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Technological diversification and firm's techno-economic structure: An assessment of Canon's sustainable growth trajectory

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Abstract

Contrary to the decrease in operating income to sales (OIS) in Japan's electrical machinery firms, Canon has demonstrated its increasing trend with increase of its technological diversification. These contrasts and Canon's conspicuous functionality development suggest that a virtuous cycle between its technological diversification strategy and increase in OIS can be the source of its sustainable growth.

Prompted by this hypothetical view, this paper attempts to assess Canon's sustainable growth trajectory by elucidating a mechanism of its technological diversification system through an effective utilization of potential resources in innovation. By means of an epidemic function, the new approach for assessing marginal productivity of technology as well as functionality development is developed. Utilizing this approach, comparative empirical analyses are conducted focusing on the consequence of technological diversification and development trajectory in Japan's leading electrical machinery firms over the last two decades.

Keywords: Technological diversification; Technoeconomic structure; Sustainable growth trajectory; Canon

1. Introduction

Contrary to the decrease in operating income to sales (OIS)[1] in Japan's electrical machinery firms, only Canon demonstrated its increasing trend under the paradigm shift from an industrial society to an

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[1] The operating income is a measure of a company's earning power from ongoing operations, equal to earnings before deduction of interest payments and income taxes. It is also called operating profit or EBIT (earnings before interest and taxes). The OIS is the operating income per sales.

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information society in the 1990s. This contrasting performance corresponds to its consistent efforts to develop technological diversification over the last four decades. These observations suggest that a virtuous cycle between its technological diversification strategy and the increase in OIS can be the source of Canon's sustainable growth.

Prompted by this observation, this paper conducts a comparative empirical analysis on the consequence of technological diversification and development trajectory in Japan's leading electrical machinery firms over the last two decades and attempts to assess Canon's sustainable growth trajectory by elucidating a mechanism of its technological diversification system through an effective utilization of potential resources in innovation.

In tracing Canon's sustainable growth trajectory, epidemic functions (logistic growth models) are employed because a number of studies have demonstrated usefulness of this approach [1–5] since Verhulst introduced the simple logistic model in 1845. While more general models have been suggested till now [6,7], Sharif and Ramanathan [8] concluded that time-varying carrying capacities are superior to the existing model with fixed carrying capacity. Therefore, simple logistic model and logistic growth model within a dynamic carrying capacity model are compared for the assessment of Canon's sustainable growth trajectories in this research.

While the importance of technological diversification has increased amidst megacompetition spurred by informatization and economic globalization in the 1990s, Japanese firms concentrated on their core business due to the economic stagnation after the bursting of the bubble economy [9]. Servas [10], Rajan et al. [11] and Scharfstein and Stein [12] postulated that research focus of the business diversification should shift to the evaluation of cost expansion accompanied with diversification from the viewpoint of excessive value approach. Therefore, the significant role of technological diversification is how to overcome this problem by constructing a virtuous cycle for an effective utilization of potential resources in innovation.

To date, while a number of studies have analyzed the significance of firm's technological diversification strategy, none has analyzed the dynamism of diversification, development trajectory, marginal productivity of technology, and subsequent income structure.

Thus, this paper focuses on the elucidation of the mechanism of technological diversification leading to high income structure.

Section 2 measures the marginal productivity of technology, functionality development and velocity of technology diffusion based on the logistic growth function within a dynamic carrying capacity and analyzes their correlation with the technological diversification. Section 3 measures the total factor productivity (TFP) and the internal rate of return to R&D investment. Section 4 elucidates factors governing a virtuous cycle between inducing factors of R&D investment and technological diversification. Section 5 briefly summarizes new findings, their policy implications and future works.

2. Technological diversification and marginal productivity of technology

2.1. Analysis of development trajectory of leading electrical machinery firms

Diffusion and development trajectory of high-technology products are actually quite similar to the contagion process of an epidemic disease [13] and exhibits sigmoid growth. This process is well modeled by the following simple logistic growth function (epidemic model) which was first introduced by Vehrulst in 1845 [14]:

$$\frac{\mathrm{d}\Sigma Y(t)}{\mathrm{d}t} = a\Sigma Y(t)\cdot\left(1-\frac{\Sigma Y(t)}{K}\right) \tag{1}$$

where $\Sigma Y(t)$: cumulative production of high-technology goods at time t; K: carrying capacity; and a, b; coefficients where a=(ΔΣY(t)/ΣY(t))/(1−(ΣY(t)K)) governs the diffusion velocity.

By developing Eq. (1), the following epidemic model depicting technological trajectory can be obtained:

$$\Sigma Y(t) = \frac{K}{1+\mathrm{Exp}(-at-b)} \tag{2}$$

Since high-technology products can be considered as the crystal of technology stock and the sales of high technology firms are proportional to the development of their high-technology products [15] and technology stock increase as time goes by, the epidemic model of Eq. (2) can be expressed by Eq. (3).

$$\Sigma S(T) = \frac{\overline{\Sigma S}}{1+\mathrm{Exp}(-aT-b)} \tag{3}$$

where $\overline{\Sigma S}$: carrying capacity of cumulative production; and T: technology stock.

