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Innovation and Competition: The True Innovativeness of Innovation and Distance to Frontier*

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In the literature on innovation and competition, consideration of the 'innovativeness' of innovation has been neglected. This paper investigates the relationship between innovation and competition conditional on the innovativeness of innovation and the distance to frontier. We measure the innovativeness of innovation by analyzing whether it is a *new-to-the-market* innovation or a *new-to-the-firm* innovation. Further, we develop a new measure of firms' technological level using firms' main objective of innovation. Using a dataset from surveys of Korean manufacturing firms from 2002 to 2004, this paper finds that the relationship between competition and innovation is conditional on both the quality of innovation and distance to frontier. The results are: (1) frontiers are more likely to innovate than technological laggard firms, (2) competition has an inverted-U shape relation with new to the market innovation, while there is no such relation with new to the firm only innovation, (3) the inverted-U shape relation between competition and innovation is driven by frontiers, not followers or laggards, and (4) new to the market innovation and R&D expenditure show a similar pattern of an inverted-U shape relation with competition, while new to the firm only innovation and patents exhibit a similar pattern of no relation with competition.

JEL Classification: O3, L1
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1. INTRODUCTION

Many studies have examined the relationship between competition and innovation with respect to the distance to technological frontier (e.g., Cohen and Levin, 1989; Cohen, 2010; Gilbert, 2006, etc.). However, consensus has not been reached yet in terms of both economic theory and empirical evidence. Aghion (2006) argues that competition fosters innovation if a firm is closer to the technological frontier, while it discourages innovation if a firm is far from the technological frontier. Thus, there is an inverted-U shape relation between competition and innovation. This is because frontier firms would have strong motives to escape from competition to achieve higher gains (escape-competition effect) at a low level of competition where technology is similar among firms (Aghion *et al*., 2005). On the other hand, technological laggard firms are discouraged to innovate because post-innovation rent is small — the Schumpeterian effect (Dasgupta and Stiglitz, 1980).

Alder (2010) partially supports Aghion's argument that competition induces innovation when a firm is closer to frontiers, but presents no evidence that laggards drive low innovation at a high level of competition. On the other hand, Amable, Demmou, and Ledezma (2008) provide evidence that there is no innovation-spurring effect of competition of frontiers.

This paper investigates the relationship between competition and innovation with respect to the distance to technological frontier using Korean Innovation Survey (KIS) 2005 for Korean manufacturing firms. Particularly, this paper analyzes the relationship between competition and innovation in two main dimensions: (1) how the relationship is affected when the 'innovativeness' of innovation is taken into account, that is, when the behavior for highly innovative innovation and the behavior for lowly innovative innovation are separately analyzed, and (2) how the relationship is different for technologically frontier firms as opposed to laggard firms.

The main contributions of this paper are fourfold. Firstly, this paper takes the true innovativeness of innovation into account. This paper

differentiates innovations into two types: (1) innovations that are *new to the market*, and (2) innovations that are *new to the firm* only. Product innovations that are new to the market are considered highly innovative products while product innovations that are new to the adopting firm only and that already exist in the market are considered lowly innovative products. No previous studies have taken the innovativeness of innovation into account. The distinction based on the innovativeness of product innovation allows us to investigate the differential effects of competition and distance to frontier on different degrees of innovativeness of innovation.[1)] Most previous studies (Acemoglu, Aghion, and Zilibotti, 2006; Amable, Demmou, and Ledezma, 2008) use R&D expenditure or the number of patents as a measure of innovation. While R&D expenditure and patents may represent a quantitative aspect of innovative activities, they fail to provide a qualitative aspect of innovation (Brouwer and Kleinknecht, 1997). There exists a considerable amount of heterogeneity in R&D productivity. Further, patents exclude non-patented innovation and have little relation to innovation (Levin *et al*., 1987). Furthermore, the fact that only a very low percentage of patents is ever cited by other patents, or has any commercial value, adds to the weakness of using patents. However, only a few studies (Alder, 2010; Mairesse and Mohnen, 2004) have examined product innovations, and no studies have considered the qualitative measure of innovation.

Secondly, we develop a new proxy to measure the distance to technological frontiers using each firm's main objective of innovation. Acemoglu, Aghion, and Zilibotti (2006) and Amable, Demmou, and Ledezma (2008) use the growth in total factor productivity and labor productivity to measure frontiers in innovation. Coad (2008) and Alder (2010) apply Tobin's *q* and perceived advancement in technology, respectively. However, TFP would not be an appropriate measure for the rate of technological change (Lipsey and Carlaw, 2000). Similarly, Tobin's *q* would not always indicate advancement in technology. For example,

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[1)] Kleinknecht, Montfort, and Brouwer (2002) suggest the number of new product innovations and the share of innovative sales.

there can be two types of firms where one type of firm earns great amount of capital value with truly advanced technology while the other type of firm obtains similar profits with little technology but through enlarging market share.[2] Both types of firms would be regarded as frontiers according to the TFP and Tobin's *q*.

