NORTH-HOLLAND

Technological Forecasting & Social Change
68 (2001) 81–104

Technological Forecasting and Social Change

Hierarchical impacts of the length of technology waves: An analysis of technolabor homeostasis

Chihiro Watanabe[a,b,*], Bing Zhu[a,b], Toshinori Miyazawa[a]

[a]*Department of Industrial Engineering and Management, Tokyo Institute of Technology, Tokyo, Japan*
[b]*International Institute for Applied Systems Analysis (IIASA), Laxenburg, Austria*

Received 29 December 1999; received in revised form 12 May 2000; accepted 16 May 2000

Abstract

This work is based on the postulate that the hierarchical order of technology development can be maintained by a subtle balance between technology waves having different lengths, and that the current collapse of the "virtuous cycle" between technology development and economic growth can be attributed to a stall in the balance of technology waves. This paper examines the subtle technolabor relationship of Japan's electrical machinery industry, and supports such phenomena by demonstrating the hierarchical impacts of the length of technology waves. © 2001 Elsevier Science Inc. All rights reserved.

Keywords: Technology waves; Technolabor homeostasis; Technometabolism; Assimilation capacity

1. Introduction

Technology can be described by a multilayer dynamic system incorporating economic, social, and geographical circumstances. It grows, develops, and matures by constructing a "virtuous cycle" between various factors, and stagnates, decays, and diminishes as this virtuous cycle collapses. This nature can be defined as "technometabolism" [1].

The stagnation of technology development has become a crucial structural problem common to many advanced economies [2]. Similarly, there is evident apprehension in Japan the collapse of the "virtuous cycle" between technological development and economic growth [3,4].

* Corresponding author. Dept. of Industrial Engineering & Management, Tokyo Institute of Technology, 2-12-1 Ookayama, Meguro-ku, Tokyo 152-8552 Japan. Tel.: +81-3-5734-2248; fax: +81-3-5734-2252.
E-mail address: chihiro@me.titech.ac.jp (C. Watanabe).

PII: S0040-1625(00)00106-2

Tansley [5], who postulated a concept of an ecosystem as a master template, pointed out that every system has a similar identical function, and this is a natural consequence of the interactions and mutual control between elements constituting the system. Koestler [6], in his book, "The Ghost in the Machine," also postulated a concept of system hierarchy.

In this work, we first postulate that the hierarchical order in a "techno-metabolism" is maintained by a subtle balance between several waves of technological innovation. Since the identification of long waves in the development of an economy by the Dutch economist van Geldren and the Russian economist Kondratiev, extensive work has been conducted in light of the elucidation of technological innovation progress [7]. Jos Delbeke [8], in his critical survey on recent long-wave theories, classified major theories into four types (1) those that consider the role of innovation to be crucial (e.g., Schumpeter and Mensch [9,10]; (2) capital theories (e.g., Mandel and Forrester [11]); (3) labor theory (e.g., Freeman [12,13]; and (4) raw materials and foodstuffs theory (e.g., Rostow [14]). Among these theories, Freeman pointed out the significance of the impact of a particular wave of innovation on employment, noting that it provided both employment generation and displacing effects.

Particularly noteworthy is van Duijn [15–17], who constructed a synthesis by combining the innovation theory of Schumpeter and Mensch, a hypothesis for the life cycle of industry along an S-curve, and Forrester's multiplier accelerator mechanism of investment, which intensified the growth and saturation of basic innovation. He also postulated the significant role of time lags essential for the unique behavior and length of a wave of innovation. Because of the significant role of time lags, impacts of innovation could be considered coevolution of various types of waves of innovation. Van Duijn postulated the following variations to the simple life-cycle pattern of waves of innovation as illustrated in Fig. 1: (1) substitution: faced with stagnating demand, an industry might develop follow-up products so that overlapping life-cycles result (e.g., substitution of color TV for black-and-white TV); (2) extensions of life cycle: alternatively, new uses may be found for an existing product so that its life-cycle is extended (e.g., nylon); (3) change in technology: after the product life-cycle is completed, use of the product changes and a new cycle is started (e.g., a bicycle originally used as a means of transportation is later used as a recreational vehicle); and (4) extended maturity phase: a product becomes an integral part of a nation's consumption pattern, not being given new uses nor being replaced by alternatives (e.g., consumer durables such as the refrigerator and vacuum cleaner).

Based on van Duijn's postulations, particularly the significant role of time lags, the life-cycle of industry along an S-curve, and coevolution of various types of waves of innovation,[1] we also postulate that the current collapse of the "virtuous cycle" between technology development and economic growth [4] in Japan can be attributed to a stall in the balance of these waves. This stall is similar to the lull between "sets" in ocean waves. The analysis presented here will demonstrate this phenomenon by looking at Japan's electrical machinery industry,[2] particularly by examining the subtle techno-labor relationship that exists in this leading industry.

[1] Technology waves are often thought of as multiple S-curves replacing one another, as demonstrated by Modis [18] and Twiss [19].

[2] The electrical machinery accounts for the biggest share of GDP, ranks highest in R&D intensity, and plays a "normative" role in determining industry wage levels (see footnote 7) in Japan's manufacturing industry.