Given the rate of obsolescence of high-technology products ρ, increasing rate at initial stage g is stable, cumulative sales can be approximated as $\Sigma S \approx S/(\rho+g)$. Therefore, Eq. (3) can be approximated by the following equation:

$$S(T) = \frac{\bar{S}}{1+\mathrm{Exp}(-aT-b)} \tag{4}$$

The development trajectory expressed by Eq. (4) assumes that the level of carrying capacity is constant through the development process of technology. However, in reality, the interaction between technology and institutions induces a structural change and enhance the level of carrying capacity in line with increase of technology stock and development of new functionality [16]. Therefore, $\bar{S}(T)$ is also an epidemic model enumerated as follows:

$$\bar{S}(T) = \frac{\bar{S}_K}{1+\mathrm{Exp}(-a_K T-b_K)} \tag{5}$$

where a_K and b_K: coefficients; and $\bar{S}_K$: ultimate carrying capacity.

The solution of the differential Eq. (1) under the condition (5) can be obtained as follows:

$$S(T) = \frac{\bar{S}_K}{1+\mathrm{Exp}(-aT-b)+\dfrac{a}{a-a_K}\mathrm{Exp}(-a_K T-b_K)} \tag{6}$$

Utilizing Eq. (6), development trajectories of Japan's leading electrical machinery firms over the period 1980−1998 are analyzed. Results of analysis are summarized in Table 1.

Table 1
Estimation results for the development trajectories of Japan's leading electrical machinery firms (1980–1998)

	K	a	b	a_K	b_K	Adj. R^2	DW	AIC
Canon	2529	0.607E-02	−3.04			0.995	0.94	4124
	(14.50)	(13.60)	(−31.00)					
	21,929	0.900E-02	−5.54	0.116E-02	−3.22	0.999	1.18	2773
	(1.18)	(4.97)	(−6.09)	(2.94)	(−3.41)			
Matsushita	6972	0.158E-02	−2.12			0.993	0.89	56,456
	(11.71)	(6.53)	(−12.43)					
	6972	0.935E-01	−4.00	0.158E-02	−2.11	0.983	0.89	161,490
	(11.73)	(8.59)	(−4.00)	(6.54)	(−12.46)			
NEC	6431	0.169E-02	−3.03			0.977	0.46	171,220
	(4.48)	(4.27)	(−12.32)					
	8719	0.853E-02	−9.06	0.110E-02	−2.38	0.968	0.67	54,621
	(5.75)	(3.15)	(−3.50)	(5.51)	(−8.36)			
Hitachi	7527	0.138E-02	−2.11			0.985	0.52	89,084
	(2.97)	(3.22)	(−13.45)					
	13,808	0.465E-02	−3.89	0.801E-03	−2.00	0.914	0.62	38,528
	(3.07)	(2.27)	(−2.65)	(4.23)	(−4.83)			
Toshiba	5409	0.244E-02	−2.55			0.987	0.59	54,601
	(11.73)	(7.03)	(−13.69)					
	19,338	0.848E-02	−7.16	0.828E-03	−2.50	0.935	1.11	44,854
	(2.01)	(3.09)	(−4.05)	(5.75)	(−4.92)			
Fujitsu	5599	0.172E-02	−2.27			0.965	0.42	137,420
	(2.47)	(3.13)	(−8.66)					
	28,453	0.981E-02	−6.49	0.821E-03	−3.22	0.936	0.64	30,662
	(2.60)	(3.73)	(−5.54)	(8.57)	(−7.70)			
Melco	3781	0.346E-02	−1.93			0.983	0.60	33,740
	(21.25)	(8.83)	(−14.60)					
	16,898	0.740E-02	−4.30	0.699E-03	−2.13	0.916	0.93	15,581
	(2.34)	(5.78)	(−7.65)	(5.79)	(−4.46)			
Sony	3972	0.301E-02	−2.46			0.992	0.58	15,768
	(3.18)	(3.58)	(−14.44)					
	17,764	0.979E-02	−5.33	0.139E-02	−3.06	0.991	0.65	15,646
	(2.27)	(2.75)	(−4.94)	(4.93)	(−5.79)			
Sharp	1932	0.600E-02	−1.80			0.939	0.45	20,740
	(8.52)	(4.70)	(−10.99)					
	3869	0.126E-01	−2.96	0.201E-02	−1.32	0.958	0.57	20,724
	(1.78)	(2.70)	(−2.81)	(2.13)	(−1.64)			

Upper two lines indicate estimation by a simple logistic growth function (Eq. (4)) and the lower two lines indicate that of by a logistic growth function within a dynamic carrying capacity (Eq. (6)).

Table 1 compares estimations both by a simple logistic growth function (Eq. (4)) and a logistic growth function within a dynamic carrying capacity (Eq. (6)). Comparing AIC (Akaike Information Criteria) we note that Table 1 suggests that the estimations by a logistic growth function within a dynamic carrying capacity demonstrates statistically more significant except Matsushita which stands the top level of sales and most matured stage in Japan's electrical machinery firms.

As Table 1 demonstrates extremely high statistical significance, Eq. (6) can be considered to represent development trajectory of high-technology firms driven by their technology stock.

