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Technology spillover as a complement for high-level R&D intensity in the pharmaceutical industry

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Abstract

The pharmaceutical industry is a typical high R&D intensive industry. This is because medical supplies are based purely on R&D. Therefore, their major tenants, the pharmaceutical industry, must be a technology-driven industry. Huge amounts of R&D resources are required for generating new products. However, these resources are generally too much of a burden for smaller pharmaceutical firms, compelling them to depend on the effective utilization of technologies and research developed by their competitors. How to best utilize these technologies depends on assimilation capacity. Firms with a well-developed assimilation capacity succeed in effectively utilizing technology spillover resulting in a very productive R&D structure.

One critical issue confronting all advanced countries is how to construct a highly productive R&D structure. Pharmaceutical firms with their highly productive R&D structure based on well-developed assimilation capacities provide us with a constructive model for addressing this issue at the national level. This paper undertakes an empirical analysis of R&D activities, focusing on inter-firm technology spillover in Japan's 30 leading R&D intensive pharmaceutical firms. This analysis covers the past two decades, elucidating the sources of success in constructing a highly productive R&D structure. © 2001 Published by Elsevier Science Ltd.

Keywords: Technology spillover; Assimilation capacity; R&D intensity of the pharmaceutical industry

1. Introduction

R&D intensity (the ratio between R&D expenditure and sales) in Japan's pharmaceutical industry was 8.1% in 1998 which is much higher than the manufacturing industry's average R&D intensity of 3.9%. This is largely because medical supplies are based purely on R&D which requires highly intensive R&D activities including huge investments in R&D (Brenner and Rushton, 1989) resources.

These R&D resources are beyond the reach of smaller-sized firms, inevitably compelling them to more effectively use technologies developed by other firms that 'spillover' into the market. As postulated by Cohen and Levinthal (1989) and Watanabe et al. (2001), effective utilization of spillover technology from a potential spillover pool depends on assimilation capacity. Assimilation capacity is a function of the level of technology stock and the ability to maximize the benefits of a learning exercise (Watanabe et al., 2001) and, consequently, it depends on the level of R&D expenditure. Smaller-sized firms in the pharmaceutical industry tend to increase R&D intensity at a faster rate than larger firms. This is so that they can increase their assimilation capacity. Interestingly, this tendency is contradictory to the general observation that R&D intensity increases as sales increase.

This paper demonstrates this hypothetical view, taking 30 leading R&D intensive Japanese pharmaceutical firms and examining their R&D over the past two decades. Many scholarly works have attempted to elucidate the sources of high R&D intensity in the pharmaceutical industry (Dimasi et al., 1991; Grabowski and Vernon 1990, 1994). However, none has looked at the relationship between R&D intensity, technology spillover and assimilation capacity.

Section 2 reviews the state of R&D structure in phar-

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maceuticals. Section 3 analyzes the state of technology spillover between pharmaceutical firms. Section 4 identifies the optimal dependency between indigenous technology and spillover technology. Section 5 summarizes the implications.

2. State of high-level R&D intensity

Table 1 summarizes the state of sales and R&D structure of 30 leading R&D intensive Japanese pharmaceutical firms in 1998 which covers 66% of sales and 77% of R&D expenditure for Japan's entire pharmaceutical industry. Table 1 indicates that the R&D intensity of these 30 firms ranks between 4.4% and 19.9% in 1998 which is an extremely high level of R&D intensity compared to the average R&D intensity of 3.9% in Japan's manufacturing industry in 1998. Table 1 also suggests that these 30 firms can be classified into three clusters (group 1, 1–9; group 2, 10–24 (excluding 22); and group 3, 25–30 (including 22)) by the indigenous technology stock ratio (T_i/T_s).

This high-level R&D intensity is indispensable for increasing the R&D investment level as enumerated in Eq. (1):

$$\Delta R/R=\Delta(R/S)/(R/S)+\Delta S/S \quad (1)$$

where R is R&D investment, ΔR (=dR/dt) the change of R&D investment, $\Delta R/R$ the rate of change of R&D investment, S the sales and R/S the R&D intensity.

This R&D intensity formulates technology stock as enumerated in Eq. (2):

$$T_t=R_{t-m}+(1-\rho)T_{t-1}$$
$$T_0=R_{1-m}/(\rho+g) \quad (2)$$

where T_t is the technology stock at time t, m the time-

Table 1
State of sales and R&D structure of 30 R&D intensive Japanese pharmaceutical firms in 1998 (\bil. at 1990 fixed prices)[a,b]

		Sales	R&D expenditure	R&D intensity (%)	Ti	Ti/Ts (%)
1.	Takeda Chemical Industries Ltd.	696.6	69.4	10.0	395.0	16.2
2.	Sankyo Co., Ltd.	503.1	52.1	10.4	233.6	9.0
3.	Yamanouchi Pharmaceutical Co., Ltd.	301.4	42.1	14.0	184.9	7.0
4.	Daiichi Pharmaceutical Co., Ltd.	256.9	30.9	12.0	158.9	5.9
5.	Eisai Co., Ltd.	259.2	34.1	13.2	227.6	8.7
6.	Shionogi & Co., Ltd.	231.2	32.1	14.4	226.0	8.0
7.	Fujisawa Pharmaceutical Co., Ltd.	222.6	32.1	14.4	226.0	8.7
8.	Tanabe Seiyaku Co., Ltd.	196.9	19.3	9.8	150.0	5.6
9.	Chugai Pharmaceutical Co., Ltd.	180.9	28.1	15.5	159.5	6.0
10.	Banyu Pharmaceutical Co., Ltd.	162.7	15.1	9.3	59.2	2.1
11.	Dainippon Pharmaceutical Co., Ltd.	145.9	11.9	8.2	77.9	2.8
12.	Ono Pharmaceutical Co., Ltd.	131.8	16.5	12.5	82.2	3.0
13.	Yoshitomi Pharmaceutical Industries, Ltd.	117.7	10.8	9.2	88.8	3.2
14.	Tsumura & Co.	79.3	8.2	9.9	73.9	2.7
15.	Santen Pharmaceutical Co., Ltd.	80.5	4.6	5.7	20.1	0.7
16.	The Green Cross Corp.	82.6	11.3	14.2	71.0	2.6
17.	Kaken Pharmaceutical Co., Ltd.	70.1	5.0	7.2	46.6	1.7
18.	Mochida Pharmaceutical Co., Ltd.	68.2	8.3	12.2	59.3	2.1
19.	Nikken Chemicals Co., Ltd.	64.8	3.0	4.6	21.8	0.8
20.	Kissei Pharmaceutical Co., Ltd.	57.1	6.6	11.5	32.0	1.1
21.	Nippon Chinyaku Co., Ltd.	52.2	6.9	13.2	51.9	1.9
22.	Fuso Pharmaceutical Ind., Ltd.	47.4	2.1	4.4	13.5	0.5
23.	Tokyo Tanabe Co., Ltd.	48.2	4.6	9.8	27.8	1.0
24.	Toyama Chemical Co., Ltd.	46.9	6.2	13.3	48.8	1.7
25.	Torii Pharmaceutical Ind., Ltd.	43.2	4.1	9.5	17.0	0.6
26.	Fujirebio Inc.	27.3	4.2	15.3	26.5	0.9
27.	Teikoku Hormone Mfg. Co., Ltd.	24.4	4.0	16.4	24.7	0.9
28.	Seikagaku Co., Ltd.	19.3	3.3	17.1	15.5	0.6
29.	Nippon Chemipha Co., Ltd.	18.3	2.0	10.9	12.9	0.5
30.	Hokuriku Seiyaku Co., Ltd.	16.3	3.2	19.9	20.1	0.7
Total 30 firms		4253.0	475.0	11.5	2837.1	3.6
Total pharmaceutical industry		6485.2	613.5	9.5	4340.3	

[a] Japan's 30 leading pharmaceutical firms which are solely responsible for R&D-driven pharmaceutical manufacturing (with the exception of firms which are concerned with other sectorial activities and distribution etc., firms of foreign capital and Japanese subsidiaries).

[b] T_i is the indigenous technology stock and T_s the potential technology spillover pool $\left(=\sum_{j(\neq i)}^{30} T_j\right)$.

lag between R&D and commercialization, ρ the rate of obsolescence of technology, and g the average rate of increase of R&D investment in the initial period.

Thus, R&D intensive firms are able to formulate larger amounts of technology stock than their competitors.

Fig. 1 demonstrates the correlation between technology stock and sales of 30 leading R&D intensive Japanese pharmaceutical firms over the past two decades by dividing them into five periods: 1979–1982 (after the second energy crisis and before the fall of international oil prices); 1983–1986 (after the fall of international oil prices and before the bubble economy); 1987–1990 (during the period of the bubble economy); 1991–1994 (after the bursting of the bubble economy); and 1995–1998 (during the serious stagnation period).

Looking at Fig. 1 we note that there exists a strong correlation between technology stock and sales over the entire period examined. This demonstrates that technology stock is really a source of sales increase for the pharmaceutical industry, compelling these firms to depend on further intensive R&D investment. As enumerated in Eq. (1), the rate of change of R&D investment can be decomposed into the rates of change of sales and R&D intensity.

Fig. 2 demonstrates the cross-sectional correlation between sales and R&D intensity in the 30 R&D intensive Japanese pharmaceutical firms over the past two decades by dividing the activity into five periods, as classified in Fig. 1.