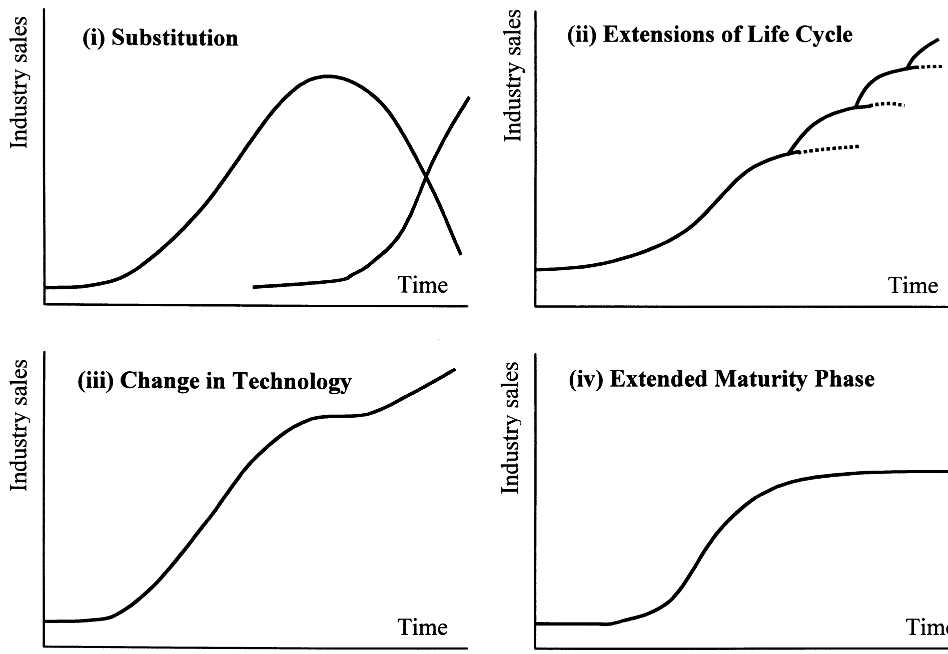


Fig. 1. Variations to the simple life-cycle pattern of technological innovation. Source: J. J. van Duijn, The Long Wave in Economic Life [16].

A number of studies have attempted to identify the impact of technology development and diffusion trajectories on the socio-economy (e.g., Price [20] and Rogers [21]). The mechanism of technology substitution for scarce resources as a source of Japan's unique techno-managerial system has also been studied (e.g., Watanabe [22,23]). However, no one has taken the approach of analyzing the hierarchical impacts of the length of technology waves on the socio-economy, particularly on the subtle techno-labor relationship aiming at maintaining maximum social welfare while minimizing inflation.

The next section of this article reviews the dynamic balance between R&D, technology development and growth, and stagnation. Then we analyzes the collapse of techno-labor homeostasis. Then we provide a warning of the collapse of the cultivated system of assimilation capacity. The last section briefly summarizes the implications for technology development.

2. Dynamic balance between R&D, technology development and growth, and stagnation

2.1. Technology substitution for scarce resources

Japan has achieved sustainable development by focusing its efforts on improving the productivity of relatively scarce resources during each respective era of its development [4]. This success is a result of industry's efforts to substitute technology for scarce resources,

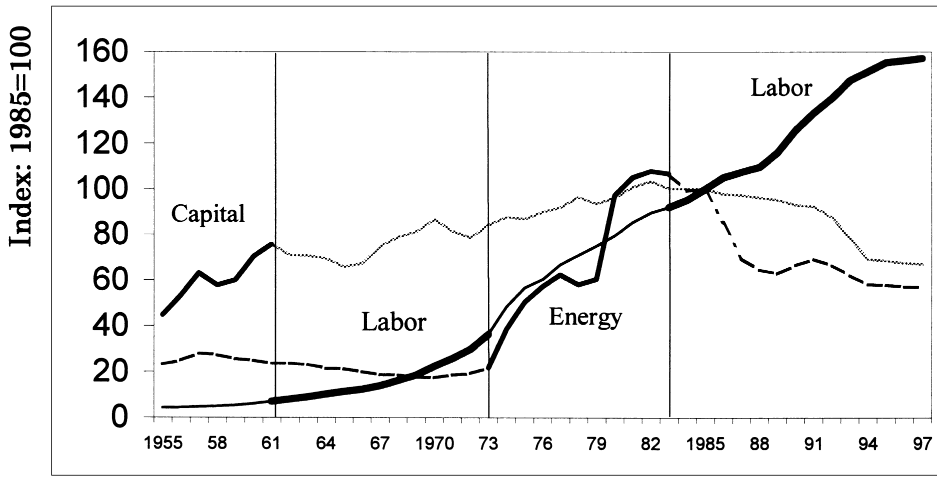


Fig. 2. Trends in prices of production factors in the Japanese manufacturing industry (1955–1997) — Index: 1985 = 100. Source: annual report on National Accounts (Economic Planning Agency) and others (see [22–24]).

leading to further technological innovation [22,23]. Fig. 2 illustrates trends in the prices of production factors in the Japanese manufacturing industry over the period 1955–1997. Provided that scarcity of resources leads to price increases, Fig. 2 demonstrates that scarce resources (production factors that demonstrates the highest price increases) shifted from capital in the 1950s to labor in the 1960s, and energy following the first energy crisis in 1973 to the mid-1980s. Currently, labor is the scarcest resource in the context of Japan [23].

Fig. 3 presents trends in the change rate of productivity of production factors in the Japanese manufacturing industry over the same period that demonstrate that the change rate of productivity shifted corresponding to the shift of scarceness of respective production factors as illustrated in Fig. 2. Fig. 3 also demonstrates that labor currently shows the highest change rate of productivity as it is the scarcest resource.

The trends shown in Figs. 2 and 3 demonstrate that Japan's manufacturing industry focused its efforts on improving the productivity of scarce resources in each respective era.

Fig. 4 shows trends in substitution and complementarity among labor, capital, energy, and technology in the Japanese manufacturing industry for 1955–1997 by measuring Allen partial elasticity of substitution[3] using a translog cost function [22,23]. These trends correspond to technology substitution for scarce resources to improve the productivity of such resources. Fig. 4 clearly demonstrates technology substitution for labor and energy (after 1973), and proves the above hypothetical view that Japan's success in achieving sustainable development can be attributed to technology substitution for scarce resources aimed at improving the productivity of scarce resources. However, if we look at these

[3] Allen partial elasticity of substitution (σ_{ij}) indicates a substitution or complement relation between i and j as follows (see, e.g., [22,23]): $\sigma_{ij} > 0.1$: substitution, $0.1 \geqslant \sigma_{ij} \geqslant -0.1$: neutral, and $-0.1 > \sigma_{ij}$: complement.