Table 2
Trends in marginal productivity of technology in leading electrical machinery firms (1980–1998)

	1980–1986	1987–1990	1991–1994	1995–1998
Canon	1.72	3.02	3.67	4.77
Matsushita	2.25	2.72	2.25	1.45
NEC	3.64	2.41	2.45	2.62
Hitachi	2.74	2.42	2.48	2.62
Toshiba	4.68	2.81	2.50	2.88
Fujitsu	3.17	1.90	1.99	2.65
Melco	3.93	2.98	2.01	1.97
Sony	2.79	2.56	2.66	3.28
Sharp	3.09	2.80	2.06	1.85

2.2. Measurement of marginal productivity of technology

Based on the foregoing analysis, the marginal productivity of technology of high-technology firms can be measured by Eq. (6). Taking partial differentiation of Eq. (6) with respect to technology stock T, the following equation depicting marginal productivity of technology can be measured.

$$\frac{\partial S}{\partial T} = \frac{\bar{S}_K\left(a\mathrm{Exp}(-aT-b) + \dfrac{aa_K}{a-a_K}\mathrm{Exp}(-a_KT-b_K)\right)}{\left(1+\mathrm{Exp}(-aT-b) + \dfrac{a}{a-a_K}\mathrm{Exp}(-a_KT-b_K)\right)^2} = aS(T)\left(1-\frac{S(T)}{\bar{S}(T)}\right)$$
$$= aS(T)\left(1-\frac{1}{\mathrm{FD}}\right) \qquad (7)$$

where FD $\equiv \bar{S}(T)/S(T)$: degree of functionality development[2] [15].

In the process of diffusion of high-technology products, the ratio of carrying capacity to the level of diffusion represents the extent of functionality development [17,18] and $\bar{S}(T)/S(T)$ in Eq. (7) represents this ratio (which is defined as the degree of functionality development).

Therefore, Eq. (7) suggests that the marginal productivity increases as the functionality development increases. In addition, the marginal productivity of technology is proportional to diffusion velocity (a) as well as sales.

The marginal productivity of technology in leading electrical machinery firms measured by Eq. (7) is summarized in Table 2.

Looking at Table 2, we note that Canon's marginal productivity of technology was the lowest among leading electrical machinery firms compared during the period of 1980–1986, it increased and ranked top level from the late 1980s.

Previous analyses demonstrated the significant correlations between R&D intensity and marginal productivity of technology [19] as well as R&D intensity and technological diversification [20].

[2] The functionality development is generally defined as the ability to dramatically improve performance of production processes, goods and services by means of innovation.

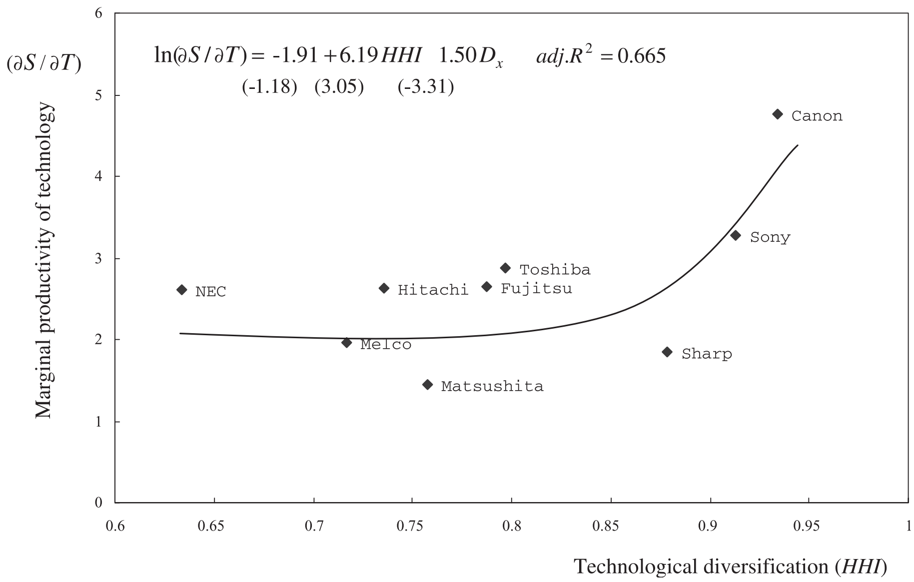

Fig. 1. Correlation between technological diversification and marginal productivity of technology (1995–1998 average). D_x: Dummy variable for Matsushita and Sharp.

Following these analyses, Figs. 1 and 2 analyze the correlation between the technological diversification [indicated by Herfindahl index (HHI)] and the marginal productivity of technology ($\partial S/\partial T$) as well as the diffusion velocity (a) in leading electrical machinery firms. Both figures demonstrate clear positive correlation suggesting that the technological diversification contributed to the increase of the marginal productivity of technology as well as the velocity of technology diffusion.