Looking at Fig. 2 we note that the coefficient of this correlation is statistically significant and has a negative value in all five periods examined. These results demonstrate that R&D intensity increases as sales decrease in the 30 R&D intensive Japanese pharmaceutical firms. Furthermore, this suggests that firms with a smaller size of sales endeavor to maintain a high level of R&D investment by increasing R&D intensity at a faster rate than larger firms, complementing the small amount of sales.

3. State of inter-firm technology spillovers

3.1. Measurement of assimilation capacity and spillover technology: numerical approach

The analysis of Fig. 1 suggests that the sales of the pharmaceutical firm (S) can be enumerated as a function of technology stock of the firm (T) as follows:

$$S=S(T) \tag{3}$$

While T is formulated by R, since it is difficult for smaller firms to secure a sufficient level of T by their own R&D investment, they have to depend on technology developed by other firms. Therefore, T should represent technology stock consisting of indigenous technology (T_i) generated by the propriety R&D of the host firm and assimilated spillover technology ($Z{\cdot}T_s$) generated by other firms (donor; Griliches, 1979; Jaffe, 1986).

In line with previous approaches (Cohen and Levinthal, 1989; Watanabe et al., 2001), provided that a firm makes every effort to maximize the contribution of assimilated spillover technology to production by embodying it into the manufacturing processes, T can be decomposed as follows:

$$\begin{aligned} T&=T_i+Z{\cdot}T_s \\ T_s&=(\Sigma_j T_j-T_i) \end{aligned} \tag{4}$$

where T_s is the potential spillover pool, Z the assimilation capacity, and T_j the technology stock in firm j.

Provided that Z is small enough and ZT_s is smaller than T_i, we assume $Z(T_s/T_i)<1$ and $\Delta Z\approx 0$. Therefore, $T(=T_t)$ can be treated as follows:

$$\ln T=\ln T_i\left(1+Z\frac{T_s}{T_i}\right)\approx \ln T_i+Z\frac{T_s}{T_i} \tag{5}$$

Taking time difference of Eq. (5), the following equation is obtained:

$$\frac{\Delta T}{T}=\frac{\Delta T_i}{T_i}+\Delta Z\frac{T_s}{T_i}+Z\Delta\frac{T_s}{T_i}\approx\frac{\Delta T_i}{T_i}+Z\Delta\frac{T_s}{T_i}\ (\because \Delta Z\approx 0) \tag{6}$$

By using this equation, the technology contribution to production change rate can be expressed as follows:

$$\begin{aligned} \frac{\partial S}{\partial T}\cdot\frac{T}{S}\cdot\frac{\Delta T}{T}&=\frac{\partial S}{\partial T_i}\cdot\frac{T_i}{S}\cdot\frac{\Delta T_i}{T_i}+\frac{\partial S}{\partial(Z{\cdot}T_s)}\cdot\frac{Z{\cdot}T_s}{S}\cdot\frac{\Delta(Z{\cdot}T_s)}{Z{\cdot}T_s} \\ &=\frac{\partial S}{\partial T}\cdot\frac{T}{S}\cdot\left(\frac{\Delta T_i}{T_i}+Z\Delta\frac{T_s}{T_i}\right) \end{aligned} \tag{7}$$

Given that the prices are determined in a competitive way,

$$\frac{\partial S}{\partial T}=\frac{P_t}{P_s},\ \frac{\partial S}{\partial T_i}=\frac{P_{ti}}{P_s},\ \frac{\partial S}{\partial(Z{\cdot}T_s)}=\frac{P_{ts}}{P_s}$$

where P_s, P_t, P_{ti} and P_{ts} are prices of S, T, T_i and T_s, respectively.

Define the marginal productivity ratio as follows:

$$\phi=\frac{\partial S/\partial(Z{\cdot}T_s)}{\partial S/\partial T_i}=\frac{P_{ts}}{P_{ti}} \tag{8}$$

$$\phi>1,\ \frac{d^2\phi}{dt^2}<0\ \text{(Diminishing return)}$$

$$P_t=\frac{T_i{\cdot}P_{ti}+Z{\cdot}T_s{\cdot}P_{ts}}{T}=\frac{P_{ti}(T_i+Z{\cdot}\phi{\cdot}T_s)}{T_i+Z{\cdot}T_s} \tag{9}$$

Incorporating these prices in Eq. (7), the following equation can be obtained:

$$\frac{\partial S}{\partial T_i}\cdot\frac{T_i}{S}\cdot\frac{\Delta T_i}{T_i}+\phi\frac{\partial S}{\partial T_i}\cdot\frac{Z{\cdot}T_s}{S}\cdot\frac{\Delta(Z{\cdot}T_s)}{Z{\cdot}T_s}$$

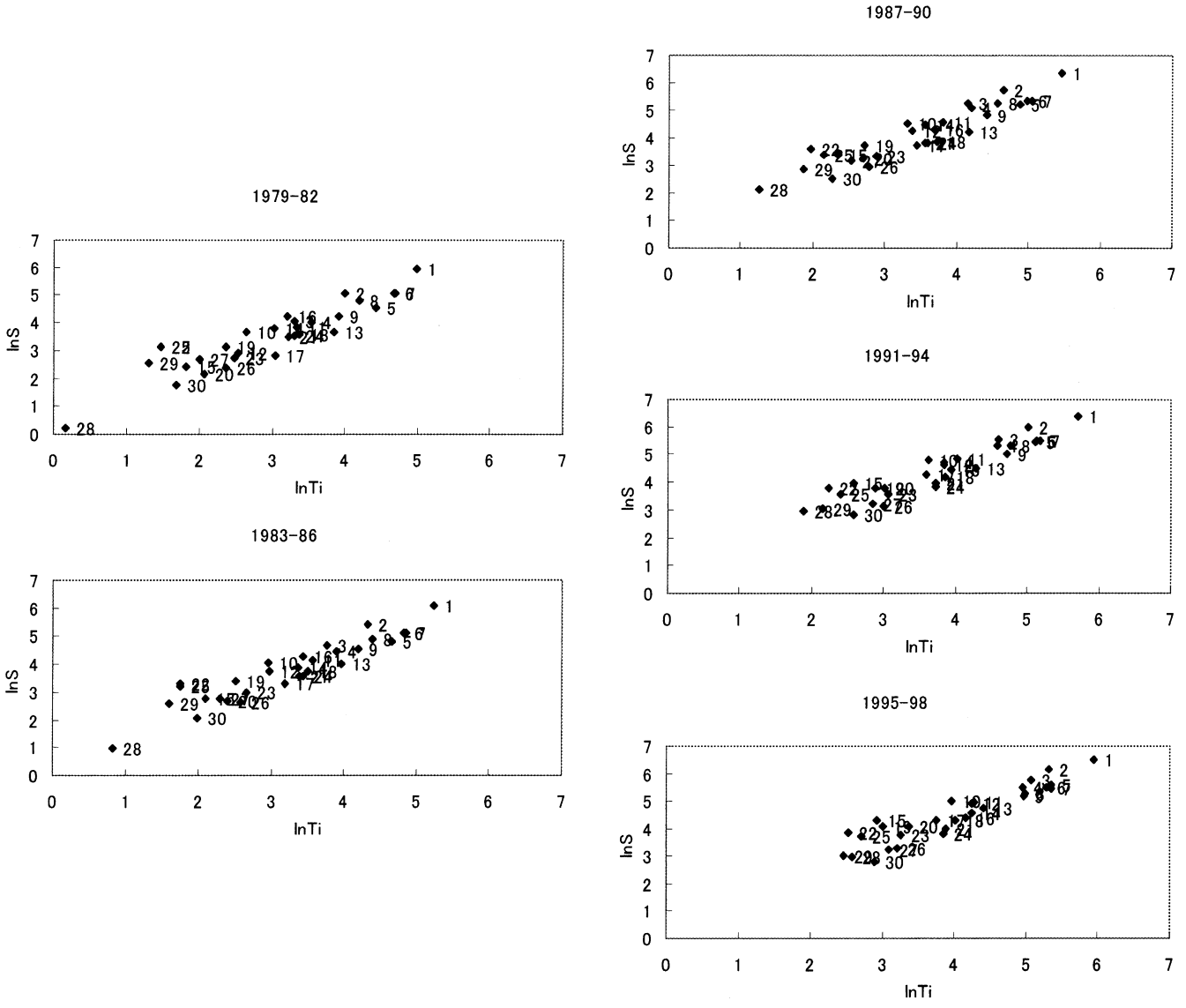


Fig. 1. Correlation between technology stock and sales of 30 R&D intensive Japanese pharmaceutical firms (1979–1998). S, sales at 1990 fixed prices; T_i, the propriety technology stock. Numbers in the plots correspond to numbers of firms in Table 1.

(a) $\ln S = 0.76 + 0.92 \ln T_i$ (11.77) adj. R^2=0.826; DW=2.48.

(b) $\ln S = 0.81 + 0.92 \ln T_i$ (13.10) adj. R^2=0.855; DW=2.31.

(c) $\ln S = 1.08 + 0.88 \ln T_i$ (13.16) adj. R^2=0.856; DW=2.03.

(d) $\ln S = 0.91 + 0.89 \ln T_i$ (12.78) adj. R^2=0.848; DW=1.93.