In contrast, this paper measures the distance to frontier using a firm's main objective for innovation. This is based on the assumption that a firm's main objective for innovation would be a reasonable reflection, or at least in line with its current level of technological competence because any rational firm would focus on objectives which it has the capability to achieve. If a firm's main objective for innovation is to pioneer a new market, the firm can be seen as a technological frontier since pioneering a new market requires possession of advanced technology. Because pioneering a new market can provide a strong escape from competition and higher gains, firms would attempt to pioneer a new market if they have the technological capability. If firms do not focus on pioneering a new market, but focus on enlarging market share, diversifying existing products, or changing designs without improving functions, it would be reasonable to assume that they do not have the technological competence to pioneer a new market. Because enlarging market share, diversifying existing products, or changing design without improving functions does not necessarily require the most advanced technology as pioneering a new market does, these firms can be considered to be technologically less competent. This measure of firm's technological competence is new and noble, and avoids the problems associated with using TFP or Tobin's *q*.

The third main contribution of this paper is the use of the firm's sentiment indicator to measure competition. The conventionally used measure of competition, Herfindahl index, is based on industry classification. If the Herfindahl index is calculated at the aggregated industry level such as commonly provided 2- or 3-digit level, the industry defined would be too

[2] It is often possible that firms make high profits (Szymanski *et al*., 1993).

broad to capture the appropriate product market competition. Thus, the degree of competition at 2-digit industry level may be irrelevant to a firm in conducting innovative activities. However, our measure of competition based on a firm's sentiment can closely capture the degree of competition that actually matters to a firm. Even if the sentiment competition indicator does not reveal the true competition level accurately, it still captures the competition level that the firm actually feels which in turn affects the firm's actual innovation decisions. Therefore, this measure of competition eliminates the problems of a broadly defined industry associated with conventional measure of competition.

The final main contribution of this paper is that this paper controls the firm and industry level heterogeneity at the most extensive level done so far by utilizing rich firm and industry level information. This provides robust results based on Korean manufacturing sector in the relevant strand of literature.[3)]

This paper's main findings are: (1) frontiers are more likely to innovate than laggards; (2) competition has an inverted-U shape relation with new-to-the-market innovation while there is no such relation with new-to-the-firm only innovation; (3) the inverted-U shape relation between competition and innovation is driven by frontiers, not followers or laggards; and (4) new-to-the-market innovation and R&D expenditure show similar pattern of an inverted-U shape relation with competition while new-to-the-firm only innovation and patents exhibit similar pattern of no relation with competition.

The remainder of this paper is organized as follows. Section 2 describes the data sources and variables. Section 3 discusses the methodology. Section 4 presents the results, and section 5 provides the conclusion.

[3)] There is little work done on innovation and competition using Korean data. Hahn and Park (2011) examine innovation and export using Korean data.

2. DATA

2.1. Sources

Data for the analysis is taken from Korean Innovation Survey (KIS) 2005 for Korean Manufacturing Sector conducted by Science and Technology Policy Institute (STEPI). The survey is designed and carried out based on the guideline of the OECD Oslo Manual, Third Edition, 2005. Therefore, it is comparable with the innovation surveys of other countries, such as Community Innovation Surveys. This survey is also designated as approved statistics by Statistics Korea.

The dataset surveys approximately 2800 firms covering the entire manufacturing sector across Korea from 2002 to 2004. The survey collects information on various aspects of innovation at firm level. Specifically, the survey reports information on firms' product innovation, R&D expenditure, patents, main objectives of innovative activities, difficulties associated with innovation, and so on. In addition, it includes a rich set of firm information such as employees, sales, and export.[4] The response rate is 60.9%.

2.2. Data Description

One of the key variables of interest is the measure of innovation. As mentioned earlier, this paper uses new product innovation as the main measure of innovation, and further distinguishes product innovation based on the innovativeness of innovation. Product innovation represents commercialized innovation, which is fundamentally different with existing products in functions or usages, and excludes non-commercialized innovation or innovation with new design that has similar functions as that of existing products. 'Innovativeness' refers to the degree of 'newness' of an

[4] It includes three-digit industry code, foundation date, address, employees, education status of employees, sales, exports, FDI, major customer, labor union and research institution/department and so on.

innovation. Highly innovative products are seen to have a high degree of newness, and lowly innovative products sit at the opposite extreme of the continuum.

About 39% of firms in the data set have tried to introduce product innovations, and 36% of them have succeeded to make innovation output. About 37% of the product innovations introduced is new-to-the-market innovations, while the remaining product innovations are new-to-the-firm only innovations. A product innovation that is new to the market refers to the very first innovation of its type in the market. Thus, it can be regarded as a truly innovative innovation. On the other hand, a product innovation that is new to the firm only indicates a new product of a firm where a similar type of product already exists in the market. Thus, it is not considered to be truly innovative. For example, when a LED TV is introduced in a market for the first time, it would be regarded as a new-to-the market innovation. However, when LED TVs with some improvements are produced afterwards by other firms, they would be regarded as new-to-the-firm only innovation.

