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The link between R&D investment and market structure: evidence from Japan

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Abstract

This paper examines how market structure affects R&D investment at the firm level. Using a sample of 1338 Japanese firms, a sample selection model is employed to estimate R&D investment. The pooled sample results suggest that the likelihood of conducting R&D is negatively associated with market concentration. However, the relationship becomes insignificant when the model is estimated by industry group. Large market sales have a positive effect on the likelihood of conducting R&D for both pooled and industry group samples.

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1 Introduction

This paper examines the link between market structure and research and development (R&D) investment using Japanese firm data. I employ a sample selection model to estimate R&D investment and focus on a firm's endogenous decision whether or not to participate in non-zero R&D investment taking into account the market structure. Market share, concentration, and price-cost margin are included as latent variables to determine the probability of conducting R&D.

Using a sample of 1338 firms listed on the Japanese Stock Exchanges, I find that all three variables have significant effects on firms' R&D decisions. The model estimates for the pooled sample indicate that the relationship between the probability of conducting R&D and market concentration is negative. This finding suggests that on average firms invest more in R&D in the atomistic setting. However, this tendency is not robust. When the model is estimated by industry group, the relationship becomes mostly insignificant. Large market sales have positive effects on the probability of conducting R&D and the amount of R&D investment (more exactly, R&D intensity). The result supports Cohen and Klepper (1996) where a large volume of sales plays an important role in cost-spreading.

2 Related literature

Theoretical studies have attempted to explain how much to spend on R&D at the firm level. Kamien and Schwartz (1972) provide a theoretical foundation for a firm's R&D investment by assuming a random date of innovation arrival. Loury (1979) employs a model where the amount of R&D investment is positively related to the hazard rate of innovation. Lach and Rob (1996) assume that a firm has a dynamic choice between positive and zero R&D investment. If the expected profit flows with continuing R&D efforts exceed the ones without R&D efforts, it commits to the positive R&D investment.

Patent race models have also attempted to clarify how incentives to invest in R&D are affected by market structure. Gilbert and Newbery (1982) study the problem of R&D investment as a patent race between a monopolist and a challenger. Under the assumption of a deterministic innovation date, the monopolist will preemptively patent the innovation whenever entry is expected to lower total duopoly profits. Reinganum (1983) also examines the effect of monopoly power on incentives to invest in R&D. She shows that the monopolist invests less than the challenger under the assumption of a stochastic innovation date.

By committing to innovative activities, firms can improve product quality. As argued by Waldman (1996), the introduction of new products of superior quality lowers the value that consumers place on old products. The R&D decision that maximizes current profits is not the same as that which maximizes the long-term profits. Gilbert and Newbery (1982) show that the monopolist might patent innovation and let it sleep; i.e., a profit-maximizing monopolist will never choose to produce the new product.

Empirical evidence suggests a positive relationship between R&D investment and firm size. Substantial effort has been devoted to identifying whether the relationship is proportional and the results are mixed. Using U.S. firm level data, Bound *et al.*, (1984) find nonlinearity in the relationship. A large amount of research measures R&D investment as percent of sales (R&D intensity). Using U.S. business unit data, Cohen *et al.*, (1987) show that size has some effect on R&D intensity but its magnitude is very small. Klette and Griliches (2000) argue that the relationship is no more than proportional by examining Norwegian firm data. On the other hand, Cohen and Klepper (1996) examine the role of sales size in spreading R&D costs. They find that size has a positive impact on R&D investment by way of cost-spreading.

Another strand of the literature using microdata examines if there is a link between R&D investment and market competition. Levin *et al.*, (1985) find that there is no significant effect of market concentration on R&D investment when they include direct measures of technological opportunity and appropriability variables in the regression. Geroski (1990) finds negative effects of concentration on R&D outcomes. Aghion *et al.*, (2005) reexamine the link and find a robust relationship. Previous studies based on microdata show that a considerable fraction of firms report zero R&D spending. The large number of firms reporting zero R&D raises several econometric issues. Using sample selection models, Czarnitzki and Kraft (2004) and Artés (2009) examine the relationship between R&D investment and market power. Czarnitzki and Kraft (2004) show that entrants or firms with smaller market shares are likely to invest more than dominant firms. However, Artés (2009) obtains opposite signs of the effects.