(e) $\ln S = 1.18 + 0.86 \ln T_i$ (13.10) adj. R^2=0.855; DW=2.00.

$$= \frac{P_{ti}(T_i + Z\cdot\phi\cdot T_s)}{(T_i + Z\cdot T_s)\cdot P_s} \cdot \frac{T_i + Z\cdot T_s}{S} \cdot \left(\frac{\Delta T_i}{T_i} + Z\Delta\frac{T_s}{T_i}\right)\Delta T_i \qquad (10)$$

$$+\phi\Delta(Z\cdot T_s) = (T_i + Z\cdot\phi\cdot T_s)\left(\frac{\Delta T_i}{T_i} + Z\cdot\Delta\frac{T_s}{T_i}\right)$$

$$\phi = \frac{T_i\Delta\dfrac{T_s}{T_i}}{\Delta T_s - \Delta T_i\cdot\dfrac{T_s}{T_i} - Z\cdot T_s\cdot\Delta\dfrac{T_s}{T_i}} = \frac{1}{1 - Z\cdot\dfrac{T_s}{T_i}} \qquad (11)$$

Deriving Z from Eq. (11):

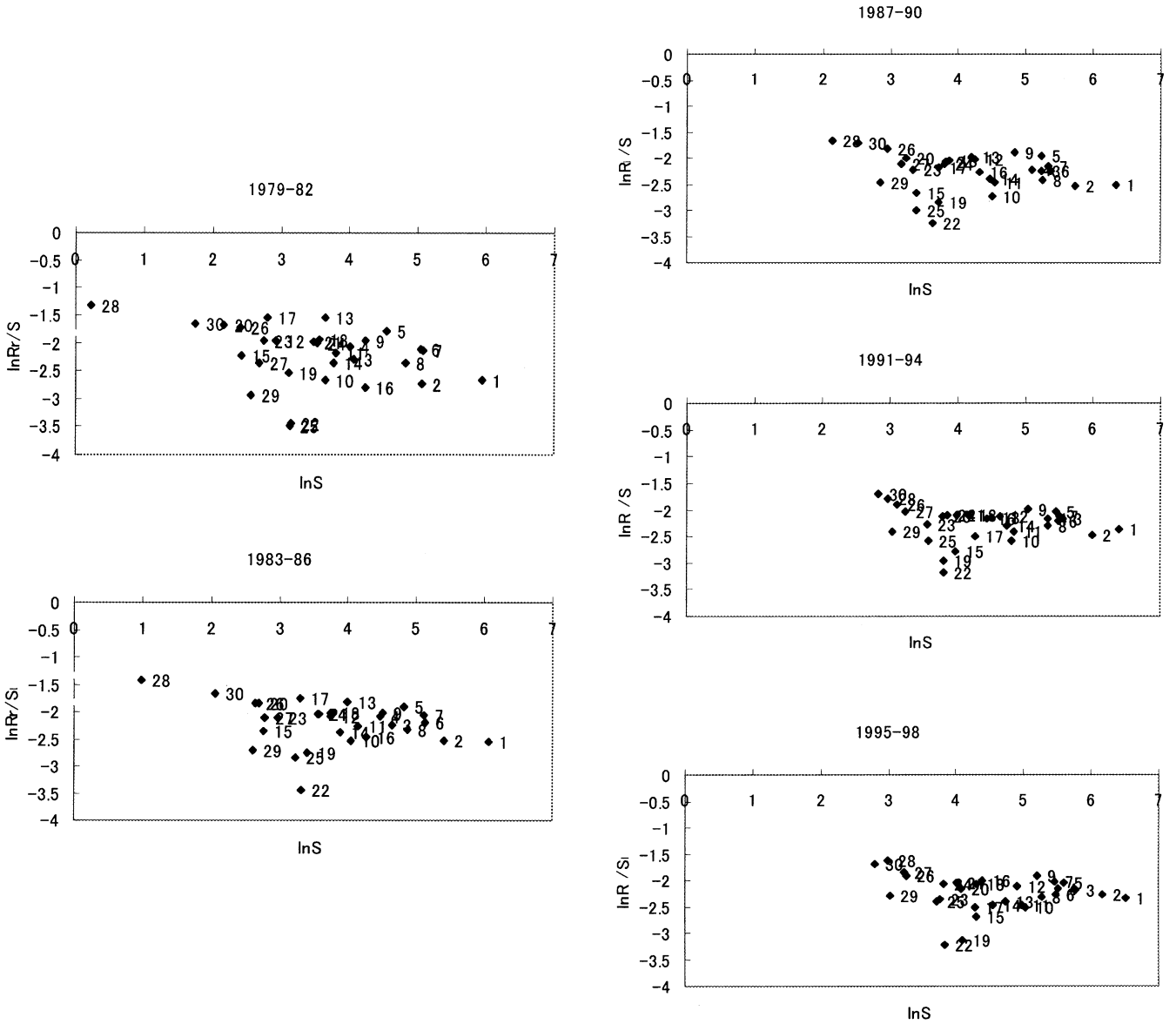


Fig. 2. Correlation between sales and R&D intensity in 30 R&D intensive Japanese pharmaceutical firms (1979–1998). Regression excluding lower R&D firms throughout 20-year period: 19 and 22 depend primarily on external R&D.

(a) $\ln R/S = -1.60 \underset{(-2.25)}{-0.16 \ln S}$ adj. R^2=0.130; DW=2.49.

(b) $\ln R/S = -1.68 \underset{(-2.42)}{-0.12 \ln S}$ adj. R^2=0.152; DW=2.42.

(c) $\ln R/S = -1.82 \underset{(-1.73)}{-0.10 \ln S}$ adj. R^2=0.068; DW=2.42.

(d) $\ln R/S = -1.90 \underset{(-1.49)}{-0.07 \ln S}$ adj. R^2=0.043; DW=2.33.

(e) $\ln R/S = -1.76 \underset{(-1.95)}{-0.09 \ln S}$ adj. R^2=0.095; DW=2.16.

$$Z=\left(1-\frac{1}{\phi}\right)\cdot\frac{T_i}{T_s},\ 0<Z<T_i/T_s \tag{12}$$

Since the production (sales, S) of the pharmaceutical industry can be depicted by a function of technology as indicated in Eq. (3), taking the time difference of Eq. (3), the change in sales can be expressed by technology stock alone as follows:

$$\frac{dS}{dt}=\frac{\partial S}{\partial T}\cdot\frac{dT}{dt} \tag{13}$$

Since the host firm, in order to maximize the effect of ZT_s, treats T_i and ZT_s homogeneously (Watanabe et al., 2001), T_i and ZT_s behave in line with Eq. (13) as follows:

$$\frac{dS}{dt}=\frac{\partial S}{\partial T_i}\cdot\frac{dT_i}{dt} \tag{14}$$

$$\frac{dS}{dt}=\frac{\partial S}{\partial (ZT_s)}\cdot\frac{d(ZT_i)}{dt}\approx\frac{\partial S}{\partial (ZT_s)}\cdot\frac{Z dT_s}{dt} \tag{15}$$

$\because$ is Z small and $\because \Delta Z\approx 0$.

From Eqs. (14) and (15) the marginal productivity of T_i and ZT_s can be obtained as follows:

$$\frac{\partial S}{\partial T_i}=\frac{\Delta S}{\Delta T_i} \tag{16}$$

$$\frac{\partial S}{\partial (ZT_s)}=\frac{\Delta S}{Z\Delta T_s} \tag{17}$$

Incorporating Eqs. (16) and (17) in Eq. (8), ϕ can be measured as follows:

$$\phi=\frac{\Delta S/Z\Delta T_s}{\Delta S/\Delta T_i}=\frac{\Delta T_i}{Z\Delta T_s} \tag{18}$$

Incorporating Eq. (18) in Eq. (12),

$$Z=\left(1-\frac{Z\Delta T_s}{\Delta T_i}\right)\cdot\frac{T_i}{T_s} \tag{19}$$

From Eq. (19) Z can be measured as follows:

$$Z=\frac{\Delta T_i\cdot T_i}{\Delta T_i\cdot T_s+\Delta T_s\cdot T_i}=\frac{T_i}{T_s}\cdot\frac{\Delta T_i}{\Delta T_i+\frac{\Delta T_s}{T_s}\cdot T_i}=\frac{1}{1+\frac{\Delta T_s}{T_s}\Big/\frac{\Delta T_i}{T_i}}\cdot\frac{T_i}{T_s} \tag{20}$$

3.2. Trends in assimilation capacity and assimilated spillover technology: empirical analysis

Results of the measurement of the assimilation capacity of the 30 R&D intensive Japanese pharmaceutical firms over the period 1979–1998 by using Eq. (19) is summarized in Table 2 and illustrated in Fig. 3. Table 2 and Fig. 3 demonstrate that the level of assimilation capacity can be also classified into three clusters corresponding to the same clusters classified according to the indigenous technology stock ratio.

Tables 3 and 4 and Fig. 4 summarize trends in dependency on assimilated spillover technology ($ZT_s/(T_i+ZT_s)$) in the 30 R&D intensive Japanese pharmaceutical firms over the period 1979–1998. Looking at Tables 3 and 4, we note that all 30 firms depend nearly 30% on assimilated spillover technology. This high level of dependency demonstrates the technology-driven nature of the pharmaceutical industry which demands a maximum utilization of spillover technology. While this dependency in large firms generally demonstrates a decreasing trend, the dependency in smaller firms demonstrates an increasing trend.