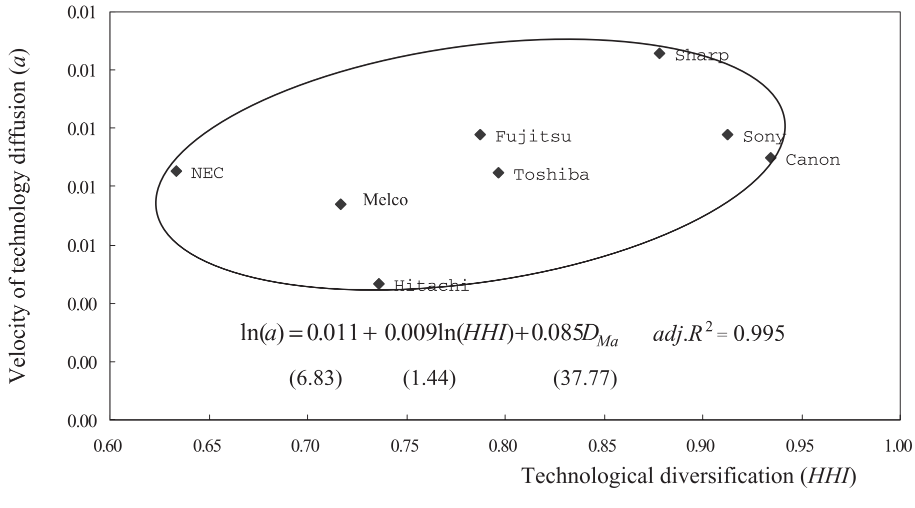

Fig. 2. Correlation between technological diversification and velocity of technology diffusion (1995–1998 average). $a = \Delta S / S(1 - S/S(T))^{-1}$: velocity of technology diffusion. D_{Ma}: Dummy variable for Matsushita.

2.3. Measurement of new functionality development

As analyzed before, Canon's marginal productivity of technology has increased and maintained top level in the 1990s. Eq. (7) suggests that this can be attributed to the functionality development together with high velocity of technology diffusion.

Since the degree of functionality development can be depicted by the following equation, trends in functionality development in leading electrical machinery firms can be measured utilizing the results summarized in Table 1.

$$\mathrm{FD} = \frac{\bar{S}(T)}{S(T)} = \frac{\dfrac{\bar{S}_K}{1+\mathrm{Exp}(-a_K T - b_K)}}{\dfrac{\bar{S}_K}{1+\mathrm{Exp}(-aT-b)+\dfrac{a}{a-a_K}\mathrm{Exp}(-a_K T - b_K)}}$$

$$= \frac{1+\mathrm{Exp}(-aT-b)+\dfrac{a}{a-a_K}\mathrm{Exp}(-a_K T - b_K)}{1+\mathrm{Exp}(-a_K T - b_K)} \tag{8}$$

Table 3 summarizes the result of the functionality development measured by an epidemic function developed by Eq. (6) in leading electrical machinery firms over the period 1980–1998, which demonstrates Canon has maintained high level of the functionality development.

Fig. 3 analyzes the correlation between technological diversification and functionality development measured by an epidemic model depicted by Eq. (6) which illustrates clear positive correlation demonstrating that technological diversification contributed to functionality development. Looking at Fig. 3, we note that among firms examined Canon demonstrates a conspicuous achievement with respect to the correlation between technological diversification and functionality development.

Table 4 summarizes the chronology of Canon's functionality development over the last three decades. Looking at Table 4, we note that Canon has developed variety of technologies based on its

Table 3
Trends in functionality development of leading electrical machinery firms (1991–1998)

	1991–1994	1995–1998
Canon	1.53	1.29
Matsushita	1.01	1.00
NEC	1.14	1.04
Hitachi	1.20	1.09
Toshiba	1.13	1.07
Fujitsu	1.16	1.07
Mitsubishi	1.13	1.07
Sony	1.18	1.14
Sharp	1.18	1.09

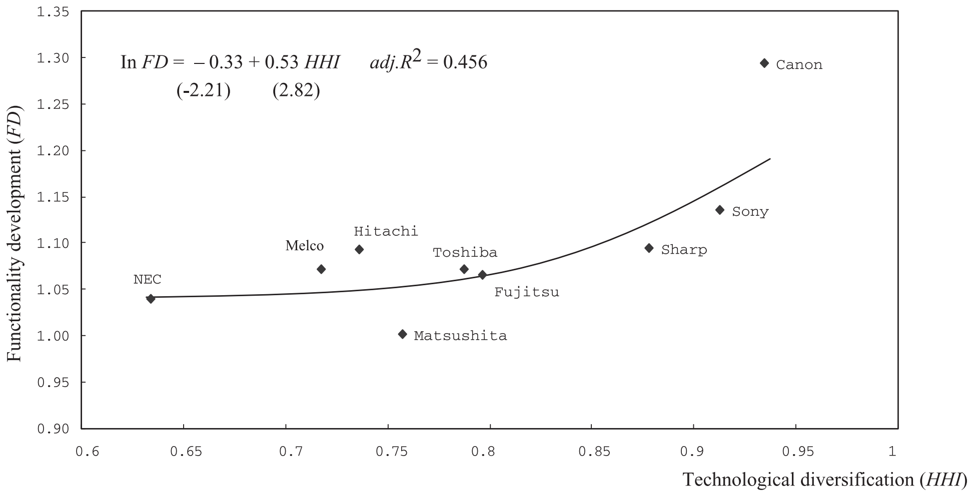

Fig. 3. Correlation between technological diversification and functionality development in leading electrical machinery firms (1995–1998 average).

indigenous technology and created new functionality similar to chain reaction in its innovation process leading to construction of the following virtuous cycle: technological diversification → devel- development of new functionality → creation of variety of technologies → further development of new functionality.