3 Empirical model

I follow Lach and Rob (1996) for modeling a firm's R&D dynamics. Let V_i be the optimal value of firm i conditional on the choice between a value with R&D investment V_i^m net of investment costs and one without R&D investment V_i^n:

$$V_i = \max E\left\{\int^{T_i} (\pi_i - x_i)\, e^{-rs} ds + e^{-rT_i}\left(V_i^m - F_i\right), V_i^n\right\}, \tag{1}$$

where T is the random success date of innovation, π is the flow of operating profits, x is R&D investment and r is a constant interest rate. If the firm succeeds in innovation, its profits increase to $\pi + \alpha$. When the firm succeeds, it must invest F to implement the new production technology.

If the firm invests in R&D, it generates instantaneous probability of success h. Suppose the date of success is an exponential random variable, $\Pr[t \leq T] = 1 - \exp(-hT)$. Then, the maximization program is specified as

$$V_i = \max\left\{\frac{\pi - x}{r + h} + \frac{h}{r + h}\left(\frac{\pi + \alpha}{r} - F\right), \frac{\pi}{r}\right\}. \tag{2}$$

Now let the hazard function be given by $h(x) = x^{\gamma}$, $0 < \gamma < 1$, and let S denote the amount of sales. If the firms invest in R&D, the following condition must hold:

$$\ln \frac{x}{S} < \Psi(\gamma, \theta, f, S) \quad (3)$$

where x/S is R&D intensity, $\theta = \alpha/S$ is an incremental price-cost margin, $f = F/S$ is sunk cost investment per sales and $\Psi = (1-\gamma)^{-1}[\ln(\theta/r - f) + \gamma \ln S]$. The probability of conducting R&D investment rises as γ or θ increases. Smaller sunk cost leads to higher likelihood of positive R&D when other structural variables, such as sales, are held constant.

Although f, θ and γ are unobservable, the literature has predicted that the market structure has effects on some of these variables. In oligopolistic industries, firms with large market shares may have superior quality products or market power which enable them to charge higher prices than their rivals (e.g., Ravenscraft 1983). Firms with larger shares may be better able to develop a higher increment of price-cost margin. Increments of price-cost margin obtained by success innovations are predicted to be larger in concentrated industries. Firms with large output may be more efficient because of scale economies or a cost-spreading advantage (e.g., Cohen and Klepper 1996). In accordance with the previous studies, I use market share, Herfindahl index, size and price-cost margin as reduced-form proxies for f and θ and assume γ to be constant.

I follow Artés (2009) to estimate the R&D investment. He argues that the market structure variables have different effects on the decisions on whether and how much to invest in R&D. I employ a sample selection model proposed by Heckman (1974), allowing for separate effects of market structure on the decision and intensity of R&D. The R&D investment equation can be expressed as

$$\ln \frac{x_i^*}{S_i} = z_i \beta + u_i \quad (4)$$

$$d_i = w_i \delta + v_i \quad (5)$$

$$x_i = \begin{cases} x_i^*, & d_i > 0 \\ 0, & d_i \leq 0 \end{cases}, \quad (6)$$

where z_i and w_i are vectors of variables representing market structure and firm characteristics and u_i and v_i are error terms. The observed R&D investment function takes the form of (4) and the selection equation is given by (5) and (6).