4. Optimal dependency between indigenous technology and spillover technology

4.1. Numerical approach

Given the rates of change of indigenous technology stock (T_i) and technology stock in the potential spillover pool (T_s), g_i and g_s, respectively, and the ratio between them, w, the assimilation capacity in time t (Z_t) can be expressed by the following equation:

$$Z_t=\frac{1}{1+\frac{1}{w}}\cdot\frac{T_i}{T_s}=\frac{w}{w+1}\cdot\frac{T_{i0}\cdot e^{g_i t}}{T_{s0}\cdot e^{g_s t}}=\left(\frac{T_{i0}}{T_{s0}}\right)\cdot\frac{w}{w+1}\cdot e^{(w-1)g_s t} \tag{21}$$

where $g_i=(\Delta T_i)/T_i$, $g_s=(\Delta T_s)/T_s$, $w=\frac{g_i}{g_s}$, and T_{i0} and T_{s0} are the initial stages of T_i and T_s, respectively.

Utilizing this equation, the technology stock at time t (T_t) in Eq. (4) can be expressed as follows:

$$T_t=T_i+ZT_s=T_i\left(1+\frac{w}{w+1}\right)=T_{i0}\cdot\frac{2w+1}{w+1}\cdot e^{w\cdot g_s\cdot t} \tag{22}$$

Given the production function (Eq. (3)) solely with technology (T_t), which is demonstrated by the empirical analysis using the assimilation capacity measured in Section 3.2 (see Appendix A), sales at time t (S_t) can be depicted by the simple Cobb–Douglas-type function as follows:

$$S_t=AT_t^{\alpha}=AT_{i0}^{\alpha}\left(\frac{2w+1}{w+1}\right)^{\alpha} e^{\alpha\cdot w\cdot g_s\cdot t} \tag{23}$$

where A is a scale factor and α is elasticity.

Since R&D expenditure of the host at time t (R_t) can be approximated by Eq. (24), R&D productivity (sales by unit R&D investment) can be depicted by Eq. (25):

$$R_t\approx\Delta T_i=g_i T_i=T_{i0}\cdot g_i\cdot e^{g_i t}=T_{i0} w g_s\cdot e^{w g_s t} \tag{24}$$

Table 2
Trends in assimilation capacity in 30 R&D intensive Japanese pharmaceutical firms (1979–1998)

		1979	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	1992
1	Takeda Chemical Industries Ltd.	0.0891	0.0958	0.0996	0.1018	0.1029	0.1312	0.0873	0.0857	0.0859	0.0895	0.0852	0.0852	0.0852	0.0893	0.0889
2	Sankyo Co., Ltd.	0.0322	0.0324	0.0333	0.0343	0.0353	0.0376	0.0322	0.0358	0.0382	0.0439	0.0465	0.0487	0.0491	0.0461	0.0428
3	Yamanouchi Pharmaceutical Co., Ltd.	0.0172	0.0175	0.0185	0.0195	0.0206	0.0266	0.0181	0.0217	0.0237	0.0267	0.0283	0.0297	0.0313	0.0329	0.0373
4	Daiichi Pharmaceutical Co., Ltd.	0.0202	0.0204	0.0211	0.0218	0.0225	0.0281	0.0209	0.0218	0.0210	0.0255	0.0277	0.0292	0.0294	0.0315	0.0322
5	Eisai Co., Ltd.	0.0424	0.0421	0.0423	0.0425	0.0427	0.0381	0.0456	0.0453	0.0453	0.0419	0.0395	0.0408	0.0448	0.0459	0.0463
6	Shionogi & Co., Ltd.	0.0430	0.0426	0.0421	0.0415	0.0409	0.0166	0.0547	0.0463	0.0389	0.0345	0.0386	0.0388	0.0350	0.0312	0.0309
7	Fujisawa Pharmaceutical Co., Ltd.	0.0463	0.0459	0.0454	0.0450	0.0445	0.0056	0.0556	0.0539	0.0532	0.0483	0.0461	0.0354	0.0308	0.0334	0.0353
8	Tanabe Seiyaku Co., Ltd.	0.0366	0.0373	0.0371	0.0367	0.0362	0.0452	0.0346	0.0264	0.0250	0.0299	0.0277	0.0243	0.0237	0.0275	0.0290
9	Chugai Pharmaceutical Co., Ltd.	0.0366	0.0373	0.0371	0.0367	0.0362	0.0452	0.0346	0.0264	0.0250	0.0299	0.0277	0.0243	0.0237	0.0275	0.0290
10	Banyu Pharmaceutical Co., Ltd.	0.0079	0.0079	0.0081	0.0083	0.0086	0.0076	0.0077	0.0105	0.0108	0.0106	0.0104	0.0106	0.0103	0.0102	0.0098
11	Dainippon Pharmaceutical Co., Ltd.	0.0136	0.0135	0.0136	0.0137	0.0137	0.0108	0.0143	0.0150	0.0148	0.0157	0.0149	0.0148	0.0151	0.0099	0.0117
12	Ono Pharmaceutical Co., Ltd.	0.0078	0.0079	0.0083	0.0088	0.0092	0.0108	0.0079	0.0104	0.0115	0.0109	0.0126	0.0137	0.0149	0.0161	0.0157
13	Yoshitomi Pharmaceutical Industries, Ltd.	0.0173	0.0172	0.0169	0.0167	0.0164	0.0189	0.0214	0.0234	0.0232	0.0191	0.0148	0.0140	0.0134	0.0116	0.0092
14	Tsumura & Co.	0.0110	0.0110	0.0112	0.0115	0.0117	0.0174	0.0122	0.0074	0.0072	0.0084	0.0109	0.0109	0.0119	0.0124	0.0142
15	Santen Pharmaceutical Co., Ltd.	0.0031	0.0031	0.0032	0.0032	0.0033	0.0039	0.0033	0.0032	0.0031	0.0035	0.0035	0.0031	0.0027	0.0033	0.0038
16	The Green Cross Corp.	0.0121	0.0121	0.0122	0.0122	0.0123	0.0092	0.0126	0.0131	0.0139	0.0143	0.0143	0.0135	0.0127	0.0125	0.0123
17	Kaken Pharmaceutical Co., Ltd.	0.0087	0.0087	0.0086	0.0086	0.0085	0.0091	0.0096	0.0108	0.0116	0.0097	0.0095	0.0094	0.0071	0.0058	0.0044
18	Mochida Pharmaceutical Co., Ltd.	0.0114	0.0113	0.0112	0.0111	0.0109	0.0121	0.0133	0.0146	0.0150	0.0127	0.0096	0.0092	0.0080	0.0075	0.0082
19	Nikken Chemicals Co., Ltd.	0.0041	0.0041	0.0041	0.0040	0.0040	0.0044	0.0049	0.0047	0.0047	0.0041	0.0036	0.0036	0.0036	0.0039	0.0036
20	Kissei Pharmaceutical Co., Ltd.	0.0044	0.0044	0.0045	0.0046	0.0047	0.0055	0.0045	0.0046	0.0053	0.0047	0.0054	0.0057	0.0058	0.0057	0.0055
21	Nippon Shinyaku Co., Ltd.	0.0099	0.0099	0.0098	0.0097	0.0096	0.0032	0.0118	0.0107	0.0101	0.0100	0.0091	0.0087	0.0089	0.0088	0.0080
22	Fuso Pharmaceutical Ind., Ltd.	0.0022	0.0022	0.0022	0.0022	0.0022	0.0027	0.0023	0.0021	0.0021	0.0018	0.0021	0.0020	0.0023	0.0028	0.0026
23	Tokyo Tanabe Co., Ltd.	0.0051	0.0051	0.0051	0.0051	0.0050	0.0014	0.0056	0.0068	0.0059	0.0037	0.0043	0.0053	0.0055	0.0045	0.0038
24	Toyama Chemical Co., Ltd.	0.0119	0.0119	0.0115	0.0111	0.0107	0.0060	0.0125	0.0106	0.0101	0.0074	0.0082	0.0087	0.0077	0.0070	0.0071
25	Torii Pharmaceutical Ind., Ltd.	0.0024	0.0024	0.0024	0.0025	0.0025	0.0014	0.0023	0.0030	0.0028	0.0042	0.0038	0.0027	0.0023	0.0020	0.0021
26	Fujirebio Inc.	0.0048	0.0047	0.0047	0.0047	0.0047	0.0040	0.0053	0.0048	0.0048	0.0042	0.0048	0.0048	0.0047	0.0049	0.0050
27	Teikoku Hormone Mfg. Co., Ltd.	0.0038	0.0038	0.0039	0.0039	0.0040	0.0044	0.0040	0.0033	0.0034	0.0042	0.0047	0.0053	0.0051	0.0045	0.0044
28	Seikagaku Co., Ltd.	0.0008	0.0008	0.0009	0.0010	0.0010	0.0016	0.0010	0.0011	0.0012	0.0015	0.0015	0.0016	0.0021	0.0024	0.0027
29	Nippon Chemipha. Co., Ltd.	0.0019	0.0019	0.0020	0.0020	0.0020	0.0023	0.0020	0.0023	0.0022	0.0018	0.0020	0.0019	0.0022	0.0027	0.0025
30	Hokuriku Seiyaku Co., Ltd.	0.0029	0.0029	0.0029	0.0030	0.0031	0.0032	0.0029	0.0035	0.0034	0.0027	0.0032	0.0040	0.0039	0.0037	0.0034

