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What Determines R&D Intensity? Evidence from Japanese Manufacturing Firms*

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We examine the determinants of research and development (R&D) intensity in Japanese manufacturing industries using a large sample of 13,000 firms for 1994. The results show that the technological opportunity and appropriability conditions of an industry play a central role in R&D investment. We also find that internal funds, firm size, advertising intensity, diversification, intra- and inter-firm networking technologies, licensing, export intensity, and foreign ownership positively affect R&D investment, while the effects of outsourcing, domestic ownership and market concentration are negative.

Key Words: R&D Intensity; Technological Opportunity; Appropriability Conditions
JEL Classification: O32, L10, O53

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Ⅰ. Introduction

A large number of studies have highlighted that research and development (R&D) expenditure is a key source in productivity growth and innovation. The main purpose of this paper is to shed some new light on possible sources of productivity growth and innovation by investigating the determinants of R&D intensity in Japan's manufacturing sector using a comprehensive cross sectional data set of about 13,000 firms and unique industry-level data drawn from an innovation survey.

The conventional wisdom with regard to the determinants of firms' R&D intensity, often referred to as the Schumpeterian hypotheses, is that R&D expenditures increase disproportionately with firm size (this is the first Schumpeterian hypothesis) and that there is a positive correlation between market concentration and R&D expenditures (the second Schumpeterian hypothesis). These hypotheses have been investigated in a rich and growing literature.[1] Previous studies investigating the two Schumpeterian hypotheses suggest that there is little support for the first hypothesis of a disproportionate effect of firm size on R&D expenditures. On the other hand, there does appear to be a positive effect of market concentration on R&D expenditures, thus providing supporting for the second hypothesis. The purpose of this study is to examine whether the Schumpeterian hypotheses hold for firms in Japan's manufacturing sector. Furthermore, we analyze the impact of other firm and industry factors on R&D intensity using detailed micro-data and several industry variables. In other words, we examine which factors are the most important in explain variations in R&D intensity across firms?

This paper contributes beyond previous research in this field in several respects. First, it provides a quantitative assessment of the relationship between a survey-based index of appropriability conditions and technological opportunity and Japanese firms' R&D activities. Second, the paper analyzes the role of the use of networking technology, technology purchases, ownership structure, and outsourcing in explaining firms' R&D activities - factors that have been neglected in the literature. Third, while

1) For a more detailed survey of the literature on the determinants of R&D intensity, see, e.g., Cohen (1995) and Radic (2005).

most previous studies on the determinants of R&D intensity were confined to large firms, the dataset used in this study, covering all firms in the Japanese manufacturing sector with more than 50 employees, includes a large number of relatively small firms. Fourth, despite the importance of this issue, there have been very few empirical studies on the determinants of R&D in Japan.[2] As a result, surprisingly little is known about the determinants of R&D intensity in Japan. Overall, our results do not provide support for the two Schumpeterian hypotheses. On the other hand, we find that internal funds, firm size, advertising, exports, firm diversification, and networking technologies all are important determinants of R&D in Japan's manufacturing sector. In line with other studies, our results suggest that there is a significant relationship between R&D intensity and technological opportunity, appropriability conditions, and horizontal *keiretsu*.

The remainder of the paper is organized as follows. Section 2 presents our data sources and provides a description of our sample. Section 3 discusses the possible determinants of R&D intensity in detail, while Section 4 provides our empirical specification and estimation results. Finally, Section 5 summarizes our findings.

Ⅱ. Data Sources and Sample Description

Our firm-level data for this study are taken from two sources. The first is *The Basic Survey of Japanese Business Structure and Activities* published by the Ministry of Economy, Trade and Industry (METI) since 1992, which provides data on firms' number of employees, sales, R&D expenditures, costs, patents, licensing, exports, imports, and other related data for all manufacturing firms with more than 50 employees. For our study, we use data from the 1994 issue. The second source is the 1994 issue of the *Innovation Survey* published by the National Institute of Science and Technology Policy (NISTEP), which contains the data used on appropriability conditions and technological opportunity.

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2) Notable exceptions are Goto, Koga and Suzuki (2002) and Hosono, Tomiyama and Miyagawa (2004).

There are 13,149 manufacturing firms in our sample. Of these, 6,340 (48.2 percent) reported in the survey that they conducted R&D.[3] The R&D expenditure of these 6,340 firms accounts for about 79 percent of total R&D in Japan's manufacturing sector.[4] Moreover, as shown in Table 1, these firms span a broad range of manufacturing activities: 11.3 percent of these firms belong to the food products and beverages industry, 6.9 percent to the chemical industry, 14.6 percent to the electrical machinery, equipment and supplies industry, 8.4 percent to the transportation equipment industry, 11.3 percent to the general machinery industry, 7.0 percent to the fabricated metal products industry, and 2.5 percent to the precision instruments industry.

<Table 1> Industry Distribution of Observations

Industry	Number of observations	Share of total observation (in %)
Food products and beverages	1481	11.3
Textiles	461	3.5
Pulp, paper and paper products	443	3.4
Chemicals	913	6.9
Petroleum and coal products	57	0.4
Non-metallic mineral products	619	4.7
Basic metals	721	5.5
Fabricated metal products	926	7.0
General machinery	1488	11.3
Electrical machinery, equipment and supplies	1921	14.6
Transport equipment	1105	8.4
Precision instruments	328	2.5
Manufacturing not elsewhere classified	2686	20.4
Total	13,149	100

Source: Authors' calculation.