Following Amemiya (1985), the joint distribution of (u_i, v_i) is assumed to be bivariate normal, $\text{BVN}(0, 0, \sigma^2, 1, \rho)$. The parameters of the investment function and the selection equation are estimated simultaneously using the maximum likelihood method. Let $y_i = \ln(x_i/S_i)$ denote log of R&D intensity. If firm i decides to conduct R&D, then its contribution to likelihood is $l(y_i, d_i > 0) = f(u_i) \Pr(v_i > -w_i\delta | u_i)$. If firm i decides not to conduct R&D, its contribution to likelihood is $l(d_i \leq 0) = \Pr(v_i \leq -w_i \delta)$. The log likelihood function is given by

$$\ln L = \sum_{x_i=0} \ln \Phi\left(-w_i\delta\right) + \sum_{x_i>0} \left[-\ln\sigma + \ln\phi\left(\frac{y_i - z_i\beta}{\sigma}\right)\right] + \sum_{x_i>0} \ln \Phi\left(\frac{w_i\delta + \left(y_i - z_i\beta\right)\rho/\sigma}{\sqrt{1-\rho^2}}\right), \tag{7}$$

where $\phi(\cdot)$ and $\Phi(\cdot)$ are the standard normal density and cumulative distribution functions. The distribution parameters must satisfy $\sigma > 0$ and $-1 \leq \rho \leq 1$. For computational convenience, σ and ρ are reparameterized as $\sigma = \exp(h)$ and $\rho = (1 - \exp(k)) / (1 + \exp(k))$ in the maximum likelihood estimation. The estimates and standard errors of the distribution parameters are then recovered from the estimates of h and k.

4 Results

This study uses a sample of 1338 firms listed on the Tokyo, Osaka and Nagoya Stock Exchanges in 1996. There is a data base for company R&D expenditures, which is based on the questionnaire on R&D expenditures compiled by the Nihon Keizai Shimbun, a Japanese business newspaper. The survey results have been published in Nikkei Kaisha Jouhou (Nikkei Company Information). The annual R&D expenditures of individual Japanese firms are taken from the Summer 1996 edition of Nikkei Kaisha Jouhou. Data on firm sales, profits and industry affiliation are taken from the company financial statements data file compiled by the Development Bank of Japan (DBJ). The sample covers 53 manufacturing and 3 construction sectors at the three-digit industry classification level. The industry classification is based on three-digit codes obtained from the DBJ data file. Details are provided in Appendix.

For each observation, R&D intensity x_i/S_i is measured as the ratio of R&D expenditures to sales. I follow Czarnitzki and Kraft (2004) to calculate market share MS_i at the three-digit level as the ratio of firm i's sales to the total sales in industry j: $S_i/\sum_{i\in j} S_i$. Herfindahl index H_j is constructed at the three-digit level and calculated by $\sum_{i\in j} MS_i^2$. Since distributions of MS_i and H_j are highly skewed, $\ln MS_i$ and $\ln H_j$ are used as regressors. Firm size is measured by $\ln S_i$. Price-cost margin PCM_i is measured by value added net of payroll divided by sales. Correlations among variables are presented in Table I. $\ln MS_i$ is highly correlated with $\ln S_i$. This collinearity might affect the validity of the model's parameters. I estimate the model including only $\ln MS_i$ to avoid multicollinearity.

Table II shows the empirical results. The model was estimated both including and excluding industry fixed effects. Column (1) contains parameter estimates for the specification that excludes industry fixed effects. Price-cost margin has no significant effect on the likelihood of conducting R&D, while having a positive and significant effect on

Table I: Correlations among variables by sample

	(a) *All firms*: 1338 obs.			
	$\ln MS_i$	$\ln H_j$	PCM_i	$\ln S_i$
$\ln MS_i$	.			
$\ln H_j$	.380	.		
PCM_i	.047	.042	.	
$\ln S_i$	.632	.028	.005	.
	(b) *R&D performers only*: 1093 obs.			
	$\ln MS_i$	$\ln H_j$	PCM_i	$\ln S_i$
$\ln MS_i$	.			
$\ln H_j$	.366	.		
PCM_i	.012	.024	.	
$\ln S_i$	.643	.028	-.037	.