Table 4
Chronology of Canon's new functionality development over the last three decades

Year	New functionality development
1970	Japan's first plain-paper copying machine "NP-1100" by original electro-photography technology
	Japan's first mask aligner "PPC-1" by precision optical technology
1976	"AE-1" camera with a built-in microcomputer
	World's first nonmydriatic retinal camera "CR-45NM"
1978	World's first screen processing copying machine "NP-8500"
1979	"LBP-10" by applying semiconductor laser
1981	World's first bubble jet printing technology development
1982	World's first personal copying machine "PC-10/20"
1984	Digital laser copying machine system "NP-9030"
	World's smallest laser beam printer "LBP-8/CX"
1985	World's first bubble jet printer "BJ-80"
1986	Still video system
1988	World's highest resolution CCD built-in still video camera "RC-760"
1990	Note book size bubble jet printer "BJ-10"
1991	World's first FLCD (Ferro-electric liquid crystal display)
1996	APS (Advanced photo system) double zoom camera "IXY"
1999	Joint development of "SED (Surface-conduction electron-emitter displays)"
2000	Compact and card sized digital camera "IXY DIGITAL"

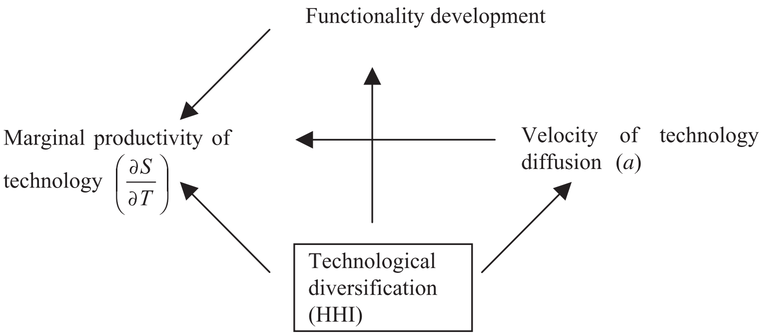

Fig. 4. Relationship among technological diversification, marginal productivity of technology, velocity of technology diffusion and functionality development.

Synchronizing results of these correlations as well as Eq. (7), the relationship among technological diversification, marginal productivity of technology, velocity of technology diffusion and functionality development can be systemized in Fig. 4.

3. Technological diversification, TFP and internal rate of return to R&D investment

3.1. Technological diversification and increase of TFP

As reviewed in Section 2, sales in high-technology firms are proportional to the volume of high-technology products as crystal of technology stock. Thus, growth rate of TFP can be depicted by the following equations:

$$S = F(X, T) \tag{9}$$

where S: sales; X: labor (L) and capital (K); intermediate input (M) and T: technology stock.

Let $(\mathrm{d}S/\mathrm{d}t) \equiv \Delta S$, $(\mathrm{d}X/\mathrm{d}t) \equiv \Delta X$ and $(\mathrm{d}T/\mathrm{d}t) \equiv \Delta T \approx R$ (R: R&D investment)

$$\frac{\Delta S}{S} = \sum_{X=L,K,M} \left(\frac{\partial S}{\partial X}\frac{X}{S}\right)\frac{\Delta X}{X} + \left(\frac{\partial S}{\partial T}\frac{T}{S}\right)\frac{\Delta T}{T} \tag{10}$$

$$\frac{\Delta TFP}{\mathrm{TFP}} = \frac{\Delta S}{S} - \sum_{X=L,K,M}\left(\frac{\partial V}{\partial X}\frac{X}{S}\right)\frac{\Delta X}{X} = \left(\frac{\partial S}{\partial T}\frac{T}{S}\right)\frac{\Delta T}{T} \approx \frac{\partial S}{\partial T}\frac{R}{S}$$

$$\therefore \frac{\Delta TFP}{\mathrm{TFP}} = \frac{\partial S}{\partial T}\frac{R}{S} \tag{11}$$

Eq. (11) suggests that the growth rate of TFP can be simply measure by a product of marginal productivity of technology and R&D intensity. Synchronizing marginal productivity of technology

Table 5
Comparison of increasing rate of TFP in leading electrical machinery firms (1980–1998)

	1980–1986	1987–1990	1991–1994	1995–1998
Canon	0.284	0.417	0.396	0.443
Matsushita	0.200	0.250	0.178	0.106
NEC	0.620	0.287	0.224	0.179
Hitachi	0.281	0.257	0.234	0.188
Toshiba	0.406	0.235	0.196	0.179
Fujitsu	0.517	0.254	0.232	0.213
Melco	0.290	0.220	0.127	0.099
Sony	0.353	0.331	0.306	0.314
Sharp	0.278	0.225	0.165	0.131

measured by Eq. (7) and R&D intensity, the trend of growth rate of TFP in leading electrical machinery firms over the period 1980–1998 can be measured by Eq. (11). The results are summarized in Table 5.

Looking at Table 5, we note that Canon has maintained the highest level of TFP growth rate from the late 1980s corresponding to increase in its marginal productivity of technology as demonstrated in Table 2. Eq. (11) suggests that this high level of TFP growth rate can be attributed to high level of marginal productivity of technology and R&D intensity.

Integrating these results, Fig. 4 which illustrates the relationship between technological diversification, marginal productivity of technology, velocity of technology diffusion and functionality development can be developed to a sophisticated dynamism incorporating impacts of R&D intensity, TFP growth and sales increase as illustrated in Fig. 5.