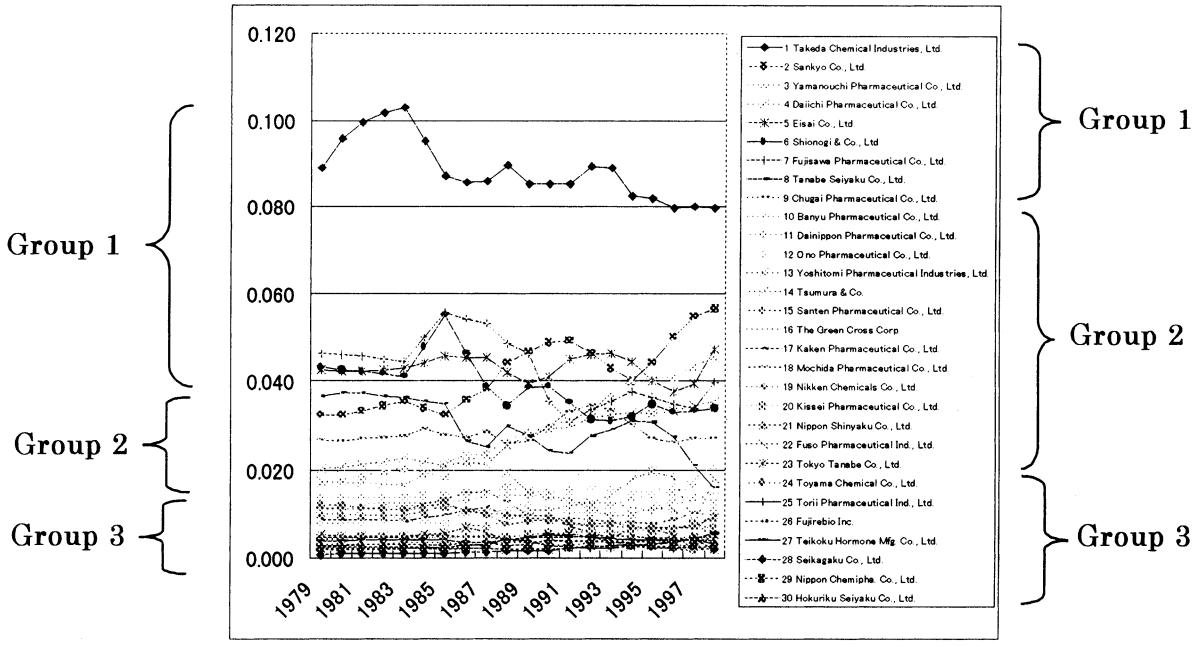


Fig. 3. Trends in assimilation capacity in 30 R&D intensive Japanese pharmaceutical firms (1979–1998).

$$\frac{S_t}{R_t}=AT_{i0}^{\alpha-1}\left(\frac{2w+1}{w+1}\right)^{\alpha}\frac{1}{w}e^{(\alpha-1)wg_s t} \tag{25}$$

R&D intensity is the reverse of Eq. (25).

4.2. Numerical simulation

In order to estimate the general trajectories of R&D intensive pharmaceutical firms in dynamic games of spillover and assimilation, first, based on Eqs. (20)–(24) with normalization and taking 30 R&D intensive Japanese pharmaceutical firms over the period 1991–1994, numerical simulation was conducted with following conditions:

$$Z=\frac{w}{w+1}e^{(w-1)\cdot g_s\cdot t} \tag{21a}$$

$$T=\frac{2w+1}{w+1}e^{w\cdot g_s\cdot t} \tag{22a}$$

$$(T_i=e^{w\cdot g_s\cdot t})$$

$$S=\left(\frac{2w+1}{w+1}\right)^{\alpha}e^{\alpha\cdot w\cdot g_s\cdot t} \tag{23a}$$

$$R=w\cdot g_s\cdot e^{w\cdot g_s\cdot t} \tag{24a}$$

$$\frac{S}{R}=\left(\frac{2w+1}{w+1}\right)^{\alpha}\frac{1}{w}e^{(\alpha-1)w\cdot g_s\cdot t} \tag{25a}$$

where $t=13.5\left(\sum_{1991}^{1994}(\text{year}-1979)/4\right)$ and $\alpha=1.0$–1.6.

The results are illustrated in the left hand side of Figs. 5–10. Looking at Fig. 5 we note that indigenous technology stock contributes significantly to sales increase as postulated in Eq. (3). This result corresponds to the analysis in Fig. 1.

Increase in indigenous technology stock also contributes to an increase in the assimilation capacity as illustrated in Fig. 6.

Thus, as the multiplier impacts, the total technology stock, which consists of indigenous and assimilated spillover technology, provides a greater contribution to sales increase as illustrated in Fig. 7. This result also corresponds to the analysis in Appendix A.

Through the analyses on Figs. 5–7, we assume that the assimilation capacity increase provides a significant increase in sales. This assumption is demonstrated by Fig. 8. This analysis provides evidence of the significance of assimilation capacity in the pharmaceutical industry for sales increase.

However, Fig. 9 demonstrates that the increase in assimilation capacity reacts to a decrease in R&D productivity in the stage when its level is low. This negative reaction becomes positive when the assimilation capacity exceeds certain levels. This analysis provides additional evidence of the enthusiasm of the pharmaceutical firms, particularly smaller firms, to increase assimilation capacity by intensive R&D investment aimed at reaching a level enabling them to make the most out of R&D productivity.

Fig. 10 provides further supporting evidence of the high level of R&D intensity in the pharmaceutical firms as it demonstrates that, as a result of the increase in R&D intensity, after reaching a certain level of assimilation capacity, it continues to further increase without depending on the further increase in R&D intensity.

Table 3
Trends in dependency on assimilated spillover technology in 30 R&D intensive Japanese pharmaceutical firms (1979–1988)[a]

		1979	1980	1981	1982	1983	1984	1985	1986	1987	1988
1	Takeda Chemical Industries, Ltd.	0.4346	0.4265	0.4158	0.4056	0.3959	0.3527	0.3413	0.3298	0.3306	0.3392
2	Sankyo Co., Ltd.	0.3527	0.3512	0.3545	0.3574	0.3600	0.3438	0.3489	0.3539	0.3642	0.3884
3	Yamanouchi Pharmaceutical Co., Ltd.	0.3841	0.3799	0.3827	0.3853	0.3875	0.3480	0.3584	0.3687	0.3808	0.3979
4	Daiichi Pharmaceutical Co., Ltd.	0.3585	0.3565	0.3597	0.3625	0.3649	0.3415	0.3414	0.3413	0.3328	0.3719
5	Eisai Co., Ltd.	0.3022	0.3044	0.3082	0.3115	0.3145	0.3262	0.3293	0.3324	0.3325	0.3169
6	Shionogi & Co., Ltd.	0.2432	0.2485	0.2527	0.2565	0.2598	0.3041	0.3023	0.3006	0.2702	0.2525
7	Fujisawa Pharmaceutical Co., Ltd.	0.2547	0.2595	0.2637	0.2674	0.2707	0.3103	0.3188	0.3272	0.3252	0.3067
8	Tanabe Seiyaku Co., Ltd.	0.3816	0.3776	0.3699	0.3626	0.3556	0.3382	0.3094	0.2806	0.2743	0.3134
9	Chugai Pharmaceutical Co.,	0.3962	0.4022	0.4018	0.3996	0.3960	0.3891	0.3558	0.3226	0.3100	0.3512
10	Banyu Pharmaceutical Co., Ltd.	0.3508	0.3495	0.3526	0.3554	0.3578	0.3459	0.3699	0.3940	0.3893	0.3795
11	Dainippon Pharmaceutical Co., Ltd.	0.3062	0.3081	0.3117	0.3149	0.3177	0.3286	0.3351	0.3417	0.3384	0.3498
12	Ono Pharmaceutical Co., Ltd.	0.3809	0.3769	0.3797	0.3822	0.3843	0.3508	0.3684	0.3861	0.3979	0.3781
13	Yoshitomi Pharmaceutical Industries, Ltd.	0.2413	0.2465	0.2505	0.2539	0.2570	0.3066	0.3288	0.3510	0.3472	0.3067
14	Tsumura & Co.	0.3362	0.3359	0.3393	0.3422	0.3448	0.3285	0.2843	0.2401	0.2394	0.2744
15	Santen Pharmaceutical Co., Ltd.	0.3265	0.3270	0.3165	0.3333	0.3359	0.3314	0.3280	0.3245	0.3218	0.3436
16	The Green Cross Corp.	0.3114	0.3129	0.2826	0.3196	0.3223	0.3311	0.3361	0.3410	0.3521	0.3561
17	Kaken Pharmaceutical Co., Ltd.	0.2752	0.2789	0.2665	0.2859	0.2888	0.3203	0.3384	0.3565	0.3676	0.3280
18	Mochida Pharmaceutical Co., Ltd.	0.2582	0.2627	0.2672	0.2699	0.2728	0.3127	0.3321	0.3515	0.3536	0.3182
19	Nikken Chemicals Co., Ltd.	0.2591	0.2635	0.3486	0.2706	0.2735	0.3114	0.3188	0.3263	0.3234	0.2979
20	Kissei Pharmaceutical Co., Ltd.	0.3465	0.3455	0.2694	0.3514	0.3539	0.3390	0.3379	0.3369	0.3666	0.3371
21	Nippon Shinyaku Co., Ltd.	0.2613	0.2656	0.3244	0.2728	0.2757	0.3115	0.3127	0.3139	0.3038	0.3042
22	Fuso Pharmaceutical Ind., Ltd.	0.3200	0.3210	0.2892	0.3274	0.3300	0.3288	0.3213	0.3139	0.3119	0.2836
23	Tokyo Tanabe Co., Ltd.	0.2822	0.2855	0.2958	0.2924	0.2953	0.3210	0.3453	0.3696	0.3384	0.2448
24	Toyama Chemical Co., Ltd.	0.2963	0.2988	0.3461	0.2927	0.2896	0.3170	0.3090	0.3010	0.2937	0.2403
25	Torii Pharmaceutical Ind., Ltd.	0.3436	0.3429	0.2984	0.3489	0.3513	0.3472	0.3686	0.3901	0.3677	0.4369
26	Tujirebio Inc.	0.2921	0.2948	0.2984	0.3016	0.3044	0.3220	0.3183	0.3147	0.3174	0.2912
27	Teikoku Hormone Mfg. Co., Ltd.	0.3276	0.3280	0.3314	0.3344	0.3369	0.3333	0.3135	0.2937	0.3065	0.3479
28	Seikagaku Co., Ltd.	0.4124	0.4053	0.4075	0.4095	0.4113	0.3430	0.3502	0.3575	0.3759	0.4127
29	Nippon Chemical Co., Ltd.	0.3324	0.3325	0.3358	0.3387	0.3412	0.3350	0.3458	0.3566	0.3476	0.3029
30	Hokuriku Seiyaku Co., Ltd.	0.3394	0.3389	0.3422	0.3450	0.3475	0.3389	0.3545	0.3702	0.3591	0.3095