Another main variable of interest is the firm's distance to technological frontiers. The survey questions firms whether their main objective for innovation is to pioneer a new market, enlarge market share, diversify the existing products, or change design. The importance of each objective is measured on a scale of 0 to 5. Based on a firm's main objective for innovation, firms' level of technological competence can be proxied. Since it is reasonable to assume that firms set their objective accordingly to their level of technological competence, a firm's technological competence should be at least in the level which the firm's objective can be reasonably achieved. In other words, only firms with frontier technology would focus on pioneering a new market as their realistic objective whereas firms with low technological competence would not rationally focus on pioneering a new market. While pioneering a new market can provide a strong escape from competition and higher gains, not every firm would actually focus on pioneering a new market because it does not have the technological competence. Therefore, a firm that focuses on pioneering a new market can

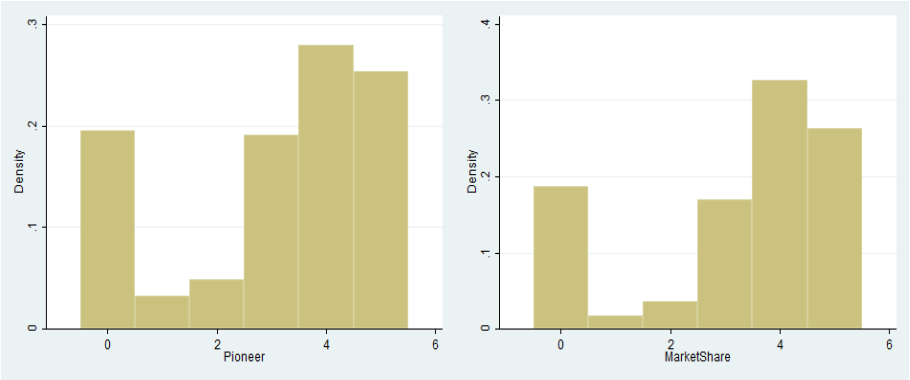
be seen as possessing such technological competence while a firm that focuses on other objectives possesses technological competence needed for such objectives. Thus, it would be safe to assume that firms choose their objectives rationally conditional on their technological competence, and consequently, it would be reasonable to proxy firm's level of technological competence from firm's objective of innovation. Therefore, we use firms' main objective of innovation as a measure of firms' technological competence.

Thus, we categorize firms into three groups based on the technological competence proxied by firms' objectives of innovation: *Frontier* (firms that focus on pioneering a new market), *Follower* (firms that focus on expanding market share or diversifying products), and *Laggards* (firms that focus on changing designs and substituting existing products). We conjecture that pioneering a new market would require the highest technological competence while changing designs would entail the lowest level of technological competence. *Frontier* takes a value of 1 if firms' importance of pioneering a new market is equal to or greater than 3 on a scale of 5, and takes a value of 0 otherwise. *Follower* takes a value of 1 if firms' importance of expanding market share or diversifying existing products is equal to or greater than 3 on a scale of 5, and takes a value of 0 otherwise. The benchmark group would be *Laggards*. Number 3 on a scale of 5 is used as a break point to decide the importance of objective since the distribution of importance for each objective breaks into two groups at scale 3. The distribution of each objective is represented in figure 1A to 1C.

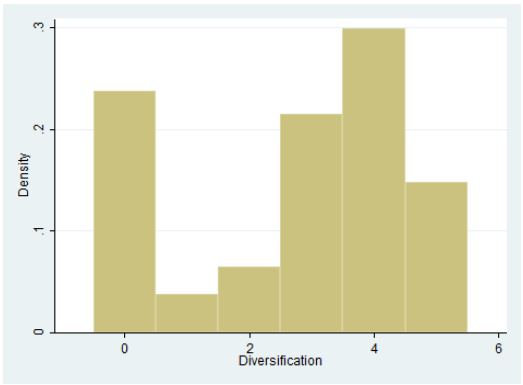
In order to measure the degree of competition, we employ the firm's competition sentiment indicator in its subjective boundary of industry. The conventional measure of competition is the Herfindahl index. However, the industrial classification of firms in the survey is reported at the 2-digit industry classification level. This industry classification used in the survey is too broad to indicate the same industry that a firm faces competition. Unless the industry is classified at a more detailed level, it is difficult to categorize firms that actually compete in the same market. The sentiment

Figure 1 Histograms of Importance of Firm's Objectives:

1A Pioneering New Market **1B Enlarging Market Share**



1C Diversifying Existing Product



competition indicator of a firm, on the other hand, reveals the competition level within the boundary where a firm actually competes with others. It elucidates the actual level of competition with rivalry. The sentiment competition indicator is presented in an ordered format on a 0 to 5 scale, where the lower number represents the lower level of competition. Comparing how the competition effect measured by the sentiment indicator complies with that measured by the Herfindahl index would be helpful. However, the survey does not provide information on firm's industry classification on the narrowly defined level. Therefore, it is not possible to compare the effect of

Table 1A Descriptive Statistics of Distance to Frontier

Variable	Definition	Mean	Std Dev.	Min	Max
High Quality Innovation	Product innovation new to the market	20.09	129.17	0	3,100
Low Quality Innovation	Product innovation new to the firm	7.17	77.67	0	2,945
Frontier	Firms' objective of innovation is to pioneer a new market	1.78	2.05	0	5
Follower	Firms' objective of innovation is to expand market share or diversify existing products	1.73	2.01	0	5
Competition	Sentiment Competition Measure	2.76	1.35	0	5

Table 1B Descriptive Statistics of Distance to Frontier

Distance to Frontier	*N*	Product Innovation New to the Market		Product Innovation New to the Firm	
		Mean	Standard Deviation	Mean	Standard Deviation
Frontier	1,147	14.55	117.10	40.77	191.63
Follower/ Laggards	1,596	1.85	21.24	5.22	42.07
Total	2,743	7.16	77.67	20.09	129.17

sentiment indicator with that of the Herfindahl index on the narrowly defined market.