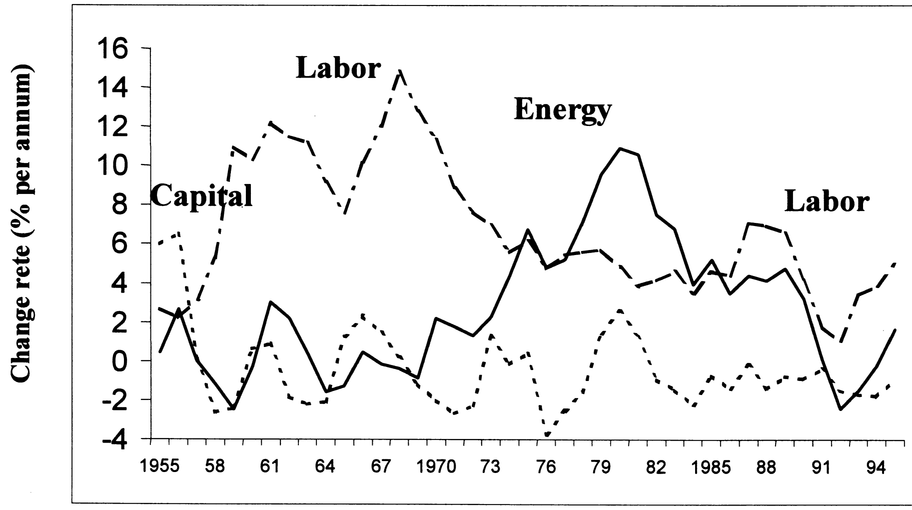


Fig. 3. Trends in change rate of productivity of production factors in the Japanese manufacturing industry (1955–1997) — 3-year moving average (%). Source: same as Fig. 2.

trends carefully, we can note that technology substitution for labor and energy has shown little or no advancement.

2.2. Stagnation of technology substitution for scarce resources

Due to a reduction in R&D efforts and an illusion created between nominal and real prices during the bubble economy[4] [3], Japan's elaborate system for inducing R&D deteriorated, resulting in a lower R&D intensity (ratio between R&D expenditure and sales) [4,25].

Fig. 5 illustrates trends in R&D intensity in Japan's overall manufacturing industry and electrical machinery industry over the period 1980–1996. We can note stagnation in R&D intensity, particularly in the ratio between R&D expenditure and sales measured by value using fixed prices,[4] in Japan's manufacturing industry starting from the years of the bubble economy (1987–1990). This trend accelerated in the years after the bursting of the bubble economy in 1991.

There was also a conspicuous downturn in the electrical machinery industry, which plays a leading role in Japan's manufacturing industry, as demonstrated by its significant GDP share (Fig. 6). The industry has the highest R&D intensity, and plays a "normative" role in determining wage levels in Japan's manufacturing industry (see footnote 7).

The decline in R&D intensity noted above stimulated a "vicious spin cycle" between R&D and economic growth [4] leading to a decrease in the marginal productivity of

[4] Although R&D intensity is a ratio, due to differences in deflators for R&D expenditures and sales (the R&D deflator exceeded the sales deflator as R&D expenditure shares a higher ratio of expenditure for land, buildings, and labor (researchers) than sales), particularly during and after the period of the bubble economy, R&D intensity measured by current prices does not reflect real the state of R&D stagnation [3].

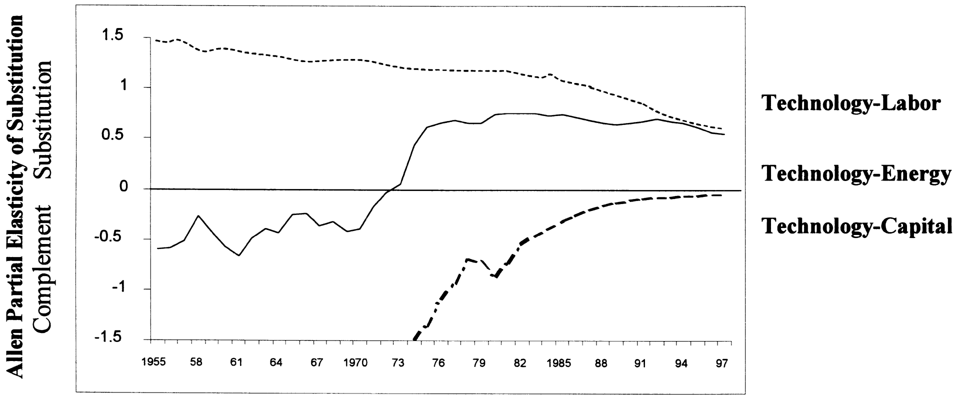


Fig. 4. Trends in substitution and complement among labor, capital, energy, and technology in the Japanese manufacturing industry (1955–1997). Allen partial elasticity of substitution. Source: see [23].

technology particularly after the bursting of the bubble economy in 1991 [1,23,26] as illustrated in Fig. 7.

Fig. 7 illustrates trends in the marginal productivity of technology (rate of return to R&D investment: RRR) in three of Japan's leading manufacturing industries (electrical machinery, chemicals, and primary metals) over the period 1960–1997. As can be seen, there was a dramatic decrease in RRR after the bursting of the bubble economy. Although there was a slight relaxation after 1995 due to devaluation of the yen, the level was much lower than the level in 1990.

Furthermore, a decrease in the marginal productivity of technology resulted in a decrease in the elasticity of technology substitution for other production factors. This was particularly the case for labor, the scarcest resource, as illustrated in Fig. 8.[5] Declining marginal productivity of technology also stimulated a collapse of the subtle mechanism of technology substitution.

