that the size and age of leading companies, which were variables rarely considered in previous studies, have the effect of moderating the relationship between competition and innovation activities. It was demonstrated that the characteristics of only the top ten companies by sales have the moderating effect on the relationship between competition and innovation activities. Several policy implications can be derived from this study. Policymakers and decision makers who are involved in or are able to control the market structure, such as government agencies and international institutions, should make efforts to implement policies to regulate monopolies and oligopolies and induce the market structure to be competitive in the pharmaceutical industry. In addition, as small and young firms tend to be more innovative with increasing competition, it is advantageous to give more opportunities for these companies to participate in the market while fostering a competitive market structure. Increasing R&D subsidies or support programs for small startups can also be a strategically advantageous policy. Strengthening investments in these companies is desirable not only to stimulate innovation but also to create a healthy industrial ecosystem.

C. Limitations and Future Research

This study has several limitations that require improvement and follow-up studies. First, although cross-sectional data of the most recent period were utilized to identify the recent conditions of market competition and innovation activities in the pharmaceutical industry, even more robust results on the effect of competition on innovation could be obtained if panel data, including long-term time-series data, are used. Second, it would be desirable to include more diverse indicators for competition and innovation (for example, the Lerner index or profit elasticity as a measure of competition reflecting the company's status and the number of patents or return on R&D as a more explicit measure of innovation), as this would enable us to derive more practical implications from the company's point of view.

In addition to the moderators identified in this study, it would be valuable to policymakers to identify other important moderators affecting the relationship between competition and innovation. Also, the analysis using data from the COVID-19 pandemic period will help to gain more significant and meaningful insights into innovations in the pharmaceutical industry.

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Ye Lim Jung received the M.S. and Ph.D. degrees in chemical and biomolecular engineering from the Korea Advanced Institute of Science and Technology, Daejeon, South Korea, in 2010 and 2014, respectively.

From 2013, she has been a Senior Researcher with the Korea Institute of Science and Technology Information, Seoul, South Korea. Her research interests include innovation management, technology management, decision support systems, pharmaceutical innovation, and public health policy. Her research works have been published in the *Expert Systems With Applications, Globalization and Health, Health Research Policy and Systems, Biosensors and Bioelectronics, Nanoscale,* and other academic journals.

Hyoung Sun Yoo received the Ph.D. degree in materials and science engineering from the Korea Advanced Institute of Science and Technology, Daejeon, South Korea, in 2010.

From 2009 to 2017, he was a Senior Researcher with the Korea Institute of Science and Technology Information, Seoul, South Korea. Since 2018, he has been a Principal Researcher with the same institute. Since 2014, he has been an Assistant Professor with the Department of Science and Technology Management Policy, University of Science and Technology, Daejeon, South Korea. His areas of interest include R&D management and policy, workforce management, resource allocation, technological forecasting, and time-series analysis. His recent research has appeared in *Technological Forecasting and Social Change*, *Expert Systems With Applications*, *Technovation*, *Energy Policy*, *Scientific Reports*, and *Globalization and Health*, among others.