The descriptive statistics of the above mentioned sets of variables — quality of innovation, distance to frontiers, and competition - are presented in table 1A and table 1B. In addition to the main variables explained above, this paper employs a rich set of firm level and industry level controls. The complete list of variables and their descriptions is presented in table 2.

Table 2 List of Control Variables

Model	Variable	Definition
Basic Model	*R&D Intensity*	log(R&D Expenditure / Employee)
	Export	Dummy for Export
	Age	Firm Age
	Demand Pull	Degree of importance of quick response to consumer needs for innovating
	Technology Push	Degree of importance of technology push
	Continuity	Dummy for continuous R&D performing firms
	ROR	Rate of return on technology (= life of knowledge obtained during product innovation / average time spent on product innovation)
	Industry	Three-digit industry fixed effects (15)
	Region	Regional fixed effects (16)
Extension 1	*Insourcing Ratio*	Ratio of insourcing to outsourcing technology
	Financial Difficulties	Dummy for financial difficulties
	Labor	Dummy for labor difficulties
	Information	Dummy for informational difficulties
	Manager	Dummy for managerial difficulties
	Region	Dummy for regional difficulties
Extension 2	*Market Uncertainty*	Degree of market uncertainty
	Technology	Degree of technology uncertainty
	Market Regulation	Degree of market regulation
Extension 3	*Appropriability*	Easiness of appropriability of technology
	Lifetime	Lifetime of major product (month)

3. MODEL

We test whether there is an inverted U-shaped relation between product innovation and competition. The theory behind the U-shaped relation is as follows: According to Schumpeterian argument, competition reduces the expected pay-off from an investment in innovation and therefore contracts

firm's innovation. On the other hand, others argue, competition forces firms to innovate in order to stay in business (Porter, 1990; Scherer, 1980; Arrow, 1962). Aghion *et al*. (2005) argue that the degree of neck-and-neckness in an industry is an important factor. In other words, if an industry is characterized by neck-to-neck competition among firms with similar technology, the gain from innovation is high. This is because instead of sharing the technological lead with its competitors, the leading firm will be the single front technology firm. Hence, more product market competition boosts firm R&D. Aghion *et al*. (2005) show that the positive impact of competition on R&D (escape competition effect) is strongest in leveled neck-to-neck industries. If competition increases, firms might escape competition by innovating. If competition is fierce, the negative Schumpeterian effect of competition on R&D dominates the positive escape competition effect. These two contradicting forces give rise to an inverted U-shaped relation between competition and product innovation.

We apply Ordinary Lease Squares (OLS) with heteroskedasticity robust covariance matrix to test the relationship among distance to frontier, competition and quality of innovation. Some previous studies assume the endogeneity between R&D expenditure and innovative output such as patents. That is, not only greater R&D expenditure lead to more innovative outputs, but more innovative outputs such as patents provide greater incentive to firms to engage in innovative activities. Thus, Crepon, Duguet and Mairesse (1998) and Mariresse and Mohnen (2004) adopt Asymptotic Least Squares (or Minimum Distance Estimation) to estimate innovation output, assuming existence of endogeneity between R&D expenditure and innovation output. Amable, Demmou, and Ledezma (2008) also use instrumental variable of R&D expenditure and use Systematic Generalized Method of Moments(S-GMM). However, when conducting the regression with Two-Stage Least Squares, Limited Information Matrix Likelihood and Generalized Method of Moments with endogenous variable of R&D expenditure, the test reveals that there is no endogeneity between R&D expenditure and product innovation. Thus, as in Coad (2008) and Alder

(2010) which adopt OLS, we used Ordinary Least Squares without instrumental variable but with heteroskedasticity robust covariance to prevent biasness from heteroskedasticity.

3.1. Distance to Frontier, Competition and Product Innovation

We first analyze how competition and the distance to technological frontier affect product innovation. We separately estimate the effects for new to the market innovation and new to the firm only innovation. The estimated baseline specification takes the following form for each type of product innovation.

$$\begin{aligned} Y_{i,\tau} = \alpha + \beta_1 Frontier_i + \beta_2 Follower_i + \beta_3 Comp_i \\ + \beta_4 Comp^2{}_i + \beta_5 X_i + \beta_6 \delta_r + \beta_7 \zeta_j + \varepsilon_i, \end{aligned} \quad (1)$$

where $Y_{i,\tau}$ is log of firm *i*'s innovation intensity of τ. A firm's innovation intensity of new to the market innovation is calculated as the number of firm's innovations that are new to the market divided by the firm's employment. Other measures of innovation τ include intensity of new to the firm innovation, R&D intensity, and patent intensity. *Frontier* is a dummy variable that indicates whether a firm pursues to pioneer a new market. *Follower* is a dummy variable that indicates whether a firm focuses on expanding market share or product diversification. $Competition_i$ is a sentiment competition indicator on a scale of 0 to 5. X_i is a vector of firm characteristics that affects innovation intensity including export, firm age, R&D expenditure, demand pull, technology push, continuous R&D, rate of return on technology, and in-sourcing ratio.[5] Demand pull, technology push and continuous R&D are directly taken from the survey. The survey

[5] Crepon, Duguet and Mairesse (1998) and Mariresse and Mohnen (2004) included demand pull, technology push and in-sourcing ratio in basic model. Also, Amable, Demmou, and Ledezma (2008) used pervious patent data in the model while we used continuosity instead of it.

contains question regarding the importance of demand pull and technology push for innovation, and whether a firm performed continuous R&D. The rate of return on technology is calculated from the information on the life of knowledge obtained during product innovation divided by the average time spent on product innovation. δ_r is regional fixed effects, and ζ_j is industry fixed effects. The detailed descriptions of control variables are presented in table 2.