Fig. 9 illustrates trends in the labor saving investment share of total investment in Japan's electrical machinery industry over the period 1977–1997. As can be seen, there are decreasing trends corresponding to the decrease in the elasticity of technology substitution for labor. These trends demonstrate the stagnation of technology substitution for labor.

[5] The general idea of primary governing factors of substitution between technology and labor can be provided by the following equation.

$$\sigma_{tl} = \frac{\frac{\Delta(T/L)}{(T/L)}}{\Delta\left(\frac{\partial Y/\partial L}{\partial Y/\partial T}\right) \Big/ \left(\frac{\partial Y/\partial L}{\partial Y/\partial T}\right)}$$

where σ_{tl} is the elasticity of technology substitution for labor; T is the technology knowledge stock [see Eq. (8) in Appendix]; and L is the labor. This equation suggests that a decrease in marginal productivity of technology ($\partial Y/\partial T$) leads to a decrease in technology substitution for labor.

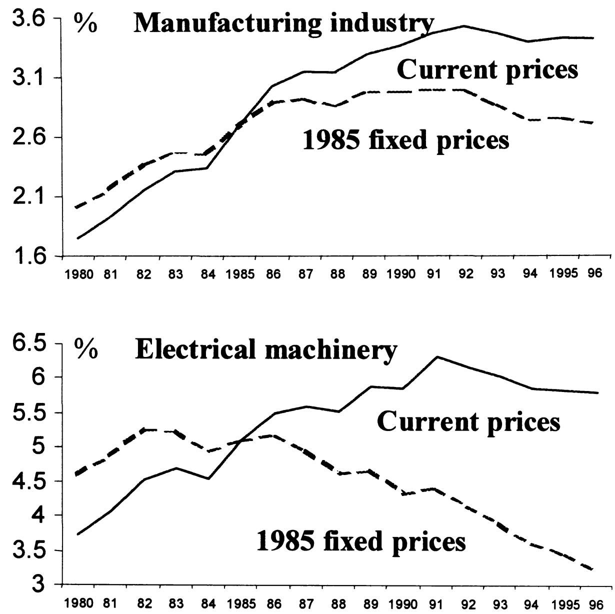


Fig. 5. Trends in R&D intensity in Japan's manufacturing industry (1980–1996). Sources: report on the survey of research and development (Management and Coordination Agency), Economic Statistics Annual (The Bank of Japan), and White Paper on Japan's Science and Technology (Science and Technology Agency).

The above analyses demonstrate that the stagnation of R&D activities in Japan's manufacturing industry during the bubble economy further accelerated after its bursting (Fig. 5), resulting in a decrease in marginal productivity of technology (Fig. 7) [1,23]. This stimulated the stagnation of technology substitution for scarce resources, particularly labor

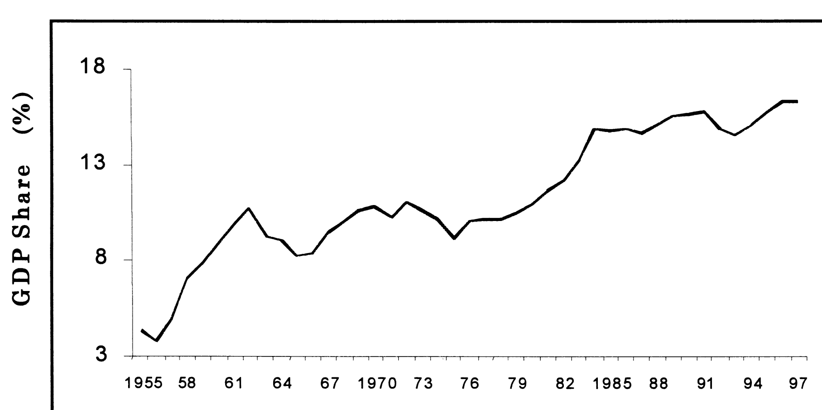


Fig. 6. Trends in GDP share of Japan's electrical machinery industry (1955–1997)—GDP share in whole manufacturing industry (%). Sources: annual report on National Account (Economic Planning Agency).

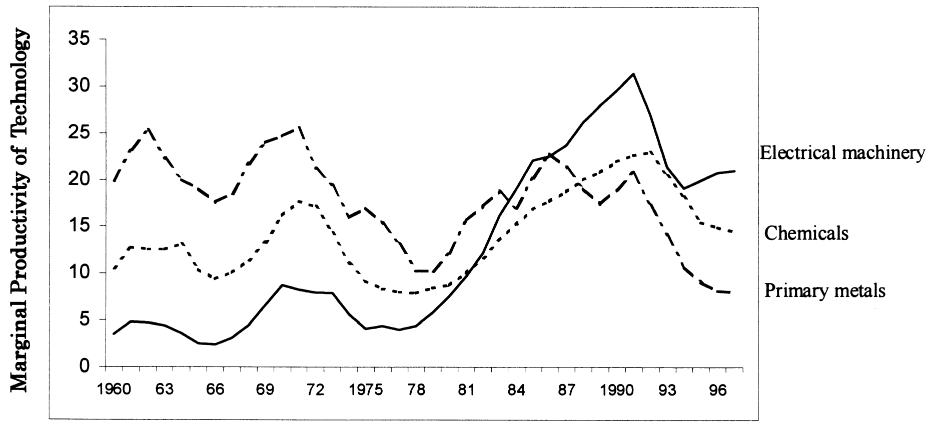


Fig. 7. Trends in rate of return to R&D investment (marginal productivity of technology) in Japan's major manufacturing industries (1960–1997)—%. Sources: see analysis by the authors using simultaneous measurement of the service price of technology and internal rate of return to R&D investment (see [1] and [23]).

(Fig. 8). This substitution mechanism played an important role, and was a very important source of Japan's competitiveness.