3) Firms reporting "virtually no" R&D expenditures were counted as conducting no R&D.

4) This figure is based on a comparison of the R&D expenditures reported in *The Basic Survey of Japanese Business Structure and Activities* published by the Ministry of Economy, Trade and Industry (METI) and data in *The Report on the Survey of Research and Development* published by the Ministry of Internal Affairs and Communications (MIAC).

<Table 2> Size Distribution of Firms

Size class	Number of firms	Number of firms reporting R&D	Percent of firms reporting R&D	Share of total sales (%)	Share of total R&D expenditure (%)
Small firms	9826	3899	39.7	14.7	3.86
Large firms	3323	2441	73.5	85.3	96.14
All sample	13149	6340	48.2	100.0	100.0

Table 2 shows the size distribution of firms in the sample. Small firms (those with less than 300 employees) represent 74 percent of our sample. Although these firms account for about 14.7 percent of the total sales of all sample firms, they are responsible only for 3.9 percent of total R&D expenditures. Conversely, large firms account for only 25.2 percent of all firms, but make up 85.3 percent of total sales and their share in R&D expenditures is 96.1 percent.

Definitions of the variables that will be used, summary statistics, and correlation coefficients are provided in Tables 3, 4, and 5.

<Table 3> Definition of Variables

Variables	Definition	Expected Sign
Dependent Variable		
RS	R&D intensity: R&D expenditure/sales	
Independent Variables		
	Firm characteristics	
ADS	Advertising intensity: Advertising expenditure/sales	(+)
AGE	Number of years since the foundation of the firm	(+)
HUM	Total wage bill/number of employees	(+)
OUTS_D	Domestic outsourcing: Expenses on domestic outsourcing/sales	(+)/(-)
OUTS_F	Foreign outsourcing: Expenses on foreign outsourcing/sales	(+)/(-)
IMS	Import intensity: Imports/sales	(+)
EXS	Export intensity: Exports/sales	(+)
F_CO	Foreign subsidiary firm: A foreign firm owns at least 50 percent of the firm	(-)
D_CO	Domestic subsidiary firm: A domestic firm owns at least 50 percent of the firm	(-)
DLICN	Domestic licensing dummy	(+)/(-)
FLICN	Foreign licensing dummy	(+)/(-)
Intra_Net	Intra-firm networking dummy	(+)
Inter_Net	Inter-firm networking dummy	(+)
IS	Internal funds intensity: (After-tax profits + depreciation)/sales	(+)
DI	Diversification index	(+)
LOGS	log(Sales)	(+)
LOGS2	Square of log(Sales)	(-)
	Industry characteristics	
TO	Technological opportunity index	(+)
AP	Appropriability index	(+)
VER	Vertical keiretsu ratio in an industry	(+)/(-)
HOR	Horizontal keiretsu ratio in an industry	(+)/(-)
CR4	Four-firm concentration ratio	(+)/(-)

<Table 4> Summary Statistics

Variable	Obs.	Mean	Std. Dev.	Min.	Max.
All firms					
RS	13149	0.009	0.021	0.000	0.525
ADS	13149	0.005	0.017	0.000	0.944
AGE	13149	35.206	12.527	1.000	105.000
HUM	13149	4.397	1.669	0.034	28.679
OUTS_D	13149	0.079	0.113	0.000	1.000
OUTS_F	13149	0.001	0.009	0.000	0.321
IMS	13149	0.010	0.048	0.000	0.964
EXS	13149	0.027	0.089	0.000	0.957
F_CO	13149	0.009	0.092	0.000	1.000
D_CO	13149	0.265	0.441	0.000	1.000
DLICN	13149	0.061	0.239	0.000	1.000
FLICN	13149	0.037	0.189	0.000	1.000
Intra_Net	13149	0.548	0.498	0.000	1.000
Inter_Net	13149	0.457	0.498	0.000	1.000
IS	13149	0.032	0.082	-3.648	1.459
DI	13149	1.395	0.615	1.000	6.959
LOGS	13149	8.401	1.307	4.727	15.922
LOGS2	13149	72.282	23.818	22.348	253.507
TO	13149	0.809	0.139	0.550	1.000
AP	13149	0.448	0.067	0.342	0.657
VER	13149	0.261	0.186	0.000	0.867
HOR	13149	0.416	0.234	0.000	0.922
CR4	13149	0.343	0.139	0.107	0.880
Small firms					
RS	9826	0.006	0.018	0.000	0.525
ADS	9826	0.004	0.012	0.000	0.376
AGE	9826	34.161	12.376	1.000	105.000
HUM	9826	4.219	1.587	0.034	28.679
OUTS_D	9826	0.081	0.115	0.000	1.000