3.2. Effect of Competition Conditional on Distance to Technological Frontier

In order to analyze how competition affects innovation differently depending on the level of firms' technological competence, we extend the model as follows:

$$\begin{aligned} Y_{i,\tau} = {} & \alpha + \beta_1 Frontier_i + \beta_2 Follower_i + \beta_4 Comp_i + \beta_5 Comp_i^2 \\ & + \beta_6 Frontier_i \times Comp_i + \beta_7 Frontier_i \times Comp_i^2 \\ & + \beta_8 Follower_i \times Comp_i + \beta_9 Follower_i \times Comp_i^2 \\ & + \delta_r + \zeta_j + \varepsilon_i, \end{aligned} \tag{2}$$

where $Frontier_i \times Comp_i$ and $Follower_i \times Comp_i$ are interaction terms between frontier and competition and between follower and competition, respectively. This specification is estimated for each type of product innovation separately.

4. RESULTS

4.1. Highly Innovative Innovation versus Lowly Innovative Innovation

We first analyze the effects of the distance to frontier and competition on

Table 3 Basic Model

	(1) Innovation New to the Market		(2) Innovation New to the Firm	
Competition	0.254*	(0.135)	0.180	(0.128)
Competition^2	–0.051*	(0.026)	–0.028	(0.025)
Frontier	0.516**	(0.148)	0.381**	(0.150)
Follower	0.326**	(0.143)	0.639**	(0.138)
R&D Expenditure	0.055**	(0.016)	0.101**	(0.016)
Export	–0.238**	(0.076)	–0.226**	(0.074)
Age	–0.035**	(0.003)	–0.032**	(0.003)
Demand Pull	0.075**	(0.037)	0.074**	(0.036)
Technology Push	0.182	(0.117)	0.344**	(0.110)
Continuity	–0.444**	(0.078)	–0.318**	(0.077)
ROR	0.017**	(0.005)	0.028**	(0.009)
Insourcing Ratio	0.001**	(0.000)	0.002**	(0.000)
Observations	2,697		2,697	
Adjusted *R*-squared	0.244		0.518	

Notes: 1) Standard errors are in parentheses. 2) ** $p<0.05$, * $p<0.10$. 3) Also included are 15 regional dummies and 14 industry fixed effects.

product innovation. The results on new to the market innovation and new to the firm innovation are presented in table 3. The first column presents the results of product innovation that is new to the market, and the second column presents the results of product innovation that is new to the firm only.

Column (1) indicates that firms with higher technological competence are more likely introduce new to the market innovation. The coefficient on *Frontier* is 0.516 while the coefficient on *Follower* is 0.326. Both are positive and significant. This implies that *Frontier* is more likely to conduct new to the market product innovation than the benchmark group, *Laggards* by 0.516 while *Follower* is more likely to conduct new to the

market innovation than *Laggards*. This result is consistent with the fact that firms with higher technological competence, *Frontier* and *Follower*, are more likely to introduce new products into the market than firms with lower technological competence, *Laggards*.

The effects of distance to frontiers on new to the firm only innovations show a similar trend. The coefficient on *Frontier* is 0.381 while the coefficient on *Follower* is 0.639. Both are positive and significant. This indicates that *Frontier* and *Follower* are more likely to conduct new to the firm product innovation than *Laggards*. The coefficients on *Frontier* and *Follower* are not statistically different. Results in column 1 and 2 in table 3 indicate that two groups of firms, Frontier and Follower, with higher technological competence are more likely to introduce new products into the market than firms, Laggards, with lower technological competence, and this is true for both new to the market and new to the firm innovation.

Next, we examine the effects of competition on each type of product innovation. The coefficient on *Competition* in new to the market innovation (column (1) in table 3) is 0.254, positive and statistically significant while the coefficient on $Competition^2$ is –0.051, negative and significant. This indicates that competition has an inverted-U shape relationship with the new to the market product innovation. Escape from competition effect from the introduction of a new to the market innovation is stronger at low level of competition. However, negative Schumpeterian effect dominates the escape from competition effect at high level of competition as the post-innovation rent becomes small.[6)]

On the other hand, we find that there is no obvious relationship between the degree of competition and new to the firm only innovation. Insignificant coefficients on *Competition* and $Competition^2$ in column (2) in table 3 indicate that there is no significant effect of competition on new to the firm innovation. This implies that an introduction of new to the firm only innovation does not provide escape from competition effect from a firm's

[6)] In the next result, the negative relationship between competition and innovation at high level of competition is mainly driven by frontiers, not laggards.

rivals. This result is intuitive that any innovation that is not truly innovative would not provide expected advantage over rivals. Results in column (1) and (2) in table 3 provide evidence that Aghion *et al*. (2005)'s conclusion on inverted-U shape relationship of competition and innovation is actually applicable *only* to the truly original innovation that is new to the market.