3. Collapse of technolabor homeostasis

3.1. Concept of technolabor homeostasis

Japan's unique technomanagerial system seen in technology substitution for scarce resources can be observed in a "technolabor homeostasis." This homeostasis maintains a maximum social welfare position while simultaneously minimizing inflation. This is achieved by constructing a subtle dynamic balance between increases in productivity and wages as illustrated in Fig. 10 [27]. Fig. 10 indicates that, although wage increases contribute to increased welfare through income increases, it sometimes decreases welfare by increasing prices of commodities and decreasing employment opportunities. Similarly, it demonstrates the possibilities of both increased and constrained labor productivity. This corresponds to Freeman's postulate [12,13] regarding the significance of the impact of a particular wave of innovation on employment as it provides both positive and negative effects.

A hierarchical system of technology based on various technology waves with different life cycle lengths as postulated by van Duijn [16] (see Fig. 1) enabled this "technolabor homeostasis" to continue, as illustrated in Fig. 11. The system included three layers of waves: (1) a short wave, which contributes to daily improvement by stimulating learning through the market (this corresponds to van Duijn's "Extended maturity phase," see Fig. 1); (2) a medium wave, which contributes to increases in productivity by technology incorporation in capital (similarly, "Change in technology" and "Extension of life cycle"); and (3) a long wave, which contributes to technology substitution for scarce resources (similarly,

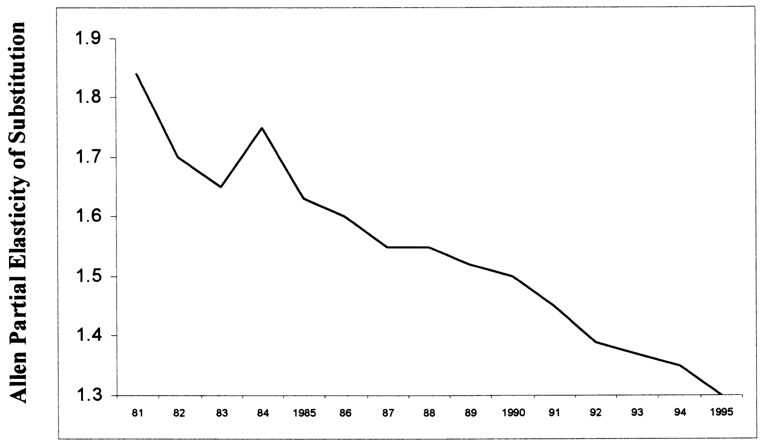


Fig. 8. Trends in elasticity of technology substitution for labor in Japan's electrical machinery industry (1981–1995). Sources: analysis by authors using a translog cost function (see [23]).

"Substitution"). The effects of the short wave appear simultaneously, and provide direct impacts on wages in an "inorganic" way, the effects of the medium wave appear with a certain short time lag and provide indirect impacts on wages in an "organic" way, while the effects of the long wave appear, generally, with a long time lag and provide impacts on wages in an "inorganic" way. These three waves contribute to maintaining a subtle dynamic balance by constructing a subtle hierarchical system with various feedback loops.

A collapse of the technology substitution system as anticipated by the analyses in Section 2 corresponds to the stagnation of the long wave, which plays a critical role at the highest level of a hierarchical system of technology. The result is a lull in the interconnection and frequency of the other waves, stimulating a breakdown of the subtle system.

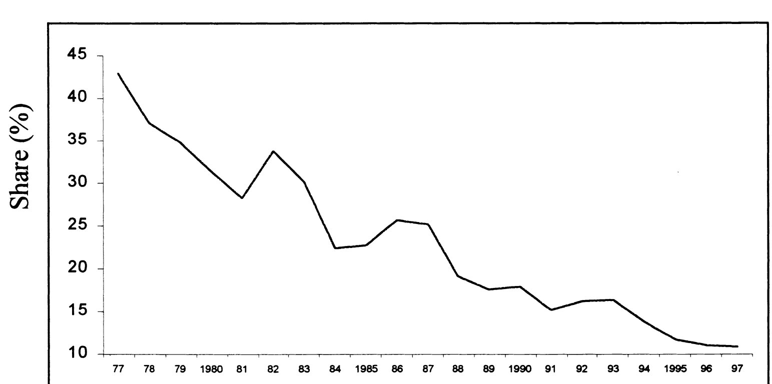


Fig. 9. Trends in the labor saving investment share of total investment in Japan's electrical machinery industry (1977–1997)—%. Sources: Annual Report on Survey of Capital Investment (Japan Development Bank).

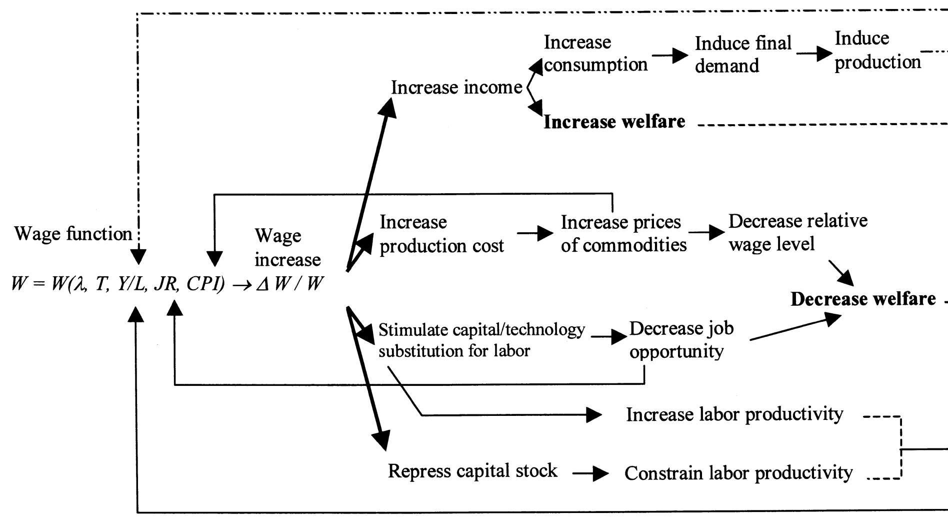


Fig. 10. Scheme of the impacts of wage increases on the trajectory of economic growth. *W*: wage; λ: technology improvement due to institutional change; *T*: technology knowledge stock [see Eq. (8) in Appendix]; *Y/L*: labor productivity; *JR*: active opening ratio; and *CPI*: consumer price index.