OUTS_F	9826	0.001	0.009	0.000	0.321
IMS	9826	0.009	0.044	0.000	0.964
EXS	9826	0.019	0.073	0.000	0.957
F_CO	9826	0.007	0.082	0.000	1.000
D_CO	9826	0.260	0.438	0.000	1.000
DLICN	9826	0.031	0.174	0.000	1.000
FLICN	9826	0.013	0.112	0.000	1.000
Intra_Net	9826	0.470	0.499	0.000	1.000
Inter_Net	9826	0.389	0.488	0.000	1.000
IS	9826	0.029	0.080	-3.648	1.459
DI	9826	1.359	0.561	1.000	5.530
LOGS	9826	7.867	0.826	4.727	11.132
LOGS2	9826	62.569	13.092	22.348	123.930
	Large firms				
RS	3323	0.016	0.024	0.000	0.222
ADS	3323	0.008	0.026	0.000	0.944
AGE	3323	38.295	12.463	1.000	102.000
HUM	3323	4.921	1.791	0.045	23.570
OUTS_D	3323	0.075	0.106	0.000	0.900
OUTS_F	3323	0.001	0.010	0.000	0.321
IMS	3323	0.016	0.058	0.000	0.894
EXS	3323	0.054	0.121	0.000	0.953
F_CO	3323	0.014	0.118	0.000	1.000
D_CO	3323	0.280	0.449	0.000	1.000
DLICN	3323	0.149	0.356	0.000	1.000
FLICN	3323	0.110	0.312	0.000	1.000
Intra_Net	3323	0.779	0.415	0.000	1.000
Inter_Net	3323	0.658	0.475	0.000	1.000
IS	3323	0.040	0.086	-3.580	0.596
DI	3323	1.504	0.743	1.000	6.959
LOGS	3323	9.979	1.189	6.356	15.922
LOGS2	3323	101.002	25.183	40.400	253.507

<Table 5> Correlation Analysis

	RS	ADS	AGE	HUM	OUTS_D	OUTS_F	IMS	EXS	F_CO	D_CO	DLICN	FLICN	Intra_Net	Inter_Net	IS	DI	LOGS	LOGS2	TO	AP	VER	HOR	CR4
RS	1																						
ADS	0.0776*	1																					
AGE	0.0744*	0.0603*	1																				
HUM	0.1636*	0.0575*	0.1538*	1																			
OUTS_D	-0.0521*	-0.0471*	0.0012	0.0085	1																		
OUTS_F	0.0173*	0.0047	-0.0135	-0.0217*	0.0460*	1																	
IMS	0.0961*	0.0287*	0.0287*	0.1003*	-0.0535*	0.1498*	1																
EXS	0.2468*	0.0186*	0.0688*	0.0919*	0.0117	0.1306*	0.1984*	1															
F_CO	0.0775*	0.0678*	-0.0605*	0.0832*	-0.0378*	-0.0066	0.2502*	0.0685*	1														
D_CO	-0.0403*	-0.0836*	-0.3168*	0.0174*	-0.0179*	-0.0078	-0.0481*	-0.0852*	-0.0409*	1													
DLICN	0.2229*	0.0075	0.0959*	0.1352*	-0.0208*	0.0027	0.0572*	0.1685*	0.0039	-0.0186*	1												
FLICN	0.2145*	0.0359*	0.0848*	0.1511*	-0.0143	0.0021	0.1123*	0.1905*	0.1038*	-0.0339*	0.3472*	1											
Intra_Net	0.1527*	0.0719*	0.0945*	0.1520*	0.012	0.0015	0.0665*	0.0983*	0.0365*	-0.0017	0.1172*	0.1071*	1										
Inter_Net	0.1023*	0.0307*	-0.0186*	0.0821*	0.0197*	-0.004	0.0237*	0.0310*	0.0369*	0.1173*	0.0940*	0.1049*	0.2454*	1									
IS	0.0446*	-0.0083	-0.0131	0.0535*	-0.0417*	-0.0131	-0.0055	-0.0392*	0.0366*	-0.0041	0.0201*	0.0280*	0.0281*	0.0419*	1								
DI	0.0658*	-0.0054	0.1185*	0.0635*	-0.0407*	0	0.0476*	0.0052	-0.0108	-0.0421*	0.1015*	0.0961*	0.0565*	0.0383*	-0.0310*	1							
LOGS	0.2387*	0.1192*	0.1730*	0.3959*	-0.0363*	0.0205*	0.1545*	0.2160*	0.0617*	0.0184*	0.2919*	0.3089*	0.3328*	0.2902*	0.0844*	0.1717*	1						
LOGS2	0.2452*	0.1191*	0.1764*	0.3901*	-0.0381*	0.0202*	0.1598*	0.2259*	0.0610*	0.0116	0.3080*	0.3332*	0.3222*	0.2864*	0.0832*	0.1758*	0.9930*	1					
TO	0.0889*	-0.0957*	0.0073	0.2012*	0.2183*	0.0209*	-0.0465*	0.1052*	0.0042	0.0147	0.0616*	0.0507*	0.0363*	0.0077	0.0124	-0.0427*	0.0318*	0.0328*	1				
AP	0.1592*	0.0997*	-0.0536*	-0.0449*	-0.2038*	0.0094	0.0676*	0.0074	0.0469*	0.0602*	0.0313*	0.0495*	0.0260*	0.0882*	0.0527*	0.0500*	0.1331*	0.1316*	-0.3176*	1			
VER	-0.0016	-0.0868*	-0.0325*	0.0248*	-0.0106	-0.0023	-0.0024	-0.0212*	-0.0104	0.0491*	0.0144	0.0149	0.0201*	0.0572*	0.0613*	-0.0062	0.0581*	0.0525*	-0.0013	-0.1104*	1		
HOR	0.0713*	-0.0709*	0.0004	0.0599*	-0.0923*	-0.0053	0.0191*	0.0722*	0.013	0.0302*	0.0576*	0.0246*	0.0035	-0.0244*	-0.0065	0.0700*	0.0214*	0.0204*	0.0358*	0.0498*	0.0339*	1	
CR4	0.0320*	-0.0207*	0.0169	0.1367*	0.0191*	0.0061	0.0601*	0.0445*	-0.0088	0.0189*	0.0434*	0.0314*	0.0118	0.0047	-0.0051	0.0634*	0.1137*	0.1170*	0.2832*	-0.0500*	-0.2190*	0.0769*	1

Note: *=significant at 5% level.