3.2. Technological diversification and internal rate of return to R&D investment

Given the lead time from R&D investment to commercialization m, rate of obsolescence of technology stock ρ and current discount rate r, the equilibrium between one unit of R&D investment and present

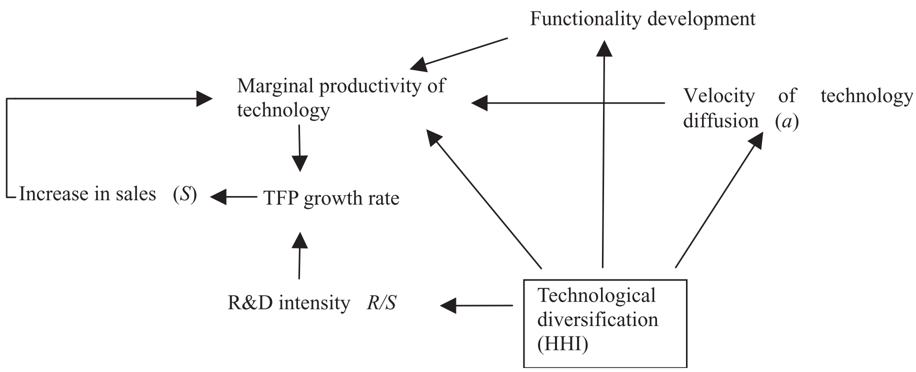

Fig. 5. Dynamism among technological diversification, functionality development, TFP growth rate and sales increase.

Table 6
Comparison of internal rate of return to R&D investment in leading electrical machinery firms (1980–1998)

	1980–1986	1987–1990	1991–1994	1995–1998
Canon	0.518	0.774	0.887	1.061
Matsushita	0.630	0.725	0.645	0.485
NEC	0.858	0.670	0.684	0.728
Hitachi	0.719	0.672	0.691	0.729
Toshiba	1.000	0.738	0.694	0.775
Fujitsu	0.787	0.570	0.594	0.733
Melco	0.901	0.766	0.599	0.601
Sony	0.726	0.697	0.723	0.842
Sharp	0.776	0.737	0.609	0.577

value of consequent benefit can be depicted by the following Eq. (12) [19]:

$$e^{mr} = \int_0^{\infty} \frac{\partial S}{\partial T} e^{-(\rho+r)t} \mathrm{d}t = \frac{\partial S}{\partial T} \Big/ (\rho + r) \tag{12}$$

By developing Taylor series of the left-hand side to the first order, Eq. (13) can be obtained.

$$1 + mr = \frac{\partial S}{\partial T} \Big/ (\rho + r) \tag{13}$$

Solving Eq. (13), internal rate of return (IRR) to R&D investment r can be depicted by the following equation:

$$r = -(1 + m\rho) + \sqrt{\frac{(1 + m\rho)^2 - 4m\left(\rho - \frac{\partial S}{\partial T}\right)}{2m}} \qquad \because r \geq 0 \tag{14}$$

Substituting $\partial S/\partial T$ by Eq. (7), the IRR to R&D investment in leading electrical machinery firms can be measured. Results of the measurement are summarized in Table 6.

Looking at this table, we note that trend in Canon's IRR to R&D investment is similar to the trend in its marginal productivity of technology which is summarized in Table 2. While Canon's IRR to R&D investment was the lowest among leading electrical machinery firms during the period of 1980–1986, it increased and ranked top level from the late 1980s.

4. Factors inducing a virtuous cycle between R&D investment and technological diversification

4.1. Inducing factors of technological diversification

The previous analysis [20] suggested that Canon's high level of OIS in the 1990s particularly when majority of electrical machinery firms decreased in their OIS could be attributed to the sustainable technological diversification effort. This effort was conspicuous as majority of electrical machinery firms

Table 7
Comparative analysis of inducing factors of Canon's technological diversification (1980–1998)

$$\ln\mathrm{HHI} = a + b\ln X_{-1} \quad X_{-1}: \frac{R}{S}, \frac{\partial S}{\partial T}, \frac{\Delta TFP}{\mathrm{TFP}}, \text{ IRR at time } t-1$$

X	a	b	Adj. R^2	DW
R/S	0.04 (1.62)	− 1.06 (− 5.86)	0.663	0.71
$\partial S/\partial T$	− 0.19 (− 17.43)	0.03 (8.74)	0.816	1.50
ΔTFP/TFP	− 0.24 (− 11.40)	0.38 (6.73)	0.722	1.88
IRR	− 0.23 (− 17.19)	0.17 (9.80)	0.848	1.88

shifted to converge by selection and concentration. Only Canon has maintained technological diversification.

Stimulated by these noteworthy observations, Table 7 analyzes inducing factors of technological diversification and compares elasticity of R&D intensity, marginal productivity of technology, TFP growth rate and IRR to R&D investment to technological diversification focusing on Canon as it demonstrates high level of technological diversification.

Looking at Table 7, we note that IRR to R&D investment demonstrates the highest statistical significance and provides noteworthy inducement of technological diversification.

Generally, to develop diversification, certain resources are indispensable for firms [7,21]. Therefore, correlation analyses are conducted by incorporating sales as the resource for diversification focusing on nine leading electrical machinery firms and IRR to R&D investment to attempt to identify inducing factors to technological diversification. The results of analyses are summarized in Table 8.