Fig. 12 analyzes the correlation between technology knowledge stock [accumulation of R&D investment measured in money terms; see Eq. (A8) in Appendix] and the ratio between wages and productivity. It suggests certain structural changes emerged in both 1986 and 1991 corresponding to the stagnation of R&D activities, resulting in the stagnation of technology substitution for labor. Fig. 12 suggests that Japan's electrical

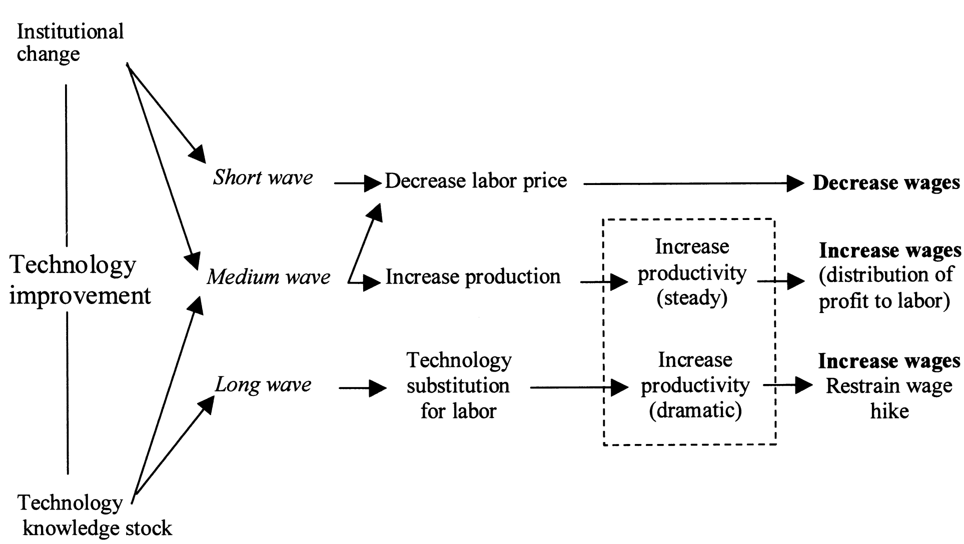


Fig. 11. Scheme of the impacts of technology improvement on wages.

machinery industry enjoyed higher productivity increases than wage increases supported by an increase in technology knowledge stock. However, the balance changed significantly from both 1986 (the year of the start of the bubble economy) and 1991 (the year of the bursting of the bubble economy).

3.2. Technology contribution to maintaining technolabor homeostasis

A typical subtle dynamic balance can be seen in the balance of increases between productivity and wages as observed in the "Productivity Based Principle" postulated by the Japan Federation of Employers' Association in 1969. This principle suggests that wage increases without inflation can be enjoyed if the wage increase rate is fixed at the same rate as a productivity increases.[6]

Technology contributes to maintaining this subtle dynamic balance, particularly the time lag between technology knowledge stock formation and its impact on wage. This contribution has been analyzed focusing on the electrical machinery industry, which plays leading role in Japan's manufacturing industry and "normative" role in determining the wage level in Japan's manufacturing industry.[7]

The analysis was conducted using a technology incorporated Cobb-Douglas-type wage profile function [Technology Incorporating Wage Profile Function (TIWPF): see Appendix] and monthly data covering 169 months between February 1983 and March 1997. This data was divided into five periods in accordance with Japan's business cycle during the period.[8]

---

[6] The Productivity Based Principle is derived from the following simple equation: Under competitive circumstances, labor elasticity ω can be defined

$$\omega = \frac{P_l \cdot L}{P_y \cdot Y}, \ P_l = \omega \cdot \frac{Y}{L} \cdot P_y$$

where Y, L, P_y, and P_l are production, labor, deflator, and labor prices (wages), respectively. The change rate of both sides with ω constant condition

$$\frac{\Delta P_l}{P_l} = \frac{\Delta(Y/L)}{Y/L} + \frac{\Delta P_y}{P_y}$$

where

$$\Delta P_l = \frac{dP_l}{dt}, \Delta P_y = \frac{dP_y}{dt}.$$

Without an inflation condition $\left(\frac{\Delta P_y}{P_y} = 0\right)$ leads the above equation to $\frac{\Delta P_l}{P_l} = \frac{(Y/L)}{\Delta Y/L}$

[7] A questionnaire to firms on factors taken into account for wage increase decisions conducted by the Ministry of Labor in 1996 demonstrated that 28.0% of firms used the electrical machinery industry's wage level as a yardstick for their own wage level decisions, followed by the iron and steel industry (19.2%), automobile industry (17.7%), and private railway industry (3.6%).

[8] The Economic Planning Agency, using a diffusion index (DI), identified peaks and troughs of Japan's economy over the period February 1983–March 1997 as follows: trough: February 1983; peak: June 1985; trough: November 1986; peak: February 1991; trough: October 1993; and peak: March 1997.

$$W_t = W\{\lambda_{t-m_1}t, T_{t-m_2}, [IIP(EP*H)]_{t-m_3}, JR_{t-m_4}, CPI_{t-m_5}\}$$
$$= Ae^{\lambda_{t-m_1^t}} T^{\alpha}_{t-m_2}[IIP/(EP*H)]^{\beta}_{t-m_3}(JR)^{\gamma}_{t-m_4}(CPI)^{\delta}_{t-m_5} \quad (1)$$

where W is the wage; s is the time span of the same period in the preceding year; λ is the technology improvement due to institutional change; T is the technology knowledge stock; IIP is the index of industrial production; EP is the employed persons; H is the work hours; JR is the active openings ratio; CPI is the consumer price index; m_i (i = 1–5) is the time lag; and α, β, γ, δ are the elasticities of respective governing factors.