Ⅲ. The Determinants of R&D Intensity[5)]

1. Firm characteristics

One assertion of the Schumpeterian hypotheses is that firms' R&D expenditures increase disproportionately with their size. In general, four factors why larger firms should spend disproportionately more on R&D are cited.[6)] First, as a result of capital market imperfections, it is easier for large firms to finance R&D investment, since they are more likely to possess the necessary internal funds and/or enjoy access to external finance, which smaller companies may lack.[7)] Second, R&D activity is subject to economies of scale, from which larger firms may benefit. Third, large firms enjoy larger profits because of complementarities between R&D and other activities (marketing, etc.). Finally, diversified firms are in a better position to reduce the risk associated with R&D or to exploit unforeseen innovations.

In order to examine whether innovative efforts are related to firm size, we consider four variables. The first variable measures the availability of internal funds. It is constructed as the sum of the firm's after-tax profits plus depreciation divided by its sales. If a positive correlation between the availability of internal funds and R&D intensity is found, then this would provide evidence that financial constraints do have an impact on R&D investment. Second, we use firm size as a proxy for scale economies in R&D activities. Firm size is measured by the log of total sales of a firm. We expect that the larger a firm, the greater its willingness to carry out R&D investment, although it should be noted that there is also evidence that the reverse may be true, i.e., that the smallness of a firm may also have positive effects on R&D investment [Graves and Langowitz (1993)]. The square of firm size is also included in order to allow for non-linearity

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5) The differences in innovative capabilities between firms will be related to the differences in regional characteristics, such as agglomeration effects due to local industry-specific knowledge spillovers and natural cost advantages. But, we do not take account of the characteristics of the region to which a firm belongs because of a lack of appropriate data.

6) See Cohen (1995) and Radic (2005).

7) For a review of the relevant literature, see Hall (2002).

in the firm size-R&D relationship. These variables also show whether the first Schumpeterian hypothesis holds or not. Third, we consider firms' advertising intensity in order to allow for complementarities between R&D and marketing activities. A higher advertising intensity indicates that a firm has complementary assets and capabilities that allow it to introduce new products created by R&D. Thus, we expect a positive correlation between advertising activity and R&D intensity. Finally, R&D intensity is thought to be associated with the extent of diversification [Nelson (1959)]. In order to examine this relationship, we use the diversification variable suggested by Crepon, Duguet and Kabla (1996). This is defined as the inverse of the Herfindahl index of a firm's sales. The higher this number, the higher is the diversification.

Another factor that may stimulate efforts to innovate and hence R&D expenditures is firms' exposure to international competition. Exposure to international markets may play a role because it provides firms with greater opportunities to learn and exerts greater pressures to innovate in order to keep up in the technology race and/or gain international competitiveness. A number of empirical studies have found evidence for such a link between exposure to international competition and R&D intensity [Canto and Gonzales (1999)]. In order to examine this issue, we include firms' export intensity, defined as exports divided by sales, as a variable.

In order to examine the effect on R&D intensity of firms' strategies to cope with domestic competitive pressure, we consider three variables: firms' import intensity (defined as imports divided by sales), their domestic outsourcing intensity (defined as the expenses on domestic outsourcing divided by sales), and their foreign outsourcing intensity (defined as the expenses on foreign outsourcing divided by sales). The import of new or cheaper intermediate and capital goods or outsourcing help firms to reduce production costs, and the lower production costs in turn help firms to compete. Therefore, we expect that firms' import and outsourcing intensities are likely to have a negative effect on R&D expenditures. In addition, we examine whether the effect of outsourcing on firms' R&D expenditure differs depending on the type of outsourcing, i.e., whether it is domestic or foreign outsourcing.

Another issue of interest where previous studies have come to conflicting conclusions is the link between internal R&D investment and technology purchases. Basant (1993) and Fikkert (1994), for example, found that these are substitutes. In contrast, other studies have stressed the complementarity of internal R&D and external sourcing [Veugelers (1997), Veugelers and Cassiman (1999)], while Odagiri (1983) showed that in Japanese manufacturing firms, internal R&D expenditures and licensing are complementary. In order to capture the effect of licensing on R&D expenditure, two binary variables (domestic and foreign) were constructed; these variables take a value of one if the firm purchased technology, and zero otherwise.

Although there are studies looking into the relationship between a firm's networking technology and its productivity [Koski (1999)], we are not aware of any research on the effect of the use of networking technology on a firm's R&D investment. Yet, it seems quite likely that the use of networking technology promotes information processing capabilities and enhances the effectiveness of R&D investment. In order to test this hypothesis, we distinguish between intra-firm and inter-firm networks to examine whether the use of networking technologies has different effects on R&D investment in these two types of networks.