[a] Dependency on assimilated spillover technology $= \frac{ZT_s}{T_i+ZT_s}$.

This provides a reasonable explanation that firms with a smaller size of sales endeavor to increase R&D intensity while the R&D intensity of the top-level firms is not necessarily high despite their high level of sales.

4.3. Empirical analysis

By utilizing the equations developed in Section 4.1, empirical analyses of the optimal dependency between indigenous technology stock and spillover technology in 30 R&D intensive Japanese pharmaceutical firms over the period 1979–1998 were conducted by dividing this period into five periods: 1979–1982; 1983–1986; 1987–1990; 1991–1994; and 1995–1998.

The results of the analysis in the period 1991–1994 are illustrated in the right hand side of Figs 5A–10A. Similar results are obtained in the other periods. All supporting observations are obtained by numerical simulation. Figure 5 demonstrates that the indigenous technology stock contributes significantly to sales increase in all of the firms examined. Figure 5 indicates that this contribution is more significant in larger firms (group 1) than smaller firms (group 2).

Figure 6 demonstrates that an increase in indigenous technology is the major source of assimilation capacity increase. Furthermore, the magnitude in large firms is more significant than in smaller firms in this case.

Similar to Fig. 5, Fig. 7 demonstrates the contribution of total technology stock to sales increase. Compared to Fig. 5, Fig. 7 demonstrates that total technology stock's contribution to sales increase is more significant in smaller firms.

Figure 8 demonstrates the significant contribution of assimilation capacity to sales increase. Contrary to the previous analyses, this contribution in smaller firms is slightly higher than the contribution in large firms.

Figure 9 demonstrates the postulates indicated by the numerical simulation that an increase in the assimilation

Table 4
Trends in dependency on assimilated spillover technology in 30 R&D intensive Japanese pharmaceutical firms (1989–1998)[a]

		1989	1990	1991	1992	1993	1994	1995	1996	1997	1998
1	Takeda Chemical Industries, Ltd.	0.3287	0.3291	0.3295	0.3393	0.3376	0.3221	0.3219	0.3180	0.3201	0.3302
2	Sankyo Co., Ltd.	0.3927	0.3932	0.3858	0.3656	0.3467	0.3313	0.3508	0.3735	0.3862	0.3855
3	Yamanouchi Pharmaceutical Co., Ltd.	0.4001	0.3999	0.3989	0.3974	0.4103	0.4117	0.3992	0.3907	0.3951	0.3936
4	Daiichi Pharmaceutical Co., Ltd.	0.3839	0.3874	0.3809	0.3867	0.3830	0.3797	0.3717	0.3702	0.3737	0.3733
5	Eisai Co., Ltd.	0.3063	0.3151	0.3356	0.3402	0.3409	0.3316	0.3119	0.3013	0.3129	0.3509
6	Shionogi & Co., Ltd.	0.2782	0.2831	0.2681	0.2527	0.2563	0.2688	0.2887	0.2823	0.2905	0.2962
7	Fujisawa Pharmaceutical Co., Ltd.	0.2996	0.2527	0.2339	0.2548	0.2706	0.2866	0.2855	0.2807	0.2797	0.3143
8	Tanabe Seiyaku Co., Ltd.	0.2997	0.2777	0.2775	0.3105	0.3231	0.3372	0.3341	0.3125	0.2601	0.1216
9	Chugai Pharmaceutical Co.,	0.3347	0.3048	0.2944	0.3199	0.3279	0.3422	0.3414	0.3200	0.2632	0.1149
10	Banyu Pharmaceutical Co., Ltd.	0.3686	0.3687	0.3593	0.3531	0.3422	0.3359	0.3695	0.3936	0.3979	0.3374
11	Dainippon Pharmaceutical Co., Ltd.	0.3382	0.3351	0.3399	0.2578	0.2950	0.3257	0.3365	0.3468	0.3600	0.3043
12	Ono Pharmaceutical Co., Ltd.	0.4006	0.4058	0.4090	0.4090	0.3918	0.3731	0.3677	0.3817	0.3891	0.4151
13	Yoshitomi Pharmaceutical Industries, Ltd.	0.2607	0.2543	0.2522	0.2322	0.2011	0.2173	0.2534	0.2449	0.1923	0.3576
14	Tsumura & Co.	0.3278	0.3297	0.3462	0.3530	0.3774	0.4128	0.4153	0.3901	0.2181	0.1988
15	Santen Pharmaceutical Co., Ltd.	0.3427	0.3195	0.2929	0.3376	0.3631	0.3697	0.3732	0.3824	0.3962	0.4884
16	The Green Cross Corp.	0.3534	0.3400	0.3275	0.3248	0.3220	0.3088	0.3029	0.3260	0.3421	0.3620
17	Kaken Pharmaceutical Co., Ltd.	0.3234	0.3231	0.2703	0.2380	0.1992	0.2682	0.2867	0.2897	0.2904	0.3605
18	Mochida Pharmaceutical Co., Ltd.	0.2660	0.2623	0.2419	0.2365	0.2583	0.2611	0.2580	0.2852	0.3207	0.3113
19	Nikken Chemicals Co., Ltd.	0.2747	0.2812	0.2874	0.3055	0.2919	0.2569	0.2108	0.2184	0.1754	0.2209
20	Kissei Pharmaceutical Co., Ltd.	0.3663	0.3720	0.3712	0.3628	0.3517	0.3689	0.3698	0.3748	0.3974	0.2292
21	Nippon Shinyaku Co., Ltd.	0.2891	0.2831	0.2916	0.2930	0.2783	0.2590	0.2510	0.2638	0.2887	0.3319
22	Fuso Pharmaceutical Ind., Ltd.	0.3154	0.3118	0.3417	0.3778	0.3599	0.3551	0.3594	0.3388	0.3471	0.2908
23	Tokyo Tanabe Co., Ltd.	0.2787	0.3252	0.3338	0.2955	0.2625	0.2563	0.3064	0.3202	0.2833	0.3426
24	Toyama Chemical Co., Ltd.	0.2637	0.2780	0.2600	0.2492	0.2580	0.2578	0.2555	0.2170	0.0954	0.2280
25	Torii Pharmaceutical Ind., Ltd.	0.3988	0.3200	0.2951	0.2728	0.2870	0.3425	0.3569	0.3745	0.4131	0.3392
26	Tujirebio Inc.	0.3199	0.3215	0.3200	0.3306	0.3318	0.3278	0.3042	0.2461	0.2197	0.3731
27	Teikoku Hormone Mfg. Co., Ltd.	0.3723	0.3885	0.3733	0.3449	0.3357	0.3271	0.3143	0.3193	0.3370	0.3827
28	Seikagaku Co., Ltd.	0.3931	0.3969	0.4333	0.4337	0.4318	0.4299	0.4254	0.4320	0.4411	0.2594
29	Nippon Chemical Co., Ltd.	0.3291	0.3261	0.3525	0.3848	0.3663	0.3587	0.3594	0.3369	0.3490	0.3433
30	Hokuriku Seiyaku Co., Ltd.	0.3465	0.3851	0.3729	0.3592	0.3381	0.3463	0.3493	0.3670	0.3804	0.3410

[a] Dependency on assimilated spillover technology $= \frac{ZT_s}{T_i+ZT_s}$.