4.2. Effects of Competition Conditional on Distance to Technological Frontier

We further investigate if the effect of competition on each type of product innovation is conditional on a firm's distance to frontier. In other words, whether the inverted-U relation between competition and new to the market innovation and whether no relation between competition and new to the firm only innovation are driven by some specific group of firms based on their technological level. The differential effects of competition conditional on a firm's technological level are captured by the interaction terms between competition and each group of technologically different firms, namely, frontiers and followers. Table 4 presents the results of the conditional effects of competition by distance to frontiers. Column (1) is for new to the market innovation while column (2) is for new to the firm only innovation.

Column (1) in table 4 shows that the coefficient on the interacted term, *Competition*Frontier* is positive and significant, while the coefficient on *Competition*^{2}**Frontier* is negative and significant. This indicates that for frontier firms, there still exists an inverted-U relationship as we have found in the previous section. Thus, at low level of competition, a firm closer to frontier is more likely to innovate new to the market product while at high level of competition, the firm reduces innovation. On the other hand, the coefficients on both interacted terms, *Competition*Follower* and *Competition*^{2}**Follower* are found to be insignificant. This implies that the effect of competition on new to the market innovation is not significant for follower firms. The result partially complies with the argument of Acemoglu, Aghion and Zilibotti (2006) that frontiers have innovation- spurring

Table 4 Effects of Competition Conditional on Distance to Technological Frontier

	(1) Innovation New to the Market	(2) Innovation New to the Firm
Competition	–0.065 (0.121)	–0.086 (0.128)
Competition^2	0.016 (0.023)	0.028 (0.025)
Frontier	–0.238 (0.477)	–0.165 (0.465)
Follower	0.505 (0.501)	0.691 (0.483)
*Competition*Frontier*	0.739* (0.426)	0.512 (0.435)
Competition^2**Frontier*	–0.137* (0.080)	–0.090 (0.085)
*Competition*Follower*	–0.088 (0.450)	0.042 (0.451)
Competition^2**Follower*^{2}	0.002 (0.084)	–0.025 (0.088)
Observations	2,697	2,697
Adjusted R-squared	0.247	0.519

Notes: 1) Standard errors are in parentheses. 2) ** $p<0.05$, * $p<0.10$. 3) Also included are all firm level characteristics that are included in the basic model, 15 regional dummies and 14 industry fixed effects.

effect when competition is low. However, at high level of competition, we find that it is also frontiers that drive the Schumpeter effect, contradicting their expectation that followers lead the decreasing innovation in competition. This may be due to the fact that high competition generates less post-innovation rent for frontiers as well as laggards. Therefore, for new to the market innovation, it is frontiers that drive both the positive effect of competition at low level and the negative effect of competition at high level. In other words, the inverted-U relation for highly innovative innovation is driven solely by technology frontier firms, and not by follower firms.

Results on the new to the firm innovation are presented in column (2) in table 4. The coefficients of *Competition*Frontier* and *Competition*^{2}** *Frontier* are both insignificant. This indicates that frontiers do not derive

the inverted-U relationship between competition and new to the firm innovation as they did on new to the market innovation. Similarly, coefficients on *Competition*Follower* and *Competition*^{2}**Follower* are found to be insignificant, indicating that the effect of competition on new to the firm only innovation is not significant for follower firms. Since new to the firm only innovation adds little, if at all, advantage to any firm whether a frontier or a follower, the effect of competition on new to the firm innovation is not significant for both frontiers and followers. Therefore, we can conclude that the result in the previous section that there is no relation between competition and new to the firm innovation is driven by both frontiers and followers.

The fact that the inverted-U shape relation is only present for new to the market innovation and only for the frontiers suggests that the expected relation between competition and innovation is mainly driven by truly innovative firms for truly innovative innovations. This implies that the relationship comes from the 'true' players of innovations for the 'true' acts of innovation. For new to the firm only innovations and for non-frontier firms, the determinants of innovation seem to come from factors other than competition. That is, non-frontier firms may engage in innovative activities to secure a market share by changing designs or diversifying their existing products, and their innovation decisions are affected less by the level of competition.

4.3. Robustness Tests and Extensions

We test how the results are robust to various specifications. Table 5A presents the results of various specifications with extended controls. First four columns present the results for new to the market innovations while the last four columns from (5) to (8) present the results for new to the firm innovations. Results from column (1) in table 3 are presented again in column (1) in table 5A for a comparison reason. Column (2) in table 5A includes various firm characteristics. The details of these firm

characteristics added are described in table 2. Column (3) includes various industry characteristics, and column (4) includes various industry-technology related characteristics. Again, the details of these controls added to each specification are explained in table 2.

The results of specification (1) to (4) indicate that the coefficients of competition and distance to frontiers on new to the market innovation are qualitatively and quantitatively consistent. It is shown in all columns that the coefficients of *Frontier* are always positive. It is confirmed that there is a positive relationship between the distance to frontier and highly innovative innovation. Further, the smaller in magnitude, but positive and significant effect of *Follower* is also robust across specifications. Results for new to the market innovation also confirms that the inverted U-shape relationship between competition and innovation remains strong and robust to specifications. In other words, the coefficients of *Competition* in the first four columns are consistently positive and those of $Competition^2$ are always negative in the model of new to the market product innovation.

The results from specification (5) to (8) in table 5A also indicate that the effects of competition and distance to technology frontiers on new to the firm innovation are consistent and robust to specifications.