Another important factor affecting R&D expenditures is firms' technological capabilities accumulated from past R&D and training expenditures. We use firm age and the wage rate (total wage bill/number of employees) as proxies to measure the impact of technological capabilities. Theoretical models suggest that firm age has a negative effect on R&D expenditure, because incumbent firms are likely to be reluctant to introduce innovations. On the other hand, human capital accumulated through past training expenditure may increase incentives to innovate and enhance the firm's capacity to absorb external knowledge. Finally, we allow for the possibility that ownership may have additional effects on R&D investment. Empirical studies on the effects of foreign ownership in Japan [Fukao and Murakami (2003), Kimura and Kiyota (2003)] indicate that foreign-owned firms differ from domestic firms. We expect that foreign-owned firms invest more in R&D than domestic firms and test this hypothesis using a foreign-ownership dummy. We also examine whether firms that belong to a *keiretsu* are more R&D intensive than independent firms. We do this by including a dummy for firms that are majority-owned by another Japanese firm. We expect that such firms conduct less R&D than independent firms due to knowledge spillovers within *keiretsu*.[8)]

2. Industry characteristics[9)]

In addition to firm characteristics, there are also a number of industry characteristics that are likely to determine firms' R&D expenditure. The variables examined here are appropriability conditions, technological opportunity, concentration ratios, and vertical and horizontal *keiretsu* ratios.[10)]

Appropriability conditions are defined as innovators' ability to capture the returns to their innovative effort. The larger the extent of appropriability, the greater is the incentive to increase R&D investment. Constructed from three-digit industry-level data of NISTEP's 1994 *Innovation Survey*, the variable representing appropriability conditions in a particular industry is defined as the maximum of industry mean scores of the responses concerning the effectiveness of seven different factors in securing a competitive advantage from product or process innovations in the preceding three years. The seven factors are: (1) the secrecy of technical information; (2) protection by patents; (3) other legal mechanisms (design registration, registration of semiconductor circuit layouts, copyrights, etc.); (4) being first to market; (5) complementary sales/services; (6) complementary manufacturing facilities and know-how; and (7) product complexity.

The notion of technological opportunity is based on the idea that there are some industries in which it is easier to innovate with a given level of resources devoted to innovation. Cohen, Levin, and Mowery (1987) and Cohen and Levinthal (1989) found that a substantial fraction of

8) Evidence of such spillovers was provided by Suzuki (1993) and Branstetter (2000).

9) Appropriability conditions, concentration ratios, and vertical and horizontal *keiretsu* ratios may be endogenous, but do not consider these relationships here.

10) Horizontal *keiretsu* are groups of firms in different industries centered around a common financial institution. Vertical *keiretsu* are based on manufacturer-supplier relationships such as Toyota *keiretsu*.

inter-industry variance in R&D intensity can be explained by technological opportunity. Here, we define technological opportunity as the maximum of industry mean scores of the responses concerning the significance of various external sources of information for new R&D projects in the preceding three years. This variable is also constructed using three-digit industry-level data from the *Innovation Survey*. The various sources of information for new R&D projects are the following: (1) affiliated suppliers; (2) independent suppliers; (3) cooperative or joint ventures; (4) customers; (5) universities; (6) government research institutes; (7) academic societies and associations; (8) competitors; (9) consulting or contract R&D firms; (10) other external information sources; (11) other R&D units within the same firm; and (12) production and manufacturing divisions within the same firm.

We expect greater appropriability and technological opportunity to have a positive impact on firms' R&D intensity.

Coming to the next point, it has been argued that market concentration is an important determinant of firms' R&D investment. Most previous studies that have examined the relationship between market concentration and R&D found a positive relationship. However, not all studies have come to this conclusion: Cohen, Levin and Mowery (1987) and Levin et al. (1987) found little evidence to support the view that concentration is a significant determinant of R&D, while Crepon, Duguet and Kabal (1996) even found a negative relationship between market concentration and R&D. In order to examine this issue, we include a variable for market concentration in our analysis, which we define as the ratio of the sales of the top-four firms to total sales at the three-digit industry level.

In order to investigate whether industries in which *keiretsu* plays an important role are more likely to be innovative, we include "*keiretsu* intensity" variables for both vertical and horizontal *keiretsu*. The *keiretsu* ratios are taken from Nakamura, Fukao and Shibuya (1997). These data were calculated as follows: the vertical *keiretsu* ratio for a particular industry is the sum of sales to vertically related firms divided by the total sales in that industry, while the horizontal *keiretsu* ratio for a particular industry is the sum of sales to horizontally related firms divided by the total sales in that industry.

Ⅳ. Specification and Empirical Results

To empirically examine the determinants of R&D intensity, we estimate the following model:

$$RS_f = \alpha + \beta \cdot Z_f + \gamma \cdot X_i + \varepsilon_i \qquad (1)$$

where RS, Z and X denote R&D intensity, firm characteristics variables, and industry characteristics variables, respectively.

Our dependent variable, firms' R&D intensity, is not normally distributed, but rather limited at zero, with 51.8 percent of firms not engaged in any R&D activity at all. This presence of censured data means that our estimates would be biased if we used ordinary least squares. Therefore, to deal with the problem of censored data, we use a Tobit model to estimate the determinants of R&D intensity. Industry characteristics variables are included to control for industry effects.