Although firms except Sony demonstrates statistical significance of sales as a resource inducing technological diversification, correlation between them demonstrates negative except Canon, which suggests the necessity of diversification increase as sales decrease. Only Canon increased technological diversification together with increase of sales and this is very noteworthy observation. It suggests a possibility of Canon's unique technological diversification structure.

Table 8
Inducing factors in leading electrical machinery firms (1980–1998)

$$\ln\mathrm{HHI} = a + b\ln\mathrm{IRR}_{-1} + c\ln S_{-1}$$

	a	b	c	Adj. R^2	DW
Canon	− 0.203 (− 2.31)	0.057 (1.91)	0.019 (1.56)	0.905	1.87
Matsushita	0.270 (2.11)	0.459 (9.65)	− 0.028 (− 1.78)	0.850	1.50
NEC	1.733 (4.72)	− 0.500 (− 1.61)	− 0.273 (− 4.83)	0.661	0.51
Hitachi	1.120 (5.13)	− 0.639 (− 1.75)	− 0.186 (− 6.44)	0.818	1.01
Toshiba	1.166 (8.41)	− 0.134 (− 2.19)	− 0.170 (− 7.74)	0.903	2.04
Fujitsu	0.391 (2.30)	− 0.424 (− 3.81)	− 0.091 (− 3.58)	0.489	0.66
Melco	0.709 (1.32)	0.245 (1.27)	− 0.107 (− 1.37)	0.677	1.00
Sony	− 0.208 (− 2.05)	− 0.240 (− 2.40)	0.008 (0.68)	0.487	1.93
Sharp	0.170 (1.01)	− 0.106 (− 0.78)	− 0.050 (− 1.60)	0.355	1.35

It is generally pointed out that firms with sufficient business resources in core business field possess high ability to diversify. However, sufficient business resources, ironically, suggest no need to diversify. Conversely, necessity to diversify is high when core business is stagnated. However, in that circumstance, the resources for diversification are limited. In this regard, there exists generally a paradox between the necessity of diversification and resources for diversification.

The sales is definitely a significant source for technological diversification. Table 8 demonstrates that seven firms demonstrating negative correlation between sales and technological diversification depend on technological diversification when their core businesses are stagnated. However, only Canon has challenged its technological diversification making full utilization of appropriate diversification resources when its core business increases and therefore technological diversification is not so urgent. This is considered the sources constructing a virtuous cycle between technological diversification and increase in OIS compared to other electrical machinery firms in the 1990s.

On the basis of the foregoing analyses, it has been identified that sources enabling Canon to maintain technological diversification even in the 1990s can be attributed to the highest level of R&D investment supported by its higher level of IRR to R&D investment as well as its continuing techno-preneurship strategy to appropriate resources for technological diversification while its core business increases.

The identity of Canon's technological diversification can be characterized as follows:

(i) Canon was reestablished in 1945 after the Second World War. Canon's business models, envisioned by Dr. Takeshi Mitarai, the founder of the reestablished corporation, has been maintained with coherency, instilled into its engineers and brewed with their potentials since its reestablishment [22].
(ii) Its technological diversification has been aimed at maximal utilization of its core technologies indigenously developed by its preceding cumulative efforts. This diversification process has been developed in such a way as spilling new functionalities incorporated with those core technologies over to new business fields, thereby induced new functionalities successively [23] as observed in the development of laser beam printers based on core technologies of copying machines in 1979 [24]. Such a diversification process resembled cloning of technology DNA and enabled self-propagation of new functionalities [25].
(iii) Its repeated practices have led to the construction of a virtuous cycle activating technology spillover, improving its assimilation capacity for the effective utilization of spillover technology, and thus increasing its technology stock. This dynamism has not only developed its organizational capabilities but also stimulated the interaction with markets leading to the construction of a global virtuous cycle [26].

Thus, Canon's identical technological diversification strategy can be defined as a core of its unique corporate business model cultivated over its 50 year development trajectory.

4.2. Factors governing internal rate of return to R&D investment

Stimulated by the inducing factors of technological diversification, focusing on Canon's IRR to R&D investment as primary contributor to technological diversification, governing factors of IRR to R&D investment are analyzed.

Table 9
Analysis on governing factors of IRR in Canon (1980-1998)

$$\ln \mathrm{IRR} = a + b\ln R/S + c\ln \mathrm{YR} + d\ln \mathrm{CI} + D_1 e_1 \ln \mathrm{HHI} + D_2 e_2 \ln \mathrm{HHI} + \lambda t$$

	a	b	c	d	e_1	e_2	λ	Adj. R^2	DW
Coefficient	− 123.03 (− 3.96)	0.55 (1.89)	− 0.22 (− 1.89)	0.10 (0.51)	4.01 (3.42)	3.76 (2.36)	0.06 (3.94)	0.968	1.88

IRR: internal rate of return; R/S: R&D intensity (R&D per sales); YR: Yen rate (US$/¥); CI: composite index; D_1, D_2: dummy variable (D_1: 1980-90 = 1, others 0, D_2: 1991–98 = 1, others 0); HHI: Herfindahl index; and t: time trend.