Taking the balance of W_t and W_{t-s} by logarithm we can obtain Eq. (2):

$$\ln\frac{W_s}{W_{t-s}} = s\lambda_{t-m_1} + \alpha\ln\frac{T_{t-m_1}}{T_{t-s-m_2}} + \beta\frac{[IIP/(ER*H)]_{t-m_3}}{[IIP/(ER*H)]_{t-s-m_3}}$$
$$+\gamma\ln\frac{JR_{t-m_4}}{JR_{t-s-m_4}} + \delta\ln\frac{CPI_{t-m_5}}{CPI_{t-s-m_5}} \quad (2)$$

To avoid seasonal variation, the ratio of the same month of the preceding year was used as indicated in Eq. (2) [28].

On the basis of this equation, by introducing time lags that demonstrate the real behavior of wage formation in the marketplace, the identification of monthly trends in the governing factors of wage formation in Japan's electrical machinery industry was attempted for the period February 1983–March 1997. Table 1 summarizes the results of the analysis for five periods. As shown in Fig. 11, the impacts of technology improvement on wages can be seen

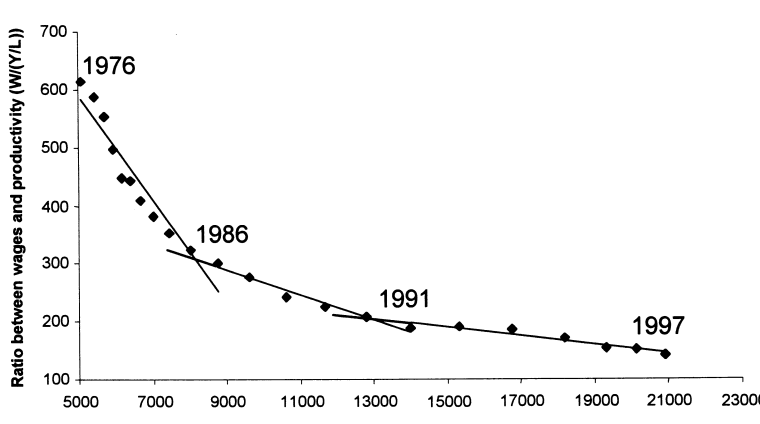


Fig. 12. Trends in the correlation between technology knowledge stock and ratio between wages and productivity in Japan's electrical machinery industry (1976–1997).

Table 1
Trends in factors governing wage formation in Japan's electrical machinery industry (1983–1997)

	TFP							
	IC λ	*T* α	*IIP*/(*EP***H*) β	*CPI* δ	*JR* γ	adj. R^2	DW	AIC*
1. 83/2–85/6	−0.0132	3.26	0.07	0.24	0.1	0.939	1.25	−319.5
	(−9.71)	(−11.69)	(−3.45)	(−1.45)	(−2.86)			
	[0]	[60]	[2]	[0]	[0]			
2. 85/6–86/11	−0.0087	2.39	0.05	0.53	−0.01	0.851	1.79	−207.2
	(−2.68)	(−3.16)	(−2.96)	(−2.79)	(−0.42)			
	[0]	[51]	[1]	[0]	[1]			
3. 86/11–91/2	−0.0005	0.43	0.08	0.24	−0.01	0.601	1.3	−531.1
	(−0.27)	(−1.77)	(−2.79)	(−1.47)	(−0.39)			
	[0]	[28]	[1]	[0]	[1]			
4. 91/2–93/10	−0.1236	15.47	0.15	−0.59	−0.04	0.728	2.07	−316.4
	(−4.56)	(−4.69)	(−5.47)	(−1.74)	(−1.80)			
	[0]	[12]	[1]	[0]	[1]			
5. 93/10–97/3	−0.0017	0.75	0.05	−0.21	0.03	0.691	2.03	−435.3
	(−2.12)	(−5.31)	(−1.45)	(−1.45)	(−2.19)			
	[0]	[3]	[1]	[0]	[1]			

Figures indicate coefficients. Figures in parentheses indicate *t*-value. Figures in square brackets indicate time lag. *IC:* institutional change; *T:* technology knowledge stock; *IIP:* index of industrial production; *EP:* employed persons; *H:* work hours; *CPI:* consumer price index; and *JR:* active openings ratio.

* AIC: Akaike Information Criteria for inspecting fittability of estimated models.

through three waves: a short wave, chiefly of institutional change; a medium wave of technology stock and institutional change; and a long wave, chiefly of technology knowledge stock. The effects of these waves can be seen in λ, β, and α in Table 1.

Looking at Table 1 we note that the impact of the short wave (λ) is relatively small and negative. This coincides with the suggestion in the early part of this section. The impacts of the consumer price index (*CPI*: δ) and active openings ratio (*JR*: γ) follow this short wave. The impacts of the medium wave incorporated into productivity (β) are bigger than the impacts of the short wave, which appear with a 1 to 2 month time lag. While the impacts of the long wave (α) are strong and significant, they appear with a long time lag, which decreases as time goes from 60 months (Feb. 1983–June 1985), 51 months (June 1985–Nov. 1986), 28 months (Nov. 1986–Feb. 1991), 12 months (Feb. 1991–Oct. 1993), and 3 months (Oct. 1993–March 1997), similar to the decrease in technology substitution for labor illustrated in Fig. 8.

The above result suggests that the technology contribution shifted from a substantial one aiming at substituting for labor to a relatively minor improvement. The dramatic decrease, starting from 1986 and 1991, coincides with structural changes regarding the relationship between increasing technology knowledge stock and the wage–productivity ratio, as illustrated in Fig. 12.