R&D intensity. The positive relationship between price-cost margin and R&D intensity suggests that firms' R&D intensity increases depending on monopoly rents. On the other hand, the decision to conduct R&D does not appear to depend on monopoly rents. $\ln MS_i$ is positively associated with the likelihood of conducting R&D while negatively associated with R&D intensity. The positive effect of market share on the likelihood of conducting R&D is consistent with Cohen and Klepper's (1996) hypothesis that a large volume of sales is required to spread the sunk costs of innovation. The negative effect of market share on R&D intensity indicates that firms with large market shares are likely to invest less in R&D. In the patent race context, this supports Reinganum (1983). $\ln H_j$ has no significant effect on the likelihood of conducting R&D, while having a positive and significant effect on R&D intensity. Market concentration increases firms' R&D intensity without changing the probability of conducting R&D. Hence, the result suggests that market competition reduces R&D investment at the industry-wide level.

Column (2) shows parameter estimates from the model, allowing for fixed effects. The signs and significance of the coefficients of PCM_i do not change between column (1) and (2). The coefficient of $\ln MS_i$ in the selection equation remains significant and of the same sign. Meanwhile, $\ln H_j$ becomes significant in the selection equation and insignificant in the R&D intensity equation after allowing for fixed effects. The coefficient of $\ln MS_i$ becomes positive and significant in the R&D intensity equation. Firms with large market shares tend to have higher R&D intensity than firms with small market shares. Contrary to the result shown in column (1), this provides support for the hypothesis maintained by Gilbert and Newbery (1982), that firms with dominant positions have more incentives to earn monopoly rents than challengers. This tendency is also observed in Artés (2009) where market share is positively related to the likelihood of conducting R&D. The effect of concentration on the likelihood of conducting R&D is negative and significant while concentration has no effect on R&D intensity. This suggests, also contrary to column (1), that market competition increases R&D investment

Table II: Sample selection estimation

	(1)		(2)	
Selection equation:				
Const.	1.15	(.174)***	a	
$\ln MS_i$	.082	(.024)***	.165	(.033)***
$\ln H_j$	-.035	(.057)	-.217	(.098)**
PCM_i	.024	(.311)	.068	(.416)
R&D intensity:				
Const.	-4.01	(.166)***	b	
$\ln MS_i$	-.073	(.026)***	.053	(.021)**
$\ln H_j$	.247	(.057)***	.043	(.061)
PCM_i	3.10	(.301)***	2.54	(.258)***
σ	1.34	(.034)***	.922	(.032)***
ρ	-.959	(.010)***	-.796	(.065)***
L.L.	-2210		-1891	
Obs.	1338		1338	
Pos.	1093		1093	

Standard errors are in parentheses. Significance: *** at 1%, ** at 5%, and * at 10% level, respectively. a,b: industry level fixed effects are suppressed.

at the industry level. All coefficients remain of the same sign and significance level when $\ln MS_i$ is replaced with $\ln S_i$ (details not shown in table).

Czarnitzki and Kraft (2004) and Artés (2009) estimate sample selection models with industry fixed effect dummies, assuming the coefficients of the market structure variables to be constant across industries. As investigated by Cohen *et al.*, (1987), the coefficients can vary across industries. In this study, there are insufficient subsample sizes to estimate the sample selection model by industry. As some of the two-digit industries are relatively small in terms of sample size, the industries were grouped into five sectors, as shown in Appendix, to increase the sample size of each group.

The results are shown in Table III. In the selection equation, PCM_i is insignificant in all five groups. In R&D intensity, each coefficient of PCM_i is positive and significant, but its magnitude varies across sector groups. The significant relationship between PCM_i and R&D intensity, and the insignificant effect of PCM_i on the likelihood of conducting R&D appear relatively robust to industry heterogeneity concerns. R&D intensity is relatively more sensitive to price-cost margin in the metals (C) and construction (E) groups, while less sensitive in the other sector groups. $\ln MS_i$ has a positive effect on the likelihood of conducting R&D in group A, C and E, while has no significant effect in group B and D. In other words, the likelihood of conducing R&D is determined independent of the volume of market sales in some industries (group B and D in this case) where sunk costs would not play an important role in committing R&D. The effect of market share on R&D intensity is positive and significant in the machinery/equipment