We further investigate if the effects of competition on innovation conditional on the distance to frontier are robust to various specifications. Table 5B presents these results. The results provide the consistent finding that frontiers are responsible for the inverted-U shaped relationship between competition and new to the market innovation. This finding that frontiers induce innovation at low level of competition and also drive decrease in innovation at high level of competition is found to be robust to various specifications and inclusions of extensive controls. Columns (5) to (8) show that the coefficients on all interaction terms between competition and frontiers and competition and followers are insignificant across specifications, which in turn confirms the robustness of the results. Table 5A and table 5B show that all of the main findings are consistent and robust to various specification and inclusion of controls.

Table 5A Extensions to Basic Model

	New to the Market Product Innovation				New to the Firm Product Innovation			
	Basic	Extension 1	Extension 2	Extension 3	Basic	Extension 1	Extension 2	Extension 3
Competition	0.254* (0.135)	0.325** (0.142)	0.280* (0.147)	0.270* (0.147)	0.180 (0.128)	0.245* (0.136)	0.205 (0.141)	0.191 (0.140)
Competition^2	–0.051* (0.026)	–0.062** (0.027)	–0.057** (0.027)	–0.056** (0.027)	–0.028 (0.025)	–0.036 (0.026)	–0.034 (0.026)	–0.031 (0.026)
Frontier	0.516** (0.148)	0.521** (0.147)	0.516** (0.148)	0.515** (0.148)	0.381** (0.150)	0.393** (0.150)	0.399** (0.150)	0.397** (0.150)
Follower	0.326** (0.143)	0.324** (0.144)	0.320** (0.144)	0.313** (0.145)	0.639** (0.138)	0.635** (0.138)	0.629** (0.138)	0.619** (0.138)
Firm Characteristics		√				√		
Industry Characteristics			√				√	
Technology Characteristics				√				√
Observations	2,697	2,697	2,697	2,697	2,697	2,697	2,697	2,697
Adjusted *R*-squared	0.246	0.249	0.249	0.249	0.519	0.520	0.521	0.521

Notes: 1) Standard errors are in parentheses. 2) ** $p<0.05$, * $p<0.10$. 3) Also included are all firm level characteristics that are included in the basic model, 15 regional dummies and 14 industry fixed effects.

Table 5B Extensions to Effects of Competition Conditional on Distance to Technological Frontier

	New to the *Market* Product Innovation				New to the *Firm* Product Innovation			
	Basic	Extension 1	Extension 2	Extension 3	Basic	Extension 1	Extension 2	Extension 3
Competition	–0.065 (0.121)	0.015 (0.131)	–0.052 (0.137)	–0.058 (0.138)	–0.086 (0.128)	–0.003 (0.139)	–0.077 (0.145)	–0.086 (0.146)
Competition^2	0.016 (0.023)	0.003 (0.024)	0.012 (0.025)	0.012 (0.025)	0.028 (0.025)	0.016 (0.026)	0.023 (0.027)	0.024 (0.027)
Frontier	–0.238 (0.477)	–0.236 (0.479)	–0.262 (0.479)	–0.257 (0.479)	–0.165 (0.465)	–0.138 (0.469)	–0.178 (0.467)	–0.171 (0.468)
Follower	0.505 (0.501)	0.540 (0.503)	0.524 (0.504)	0.516 (0.505)	0.691 (0.483)	0.720 (0.486)	0.677 (0.485)	0.665 (0.486)
*Competition*Frontier*	0.739* (0.426)	0.747* (0.429)	0.769* (0.428)	0.758* (0.428)	0.512 (0.435)	0.502 (0.439)	0.540 (0.437)	0.523 (0.437)
Competition^2**Frontier*	–0.137* (0.080)	–0.139* (0.081)	–0.143* (0.080)	–0.140* (0.080)	–0.090 (0.085)	–0.089 (0.085)	–0.095 (0.085)	–0.090 (0.085)
*Competition*Follower*	–0.088 (0.450)	–0.130 (0.453)	–0.117 (0.452)	–0.113 (0.453)	0.042 (0.451)	0.001 (0.454)	0.035 (0.453)	0.043 (0.453)
Competition^2**Follower*	0.002 (0.084)	0.010 (0.085)	0.008 (0.085)	0.006 (0.085)	–0.025 (0.088)	–0.015 (0.088)	–0.021 (0.088)	–0.024 (0.088)
Firm Characteristics		√				√		
Industry Characteristics			√				√	

Technology Characteristics				√				√
Observations	2,697	2,697	2,697	2,697	2,697	2,697	2,697	2,697
Adjusted *R*-squared	0.247	0.250	0.250	0.250	0.519	0.520	0.521	0.522

Notes: 1) Standard errors are in parentheses. 2) ** $p<0.05$, * $p<0.10$. 3) Also included are all firm level characteristics that are included in the basic model, 15 regional dummies and 14 industry fixed effects.

4.4. Other Measures of Innovation: R&D Expenditures and Patents

We investigate the effects of distance to frontiers and competition on innovation using other measures of innovation, namely R&D expenditure and patent. The first two columns in table 6 present the results of the effects of distance to frontiers and competition on R&D intensity while the last two columns present the results on patent intensity. Here, R&D intensity is logarithm of R&D expenditure divided by employees and patent is logarithm of number of patent divided by employees.