In order to examine differences in R&D activity among firms of different sizes, we classified firms into two groups by size. The classification by size is based on the number of employees: those with 300 or fewer employees are classified as small firms, while those with more than 300 employees make up the large firms. We also run a separate regression for three high-tech industries - the chemical industry, the electrical machinery industry, and the machinery industry - to examine whether patterns differ across industries.

<Table 6> Determinants of R&D Intensity by Firm Size Group

Tobit model			
Variable	All firms	Small firms	Large firms
ADS	0.095 ***	0.180 ***	0.046 *
	(0.017)	(0.030)	(0.018)
AGE	0.000 ***	0.000	0.000 ***
	(0.000)	(0.000)	(0.000)
HUM	0.001 ***	0.002 ***	0.002 ***
	(0.000)	(0.000)	(0.000)
OUTS_D	-0.011 ***	-0.012 **	-0.011 *
	(0.003)	(0.004)	(0.005)
OUTS_F	-0.009	-0.049	0.048
	(0.032)	(0.043)	(0.049)
IMS	0.007	0.014	0.006
	(0.006)	(0.009)	(0.009)
EXS	0.060 ***	0.074 ***	0.043 ***
	(0.003)	(0.005)	(0.004)
F_CO	0.006 *	0.006	0.007
	(0.003)	(0.005)	(0.004)
D_CO	-0.004 ***	-0.005 ***	-0.002
	(0.001)	(0.001)	(0.001)
DLICN	0.015 ***	0.019 ***	0.011 ***
	(0.001)	(0.002)	(0.002)
FLICN	0.010 ***	0.010 ***	0.011 ***
	(0.002)	(0.003)	(0.002)
Intra_Net	0.008 ***	0.008 ***	0.005 ***
	(0.001)	(0.001)	(0.001)
Inter_Net	0.003 ***	0.003 ***	0.002
	(0.001)	(0.001)	(0.001)
IS	0.012 **	0.015 **	0.007
	(0.004)	(0.005)	(0.006)
DI	0.002 ***	0.002 ***	0.001 *

Tobit model			
Variable	All firms	Small firms	Large firms
	(0.000)	(0.001)	(0.001)
LOGS	0.019 ***	0.052 ***	0.025 ***
	(0.002)	(0.007)	(0.005)
LOGS2	-0.001 ***	-0.003 ***	-0.001 ***
	(0.000)	(0.000)	(0.000)
TO	0.019 ***	0.013 ***	0.026 ***
	(0.003)	(0.003)	(0.004)
AP	0.075 ***	0.071 ***	0.085 ***
	(0.005)	(0.006)	(0.007)
VER	0.002	0.000	0.006 *
	(0.002)	(0.002)	(0.003)
HOR	0.008 ***	0.009 ***	0.008 ***
	(0.001)	(0.002)	(0.002)
CR4	-0.008 ***	-0.008 **	-0.006
	(0.002)	(0.003)	(0.004)
_cons	-0.175 ***	-0.296 ***	-0.219 ***
	(0.010)	(0.028)	(0.025)
/sigma	0.030 ***	0.032 ***	0.026 ***
	(0.000)	(0.000)	(0.000)
Pseudo R2	-0.183	-0.142	-0.118
Log likelihood	9761	5058	4832
No. of observations	13149	9826	3323

Notes: The coefficients show the marginal effects from the Tobit estimation.
Standard errors are given in parentheses.
*=significant at 10% level; **=significant at 5% level; ***=significant at 1% level.

To begin with, let us test the first Schumpeterian hypothesis, according to which large firms are more inclined to undertake R&D than smaller ones. Our estimations yield varying but interesting results. The internal funds (*IS*) coefficient is positive and significant for the sample of all firms. Moreover, it is larger and more statistically significant in the subsample consisting of small firms, whereas in that of large firms it is statistically insignificant. These results are consistent with those obtained by Himmelberg and Peterson (1994) in their study on American firms which showed that cash flow has a positive effect on the R&D expenditures of small firms. On the other hand, our results are somewhat at odds with the study by Goto, Koga and Suzuki (2002), which found that the effect of cash flow is significant for large firms.

Our results show that R&D intensity is positively related with firm size as measured by sales. On the other hand, the coefficient on the square of firms' sales is negative and significant, indicating diminishing marginal effects of firm size. Therefore, the relationship between firm size and R&D appears to be an inverted U-shape, which means that R&D first rises with increasing size and then drops. This finding rejects the first Schumpeterian hypothesis.

We consider advertising intensity (*ADS*) to examine whether there are complementarities between R&D expenditures. We find that advertising intensity has a significant and positive effect on R&D intensity in all specifications. In addition, the coefficient on *ADS* is larger for the small firm group. These results suggest that advertising is a complement to firms' R&D activity, and the role of complementary assets is more important for small firms.

We find that the effect of diversification on R&D intensity is significant and positive. We also find that the positive relation holds for both size groups. These results support the hypothesis that diversification may be a means of spreading risks over various different projects.

Next, we look at the proxy variable measuring exposure to international competition. The coefficient on export intensity is large, positive and highly significant in all equations. This result indicates that export activity tends to be associated with greater R&D expenditures because competing in foreign markets requires more advanced technology. In contrast with international competition through export, domestic competition - as measured by the three proxy variables representing import intensity, foreign outsourcing intensity, and domestic outsourcing intensity - appears to have an insignificant or negative effect on R&D intensity. Both import intensity and foreign outsourcing intensity are insignificant. On the other hand, as expected, we find that domestic outsourcing intensity has a negative effect on R&D intensity. This result is in line with the argument that domestic outsourcing acts as a substitute for R&D to remain competitive.