(D) and construction (E) groups and insignificant in three groups. The coefficient of $\ln H_j$ is significant only in group E. The negative effect of concentration on the likelihood of conducting R&D is insignificant in the other groups. Hence, the negative relationship between concentration and the likelihood of conducting R&D obtained from the pooled sample is not robust after allowing the coefficients of market structure variables to vary across industries. The effect of concentration on R&D intensity is significant in all groups except group A, though the sign of the effect varies across industries. How market structure variables affect the likelihood and intensity of R&D differs by industry. In experiments not shown in this paper, essentially the same results were obtained using $\ln S_i$ instead of $\ln MS_i$.

5 Concluding remarks

This paper has examined how market structure affects R&D investment at the firm level. The empirical results suggest that the likelihood of conducting R&D is negatively associated with market concentration and that market share has positive effects on the likelihood and intensity of R&D, when the coefficients of market structure variables are assumed homogeneous across industries. On the other hand, when the coefficients are allowed to vary across industries, the results show that the relationship between the market structure variables and the likelihood and intensity of R&D tends to be industry specific. This study does not include information about appropriability conditions due to the limitation of data. Further analysis with more detailed data is needed to examine the discrepancy among the results on the effect of market structure on R&D investment at the micro-level.

Table III: Sample selection estimation by industry group

	(A)		(B)		(C)		(D)		(E)	
Selection equation:										
Const.	.878	(.486)*	1.241	(.455)***	2.03	(.461)***	.952	(.335)***	1.11	(1.18)
$\ln MS_i$	.130	(.061)**	0.021	(.092)	.244	(.086)***	.024	(.041)	.810	(.142)***
$\ln H_j$	-.118	(.259)	-0.004	(.244)	.161	(.183)	-.098	(.093)	-.957	(.407)**
PCM_i	.177	(.658)	0.544	(1.06)	-.705	(1.59)	-.179	(.600)	1.28	(2.27)
R&D intensity:										
Const.	-3.56	(.554)***	-4.779	(.255)***	-4.74	(.370)***	-3.00	(.217)***	-6.49	(.578)***
$\ln MS_i$	.064	(.069)	0.009	(.044)	.063	(.093)	.073	(.029)**	.396	(.115)***
$\ln H_j$	.258	(.294)	-0.302	(.128)**	.520	(.169)***	.169	(.064)***	-.481	(.215)**
PCM_i	1.24	(.748)*	2.577	(.382)***	9.09	(1.63)***	2.00	(.446)***	7.31	(1.52)***
σ	1.25	(.097)***	0.855	(.042)***	1.01	(.076)***	.993	(.038)***	.808	(.055)***
ρ	-.989	(.017)***	-0.949	(.032)***	.169	(.385)	-.939	(.024)***	-.026	(.323)
L.L.	-311.9		-336.7		-250.6		-757.6		-206.2	
Obs.	208		260		162		526		158	
Pos.	152		242		111		455		109	

See Appendix for details of grouping. Standard errors are in parentheses. Significance: *** at 1%, ** at 5%, and * at 10% level, respectively.

Appendix

Composition of industry classes

Two-digit industry	Obs.	Zero R&D exp.	Group:
Foods(6)	109	26	**A**
Textiles(6)	69	24	
Paper & Pulp(1)	30	6	
Chemicals(7)	170	8	**B**
Petroleum(1)	8	4	
Rubber(2)	19	0	
Stone, Clay & Glass(3)	63	6	
Iron & Steel(3)	55	18	**C**
Nonferrous Metals(4)	41	7	
Fabricated Metal Products(1)	66	26	
Machinery(4)	193	32	**D**
Electric Equipment(5)	178	18	
Transportation Equipment(5)	118	19	
Precision Instruments(1)	37	2	
Other Manufacturing(4)	24	0	*Excluded*
Heavy Construction(1)	98	30	**E**
Dredging(1)	5	0	
Other Construction(1)	55	19	
Total(56)	1338	245	

The number of three-digit industries is in parentheses.

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