When R&D intensity is used as a measure of innovation instead of product innovation, qualitatively similar results arise. The effects of *Frontier* and *Follower* are positive and significant. As for the effects of competition, there is an inverted-U shape relationship between competition and R&D expenditure. However, the interaction terms show that the effect of competition on R&D is not conditional on the distance to frontiers. The results indicate that the same qualitative effects of distance to frontier and competition on innovation are found for R&D expenditure as in new to the market innovation. However, the inverted-U relation between competition and R&D expenditure is not specific to frontiers as it is the case in new to the market innovation.

When we analyze the effects on patents, results are different from new to the market innovation, but are qualitatively similar to new to the firm innovation case. We find that there seems to be no significant relationship between competition and patents as was the case in new to the firm innovation. In addition, the effect of distance to frontier on innovation does not show consistent pattern. Further, the coefficients of all interaction terms demonstrate that the effect of competition on patent is not conditional on the distance to frontier.

It is interesting to point out that the results on new to the market innovation and R&D expenditure are qualitatively similar while the results on new to the firm only innovation and patents are qualitatively similar. Results on the relationship on various types of innovation measures, new to

Table 6 Models with Conventional Measures of Innovation

	R&D Intensity		Patent Intensity	
	(1)	(2)	(3)	(4)
Competition	0.607** (0.220)	0.543** (0.244)	0.019 (0.127)	–0.319** (0.127)
Competition^2	–0.125** (0.043)	–0.115** (0.048)	0.001 (0.025)	0.065** (0.025)
Frontier	1.096** (0.258)	1.349 (0.838)	0.668** (0.152)	0.171 (0.497)
Follower	0.837** (0.235)	0.353 (0.851)	0.388** (0.137)	0.081 (0.503)
*Competition*Frontier*		–0.368 (0.760)		0.452 (0.462)
Competition^2**Frontier*		0.092 (0.148)		–0.077 (0.091)
*Competition*Follower*		0.569 (0.776)		0.324 (0.473)
Competition^2**Follower*		–0.125 (0.152)		–0.066 (0.093)
R&D Expenditure			0.151** (0.016)	0.150** (0.015)
Export	0.810** (0.124)	0.810** (0.124)	–0.125* (0.074)	–0.129* (0.074)
Age	0.016** (0.005)	0.016** (0.005)	–0.033** (0.003)	–0.033** (0.003)
Demand Pull	0.366** (0.062)	0.368** (0.062)	–0.017 (0.036)	–0.019 (0.037)
Technology Push	1.288** (0.178)	1.288** (0.179)	0.229** (0.111)	0.228** (0.111)
Observations	2,697	2,697	2,697	2,697
Adjusted *R*-squared	0.534	0.533	0.291	0.292

Notes: 1) Standard errors are in parentheses. 2) *** $p<0.01$, ** $p<0.05$, * $p<0.10$. 3) Also included are all firm level characteristics that are included in the basic model, 15 regional dummies and 14 industry fixed effects.

the market innovation, new to the firm innovation, R&D expenditure, and patents, suggest that the relationship between innovation and competition with respect to the distance to frontiers is sensitive to the measures of

innovation in investigation. We can further suggest, with much care, that the innovation effort of a firm (measured by R&D expenditure of a firm) is closely related to the innovativeness of a firm's innovation activity while the patenting activity is more closely related to the strategic innovative behavior of a firm as represented by new to the firm only innovation.

5. CONCLUSION

This paper analyzes the relation between innovation and competition conditional on the distance to frontier. This paper makes some important contributions. We have analyzed the effect of competition and distance to frontiers on different types of product innovation based on the innovativeness of innovation; one is new to the market innovation, and the other is new to the firm only innovation. In addition, we have developed a measure of distance to frontier using a firm's main objective for innovation, thereby avoid the problems of conventionally used measure of distance to frontiers such as TFP, labor productivity, or Tobin's *q*. Furthermore, the use of new competition measure allows us to capture the level of competition that a firm really faces. Lastly, by employing extensive controls at firm and industry levels, we capture great portion of firm and industry heterogeneity, and confirms the robustness of the results to various specifications.

We find that (1) frontier and follower firms are more likely to conduct both types of new to the market and new to the firm only innovation; (2) competition has an inverted-U shape relationship with new to the market innovation while there is no relationship with new to the firm innovation; (3) the inverted-U shaped relation between competition and innovation is actually driven by the behaviors of frontiers, and not laggards; and (4) new to the market innovation and R&D expenditure show similar pattern of an inverted-U shaped relation with competition, while new to the firm only innovation and patents exhibit similar pattern of no relation with competition.

The results found in this paper are in general supportive of Aghion's

inverted-U shaped relation between competition and innovation. However, instead of the inverted-U shaped relation between competition and innovation for all firms as suggested in the previous literature, our results pinpoint the type of firms that drive the inverted-U shaped relation. Furthermore, we also find that such relation is only present for certain innovation, namely new to the market product innovation as opposed to new to the firm innovation, R&D expenditures as opposed to patents. Therefore, the mixed empirical evidence on the relation between competition and innovation in previous studies may be partially attributable to the analysis of the relation for overall innovation and all types of firms. The findings of this paper are very significant because it is the first to (1) analyze the differential effect of distance to frontiers and competition on the innovativeness of innovation, (2) find which firms drive an inverted-U relation between competition and innovation, and (3) find different patterns between innovation and competition depending on the measures of innovation.

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