The effects of foreign and domestic licensing on R&D intensity are positive and significant in all specifications. The effect of foreign licensing is more or less the same irrespective of firms' size. In contrast, the effect of domestic licensing on R&D intensity is larger for small firms than for large ones. This result indicates that for Japanese manufacturing firms, domestic technology sources are more important for R&D activities than licensing from abroad.

Regarding the impact of the use of network technologies on firms' R&D activities, there are, to our knowledge, no previous empirical studies that have examined this aspect. Our findings suggest that intra- and inter-firm networking technologies indeed are determinants of firms' R&D intensity: the coefficients on both variables are statistically significant and positive. The effect of intra-firm networking technology is larger than that of inter-firm networking technology. Moreover, the separate regressions for the two size groups yield interesting results: the use of intra-firm networking technology has a statistically significant impact on R&D intensity in both size groups, while inter-firm networking technology has a significant effect on the R&D intensity of small firms, but not of large firms.

As for firm age, we expected a negative effect on R&D intensity but in fact find that, although it is small, the impact is positive and significant. This result suggests that older firms tend to engage more actively in R&D. On the other hand, human capital, which is taken to represent firms' technological capabilities, has a significantly positive effect on R&D intensity. This result suggests that firms' technological capabilities have a positive influence on R&D intensity because firms with greater technological capabilities have a greater capacity to absorb new external technologies and grasp the significance of new technological developments.

Next, looking at foreign-owned firms in Japan, we find that their R&D intensity tends to be higher than that of other firms in the sample consisting of all firms. However, there appears to be no difference in the R&D intensity between foreign-owned firms and domestic firms in the two subsamples of small and large firms. The coefficient on the dummy variable that represents domestically-owned firms is significantly negative except in the large firm group. This suggests that the benefits from inter-firm knowledge spillovers are higher for small firms than for large firms.

Let us now turn to the industry variables. The key industry variables we are interested in are appropriability (AP) and technological opportunity (TO). The estimated coefficient on the technological opportunity variable is positive and significant, which is in line with the results obtained by Goto, Koga and Suzuki (2002). Moreover, our findings by firm size group indicate that technological opportunity through knowledge spillovers between firms and the scientific infrastructure provided by universities, research institutes, etc., has a greater positive impact on large firms than on smaller firms. The estimation results also indicate that appropriability has a substantial impact on R&D intensity. That is, inter-industry variations in appropriability conditions play an important role in explaining variations in firms' R&D intensity. These results suggest that policies to strengthen firms' intellectual property rights and promote linkages between university and industry could potentially help to stimulate R&D.

Turning to the role of the *keiretsu*, we find that the horizontal *keiretsu* ratio (*HOR*) has significant positive effects on firms' R&D intensity. This confirms our expectation that firms with stronger horizontal *keiretsu* ties find it easier to access external financial resources. This is consistent with the empirical finding of Hoshi, Kashyap and Scharfstein (1991), who report that a positive link between main bank relationship and investment. On the other hand, while the impact of the vertical *keiretsu* ratio in an industry (*VER*) is positive and significant for large firms, it is insignificant for small firms, indicating that R&D spillovers within vertical *keiretsu* have a positive effect on R&D activities in large firms, but have no effect on the R&D activities in small firms.

The relationship between market concentration and R&D activity is significantly negative in the whole sample and in the subsample consisting of small firms. As a consequence, the second Schumpeterian hypothesis fails to hold at least for Japanese manufacturing sectors, like the first Schumpeterian hypothesis. This suggests that Japanese manufacturing firms conduct less R&D in concentrated industries with high barriers to entry. This result is consistent with the finding of Aghion et al. (2005) that there is an inverted U-shaped relationship between market competition and R&D.

<Table 7> Determinants of R&D Intensity in Selected Industries

Tobit model			
Variable	Chemicals	Electrical machinery, equipment and supplies	General machinery
ADS	-0.103 **	0.525 ***	0.288 ***
	(0.037)	(0.098)	(0.061)
AGE	0.000 *	0.000 *	0.000
	(0.000)	(0.000)	(0.000)
HUM	0.003 ***	0.003 ***	0.001
	(0.001)	(0.001)	(0.000)
OUTS_D	-0.005	-0.002	-0.011 *
	(0.025)	(0.008)	(0.005)
OUTS_F	0.475	0.109 *	0.035
	(1.410)	(0.055)	(0.062)
IMS	0.028	-0.024	0.017
	(0.021)	(0.020)	(0.017)
EXS	0.083 ***	0.038 ***	0.032 ***
	(0.015)	(0.007)	(0.005)
F_CO	0.005	0.003	-0.011
	(0.007)	(0.010)	(0.007)
D_CO	-0.008 **	-0.007 ***	-0.006 ***
	(0.003)	(0.002)	(0.002)
DLICN	0.011 **	0.013 ***	0.010 ***
	(0.004)	(0.003)	(0.002)
FLICN	0.008	0.013 **	0.003
	(0.004)	(0.004)	(0.003)
Intra_Net	0.006 *	0.011 ***	0.007 ***
	(0.003)	(0.002)	(0.001)
Inter_Net	0.005 *	0.000	0.003 *
	(0.003)	(0.002)	(0.001)
IS	0.033	0.034 **	-0.005