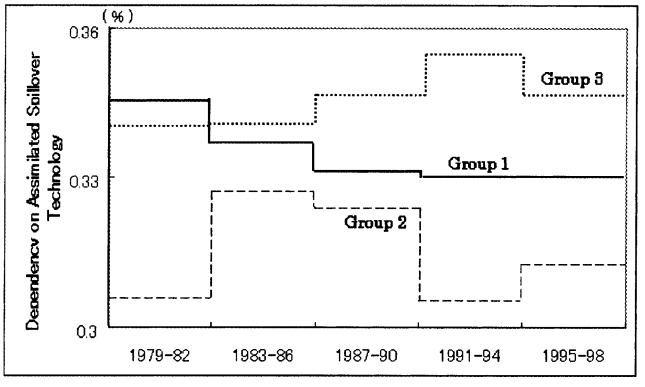


Fig. 4. Trends in dependency on assimilation spillover technology in major R&D intensive Japanese pharmaceutical firms in five periods (1979–1998).

capacity reacts to decreases in R&D productivity in the initial stage but becomes positive when the assimilation capacity exceeds certain levels. This inflection point can be clearly observed between smaller firms in group 2 and large firms in group 1. Figure 10 demonstrates that, as a result of the increase in R&D intensity, after reaching a certain level of the assimilation capacity, it contributes to a further increase without depending on the further increase in R&D intensity. This inflection point with respect to the assimilation capacity level can be observed between smaller firms in group 2 and large firms in group 1. It is generally observed in large firms that they can enjoy the benefit of spillover not only flowing from their own R&D but also by autonomous contributions by suppliers and other depend firms.

All these analyses demonstrate the significance of the numerical approach developed in Section 3.1 and findings on the structural sources of the high level of R&D intensity in the pharmaceutical industry.

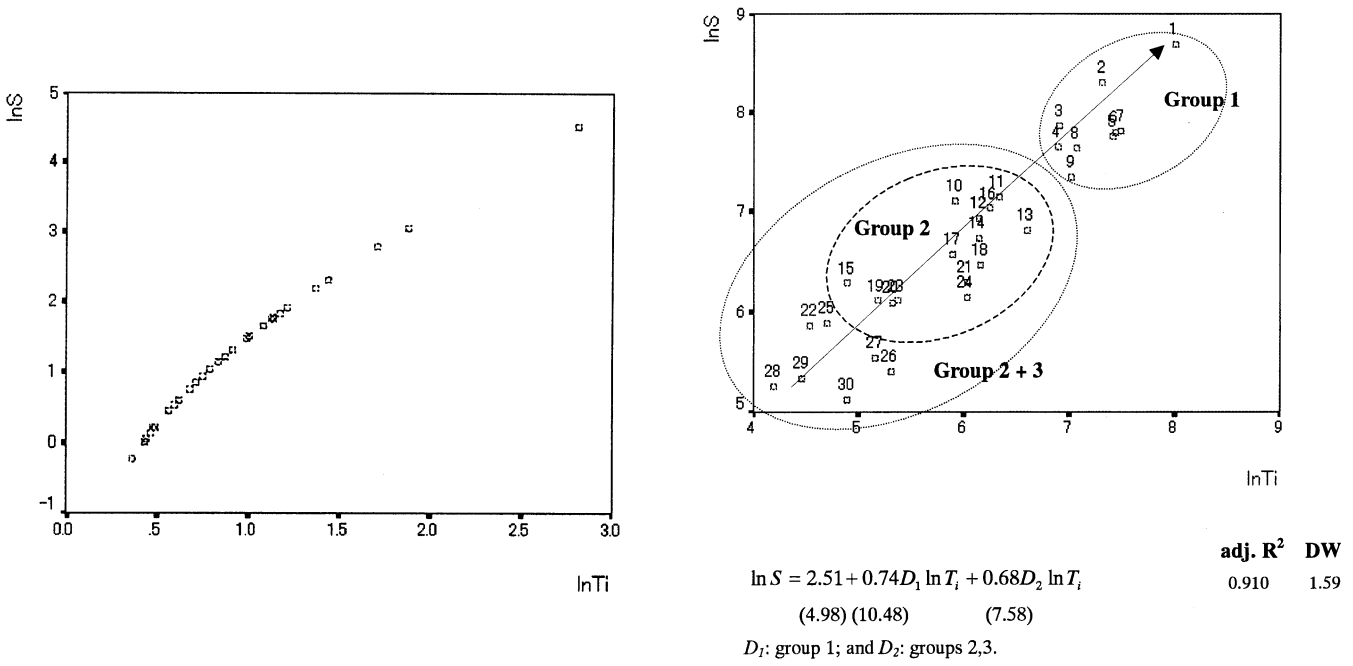


Fig. 5. Correlation between indigenous technology stock and sales in 30 R&D intensive Japanese pharmaceutical firms (1991–1994).

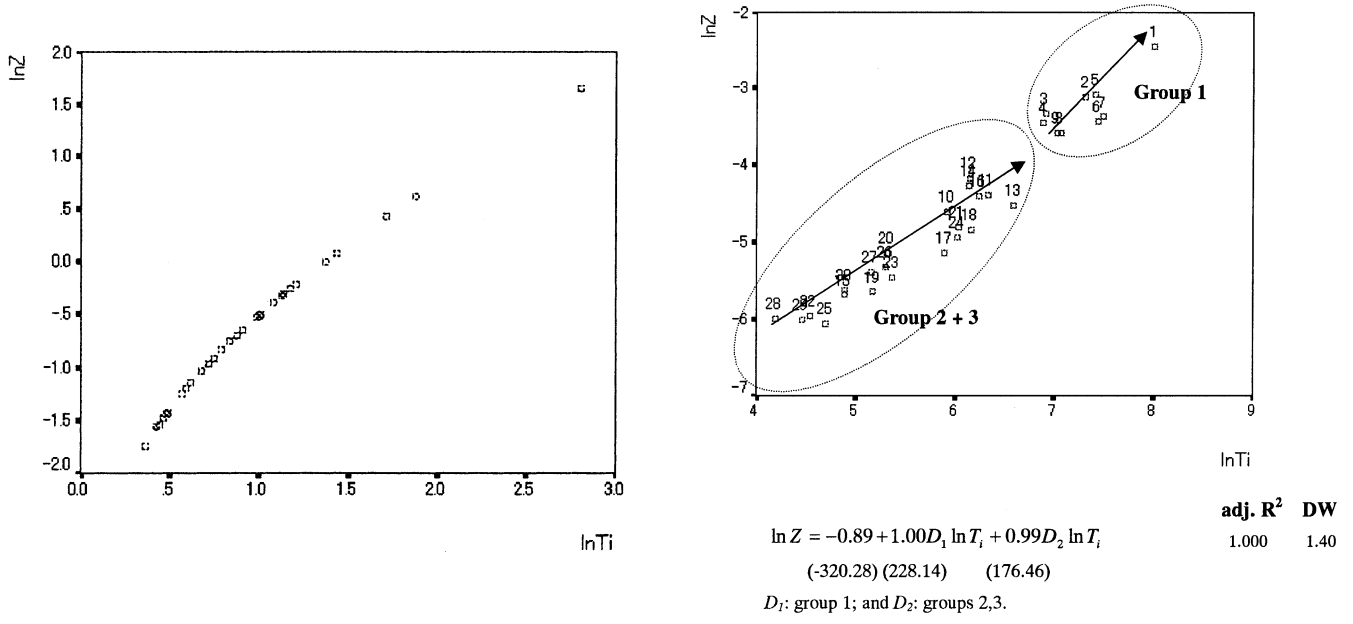


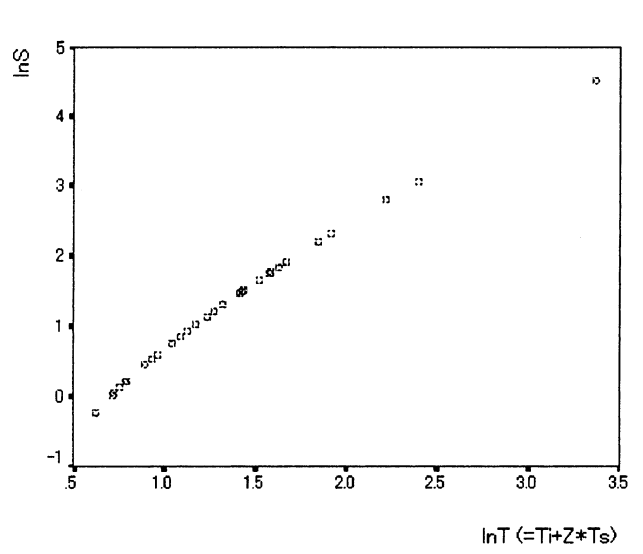
Fig. 6. Correlation between indigenous technology stock and assimilation capacity in 30 R&D intensive Japanese pharmaceutical firms (1991–1994).

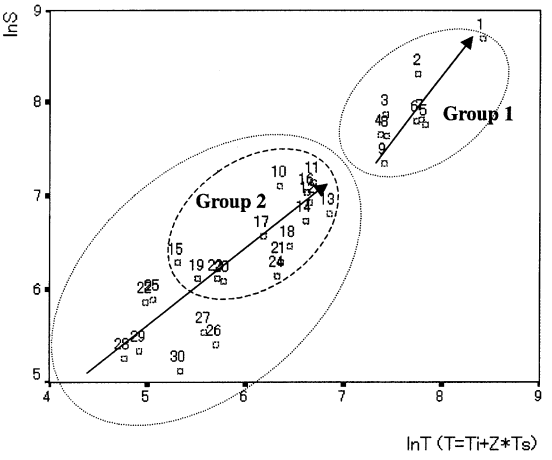
5. Implications

This analysis attempts to elucidate the structural sources of the high level of R&D intensity in pharmaceutical firms. Focusing on their interactions with competitors by the assimilation of spillover technology, the motivations of R&D investment and increases in R&D intensity are identified, particularly in smaller-sized firms.