It is generally pointed out that IRR to R&D investment is governed by efforts to increase firm's R&D investment represented by R&D intensity and external factors such as exchange rate [19].

Therefore, an analysis is conducted taking R&D intensity (R/S), exchange rate of Yen (YR), economic situation (CI), technological diversification (HHI) and time trend (t) focusing on leading electrical machinery firms by using the following equation:

$$\mathrm{IRR} = A(R/S)^b(\mathrm{YR})^c(\mathrm{CI})^d(\mathrm{HHI})^{\mathrm{De}}e^{\lambda t}$$

Table 9 summarizes the result of analysis, which demonstrates that Canon's elasticity of technological diversification to IRR to R&D investment is higher than that of R&D intensity. The elasticity of economic situation as well as exchange rate is statistically insignificant and their impacts on IRR to R&D investment are low.

4.3. Dynamism leading to a virtuous cycle for technological diversification

On the basis of the foregoing analyses, we can conclude that the following cyclical dynamism as illustrated in Fig. 6, based on a virtuous cycle between technological diversification and IRR to R&D

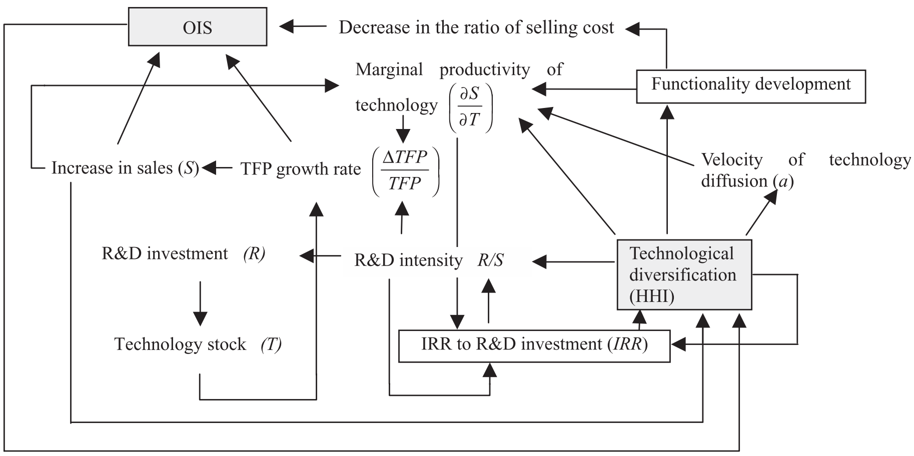

Fig. 6. A virtuous cycle enabling Canon to increase and sustain high level of OIS.

investment, which contributed to increase in OIS in the 1990s enabled Canon to increase and sustain high level of its OIS:

(i) Supported by its consistent technological diversification strategy, Canon has succeeded to achieve successive new functionality development.
(ii) This diversification contributes to improve marginal productivity of technology as well as IRR to R&D investment.
(iii) Increased IRR to R&D investment induces R&D intensity, which, together with increased marginal productivity of technology, increases TFP growth leading to the effective increase in sales.
(iv) These high productivities together with decrease in the ratio of selling cost attributed by functionality development contribute to increase in OIS.
(v) Increase in sales and OIS further encourages technological diversification strategy which further induces functionality development as well as high productivities leading to constructing a virtuous cycle between technological diversification and high level of OIS.

5. Conclusion

Prompted by conspicuous Canon's behavior with respect to technological diversification as well as high level of operating income to sales, this paper attempted to elucidate its dynamism. Based on a theoretical relationship between assimilation capacity of spillover technology and diversification of R&D activities, new methodology to measure the extent of technological diversification of firms by means of assimilated spillover technology was developed.

Utilizing this methodology, technological diversification trend in Japan's leading electrical machinery firms was measured and its impacts on R&D intensity were analyzed. In addition, based on a logistic growth function within a dynamic carrying capacity incorporating technology stock, development trajectories of these firms were estimated, thereby marginal productivity of technology, functionality development, TFP growth rate, IRR to R&D investment and impacts of technological diversification on them were analyzed. All correlation analyses among them revealed that Canon demonstrated the highest significance.

Inducing factors of technological diversification were analyzed and both IRR to R&D investment and sales were identified as sources of Canon's technological diversification.

Noteworthy is that while Canon's technological diversification increased as its sales increased, reverse trends were observed in other electrical machinery firms, which supports a postulate of diversification paradox. This demonstrates that Canon, against such paradox, sustained its technological diversification consistently fully utilizing its sales increase.

These results demonstrate that Canon constructed a sophisticated virtuous cycle between high level of IRR to R&D investment, technological diversification and increase in operating income to sales. These observations provide noteworthy suggestions to firms, particularly electrical machinery firms amidst megacompetition as follows:

(i) Canon's technological diversification strategy is beyond the discussion on selection and concentration as well as diversification paradox leading to a new diversification theory in an information society.

(ii) Canon's diversification strategy provides a constructive suggestion for effective utilization of spillover technology which is considered the key of competitiveness in an increasing trend in global technology spillover.
(iii) Thus, Canon's technological diversification trajectory provides a constructive suggestion to best utilization of potential resources in innovation by constructing an effective virtuous cycle.

Future works should focus on the adaptability of Canon's business model based on such technological diversification strategy to other firms facing similar situation.

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