Tobit model			
Variable	Chemicals	Electrical machinery, equipment and supplies	General machinery
	(0.020)	(0.012)	(0.010)
DI	0.000	0.000	0.000
	(0.002)	(0.001)	(0.001)
LOGS	0.014	0.020 ***	0.015 ***
	(0.009)	(0.005)	(0.004)
LOGS2	-0.001	-0.001 **	-0.001 *
	(0.000)	(0.000)	(0.000)
TO	0.180 ***	0.064	-0.227 ***
	(0.054)	(0.046)	(0.046)
AP	0.075 ***	-0.008	0.125 *
	(0.019)	(0.028)	(0.055)
VER	---	0.012	-0.022 ***
	---	(0.031)	(0.005)
HOR	-0.029	0.023	-0.105 ***
	(0.017)	(0.024)	(0.020)
CR4	-0.009	0.021 *	-0.034 ***
	(0.023)	(0.009)	(0.007)
_cons	-0.254 **	-0.210 ***	0.106 ***
	(0.081)	(0.033)	(0.026)
/sigma	0.034 ***	0.033 ***	0.028 ***
	(0.001)	(0.001)	(0.001)
Pseudo R2	-0.114	-0.226	-0.178
Log likelihood	1392	1478	2379
No. of observations	913	1921	2655

Notes: The coefficients show the marginal effects from the Tobit estimation.
Standard errors are given in parentheses.
*=significant at 10% level; **=significant at 5% level; ***=significant at 1% level.

It has long been recognized that the determinants of R&D intensity differ across industries. To cast some light on inter-industry differences of the determinants of R&D activity, we reexamine the determinants of R&D intensity in three R&D intensive industries: the chemical, the electrical machinery, equipment and supplies, and the general machinery industry.[11] The estimation results are shown in Table 7. The relationship between appropriability (*AP*) and technological opportunity (*TO*) on the one hand and R&D intensity on the other is significantly positive only for firms in the chemical industry. On the other hand, no significant relationship between *AP* and *TO* and R&D intensity can be found in the electrical machinery industry. For the general machinery industry, we find that the coefficient on *AP* is significantly positive and quite large, whereas the coefficient on *TO* is significantly negative. These findings suggest that the impact of *AP* and *TO* on R&D investment substantially differs across industries.

In addition, the estimation results for the three industries suggest that the effects of export intensity, domestic licensing, intra-firm networking, and domestically-owned firm on R&D intensity are consistent with the estimation results of the whole sample. More interesting, however, are the differences across industries in the coefficients on the internal funds and advertising intensity variables. With regard to internal funds, we find that these have a significant positive effect on R&D intensity in the electrical machinery industry, but not in the general machinery or chemical industries. On the other hand, with regard to advertising intensity, we find that this has a significant positive impact on R&D intensity in the electrical and general machinery industries, but a significant negative impact in the chemical industry.

Overall, our findings suggest that it is possible to reject the Schumpeterian hypotheses that firms' R&D expenditures increase disproportionately with their size and that R&D efforts are greater in more concentrated industries. However, we also found that the advantages of

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11) "Chemical industry" here includes not only the chemical industry as typically defined but also the pharmaceutical industry, while the general machinery industry comprises the general and the transportation machinery industries.

large firms in terms of their internal funds, advertising intensity, and diversification exist. Finally, technological opportunity and appropriability conditions of industries play a crucial role in R&D.

Ⅴ. Conclusion

Using firm survey data on Japanese manufacturing firms and unique industry-level data drawn from an innovation survey, we attempted to analyze the determinants of R&D activity using a Tobit model. We considered factors which are not included in traditional models of the determinants of R&D and therefore have not been examined before.

Our estimation results on firm characteristics suggest that (1) internal funds, firm size, advertising intensity, export intensity, and diversification influence R&D intensity positively; (2) the effect of outsourcing is insignificant (foreign outsourcing) or negative (domestic outsourcing); (3) R&D intensity is positively and significantly correlated with licensing; (4) intra- and inter-firm networking technologies have a positive effect on firms' R&D intensity; (5) technological capabilities have a significant positive effect; (6) domestically-owned firms tend to be less R&D intensive while foreign-owned firms tend to be more R&D intensive. The estimation results for small and large firms separately are mostly consistent with the results for the whole sample.

Our findings on industry characteristics indicate that technological opportunity, appropriability conditions and the horizontal *keiretsu* ratio are important factors determining R&D activities in Japanese manufacturing industry. In addition, we were able to confirm that the effects of technological opportunity and appropriability conditions on firms' R&D activities differ across industries. Moreover, we found that the horizontal *keiretsu* ratio has a significant positive effect, whereas concentration has a significant negative on R&D intensity.

Overall, our study showed that firms' R&D activities are influenced by a wide range of factors, some of which have not been empirically examined before. However, a shortcoming of our analysis should also be mentioned. Because we did not employ a panel data set, our estimation may suffer from biases resulted from problems regarding unobserved heterogeneity and endogeneity between R&D and firm specific characteristics. Employing such a panel data set to examine the questions addressed here remains a task for the future.

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