On the basis of numerical analysis and empirical demonstration, the following findings provide an explanation of the structural sources of the high level of R&D intensity in the pharmaceutical industry:

1. Technology contributes significantly to sales increase in this industrial sector and, thus, an increase in technology stock by R&D investment.
2. In order to increase technology stock, not only





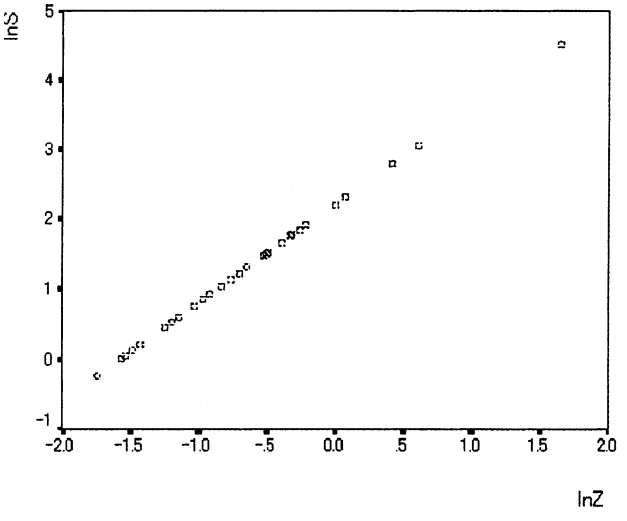
$$\ln S = 1.01 + 0.88 D_1 \ln T + 0.86 D_2 \ln T$$

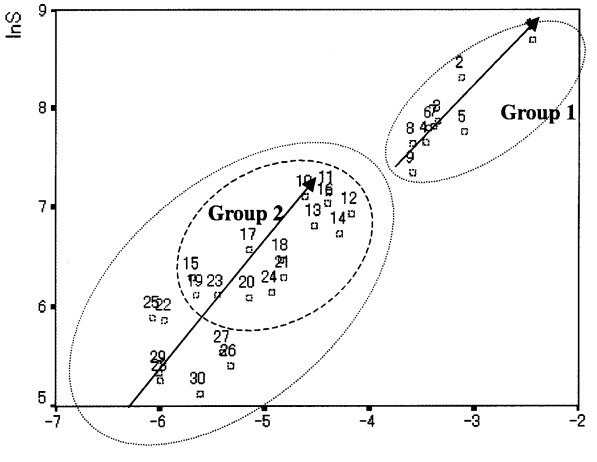
(2.18) (14.51) (11.05)

adj. R^2 = 0.940 DW = 1.82

D_1: group 1; and D_2: groups 2,3.

Fig. 7. Correlation between total technology stock and sales in 30 R&D intensive Japanese pharmaceutical firms (1991–1994).





$$\ln S = 9.51 + 0.62 D_1 \ln Z + 0.73 D_2 \ln Z$$

(25.94) (4.40) (8.81)

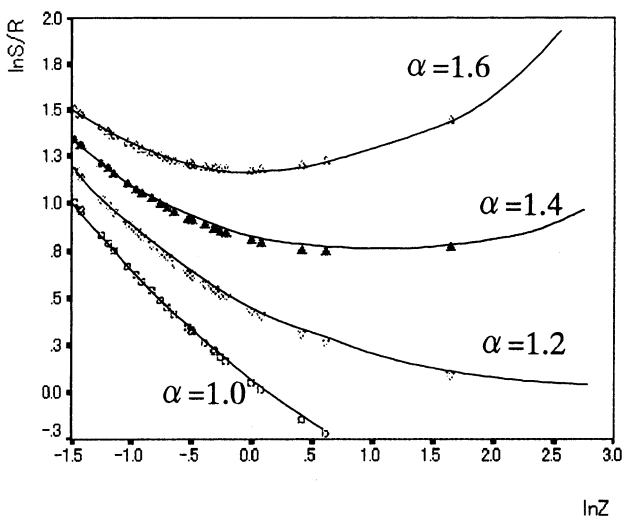
adj. R^2 = 0.911 DW = 1.73

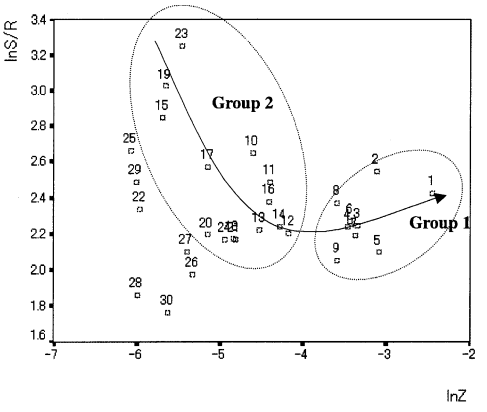
D_1: group 1; and D_2: groups 2,3.

Fig. 8. Correlation between assimilation capacity and sales in 30 R&D intensive Japanese pharmaceutical firms (1991–1994).

indigenous R&D investment but also effective utilization of spillover technology is essential.

3. Improvement of assimilation capacity is essential for effective utilization of spillover technology, and this depends on the level of technology stock in the host.
4. The assimilation capacity reacts to decreases in R&D productivity in the stage when its level is low. However, this negative reaction becomes positive when the assimilation capacity exceeds certain levels.
5. As a result of the increase in R&D intensity, after reaching a certain level of assimilation capacity, it continues to increase further without depending on a further R&D intensity increase.
6. Thus, smaller firms endeavor to increase their R&D intensity while R&D intensity of the top-level firms is not necessarily high despite their high level of sales.
7. However, it is questionable whether this trend in top-level firms can be maintained under mega-competition. In this situation, the world's leading pharmaceutical firms endeavor to win the race primarily by huge R&D investments.

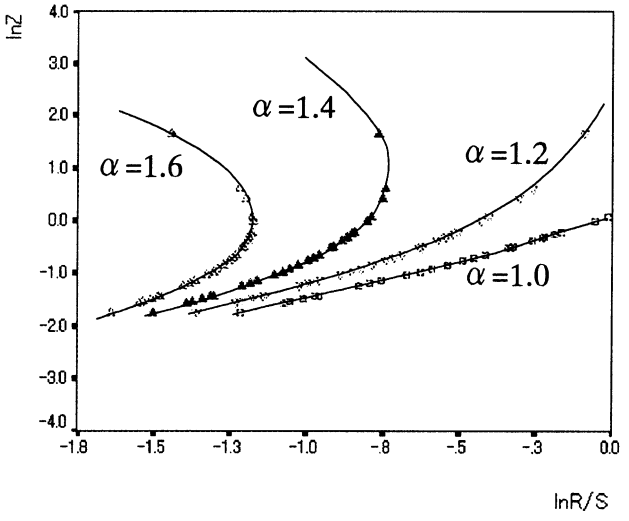


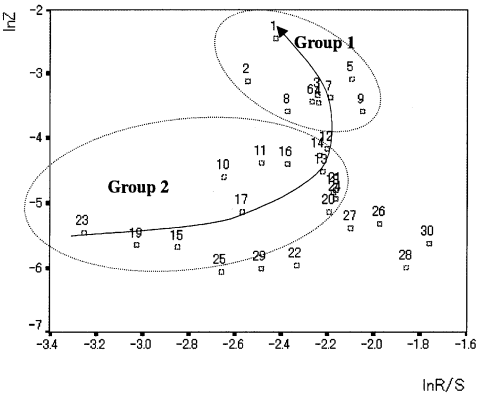


		adj. R^2	DW
Total	$\ln S/R = 4.55 + 0.69D_1 \cdot \ln Z - 0.14D_2 \cdot \ln Z + 2.16D_{22}$	0.938	1.91
	(4.12) (2.03) (-2.43) (3.02)		

D_1: group 1; and D_2: group 2.

Fig. 9. Correlation between assimilation capacity and R&D productivity in 30 R&D intensive Japanese pharmaceutical firms (1991–1994).





		adj. R^2	DW
Total	$\ln Z = -9.65 - 0.93D_1 \cdot \ln R/S + 1.87D_2 \cdot \ln R/S - 3.05D_{19}$	0.973	1.08
	(-5.19)(-3.38) (2.46) (-2.81)		

D_1: group 1; and D_2: group 2.

Fig. 10. Correlation between R&D intensity and assimilation capacity in 30 R&D intensive Japanese pharmaceutical firms (1991–1994).

Appendix A. Technology contribution to sales in 30 R&D intensive Japanese pharmaceutical firms (1979–1998): comparison between T_i and T_i+ZT_s

T is indigenous technology stock only (T_i); and T' is with assimilated spillover technology (T_i+ZT_s).

$$\ln S = \underset{(2.45)}{0.82} + \underset{(17.96)}{0.93D_a \ln T} + \underset{(17.62)}{1.05D_b \ln T}$$

adj. R^2=0.919; DW=2.44.

D_b, 2, 10, 15, 19, 22; and D_a, other firms.

$$\ln S = \underset{(-0.26)}{-0.09} + \underset{(18.66)}{1.01D_a \ln T'} + \underset{(20.62)}{1.14D_b \ln T'}$$

adj. R^2=0.936; DW=2.12.

D_b, 13, 15, 17, 29; and D_a, other firms.

Contribution of T' to S is more significant than T and its elasticity is higher than T.

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