Furthermore, the correlational trends between increasing technology knowledge stock and decreasing time lag in each respective period suggest similar behavior as an epidemic function.

On the basis of the above finding, by using the following epidemic equation, a time lag function that indicates trends in the time lag between technology knowledge stock formation and its impact on wages was developed:[9]

$$m = m^{\#} - \frac{m^{\#}}{1 + e^{-(aT+b)}} \tag{3}$$

where m is the time-lag between technology knowledge stock formation and its impact on wages; $m^{\#}$ is the ceiling of time lag; T is the technology knowledge stock; and a and b are coefficients.

Fig. 13 illustrates trends in the time lag between technology knowledge stock formation and its impact on wages estimated by applying an epidemic function.

To incorporate a time lag function as part of technology knowledge stock in the Technology Incorporating Wage Profile Function (TIWPF), the technology knowledge stock ratio ($T_t/T_{t\text{-}s}$) in Eq. (2) over the period February 1983–March 1997 was developed as a function of time (t) as follow:[10]

$$T_t/T_{t-s} = 1.055 + 4.788 * 10^{-4}t + 1.135 * 10^{-5}t^2 - 1.377 * 10^{-7}t^3 + 3.370 * 10^{-10}t^4$$

(34.40) (27.00) (−24.02) (15.93)

$adj.\,R^2$	DW[10]	
0.963	0.01	(4)

Utilizing the time lag measured by Eq. (3) and substituting $t - m$ for t in Eq. (4), TIWFF was obtained using the time lag function. Results of the identification of factors governing wage formation based on this function are summarized in Table 2.

Table 2 demonstrates that the results of the analysis of trends in factors governing wage formation using a time lag function is statistically more significant than the analysis in Table 1, which depended on the average time lag. This comparison demonstrates the significance of the trajectory illustrated in Fig. 13 using the epidemic function estimation.

3.3. Collapse of the subtle dynamic balance

Provided that technology knowledge stock plays a significant role with respect to medium and long waves, particularly on the long wave, as illustrated in Fig. 11, such a dramatic decrease in time lag between technology knowledge stock formation and its impact on wages provides a significant on "technolabor homeostasis."

[9] Change in time lag by unit change in technology stock can be expressed as $dm = am(m^{\#} - m)dT$. Therefore, $dm/dT = am(m^{\#} - m)$. Eq. (3) is obtained by solving this differential equation (see, e.g., [18]).

[10] Because Eq. (4) is a function of time t, it naturally contains autocorrelation, and DW (Durbin-Watson ratio) should be a low value.

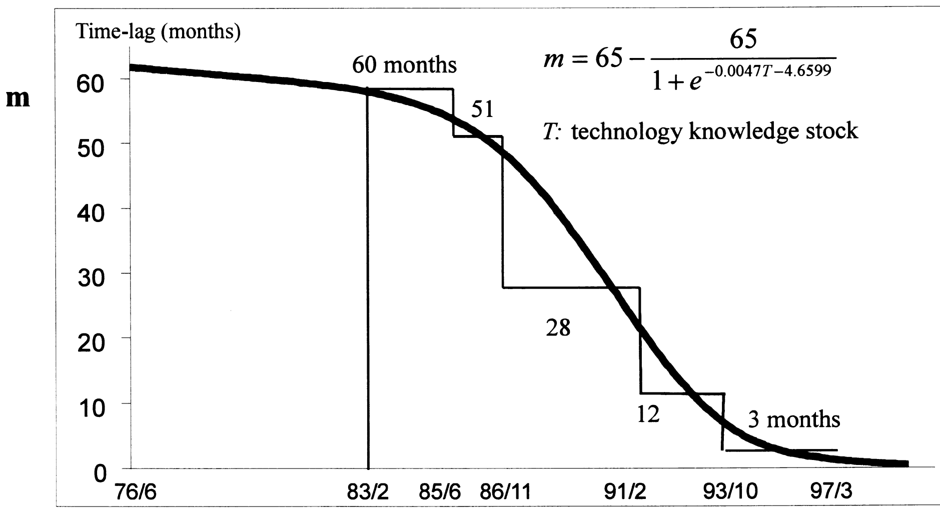


Fig. 13. Trends in time lag between technology knowledge stock formation and its impact on wages in Japan's electrical machinery industry (1976–1997).

Table 3 attempts to show this impact by analyzing trends in technology contribution to minimizing the discrepancy between changes in wages and productivity essential to wage increases without inflation (see footnote 6). Looking at coefficient b_1, which indicates the magnitude of technology contribution to performance by minimizing the above discrepancy, we note that such a magnitude demonstrated a dramatic decrease from 1986 similar to the

Table 2
Trends in factors governing wage formation in Japan's electrical machinery industry (1983–1997)—using time lag function for technology

	TFP							
	IC λ	T α	IIP/(EP*H) β	CPI δ	JR γ	adj. R^2	DW	AIC
1. 83/2–85/6	−0.0167	4.25	0.03	0.17	0.21	0.939	1.66	−319.4
	(−10.84)	(−13.33)	(−1.64)	(−1.13)	(−5.74)			
	[0]	[m(T)]	[2]	[1]	[0]			
2. 85/6–86/11	−0.0098	2.59	0.04	0.43	−0.01	0.862	2.08	−208.6
	(−2.78)	(−3.34)	(−2.74)	(−2.11)	(−0.39)			
	[0]	[m(T)]	[1]	[0]	[1]			
3. 86/11–91/2	−0.0004	0.48	0.09	0.09	−0.01	0.652	1.43	−538.3
	(−0.44)	(−3.15)	(−3.41)	(−0.58)	(−1.57)			
	[0]	[m(T)]	[1]	[0]	[1]			
4. 91/2–93/10	−0.0253	3.51	0.15	−0.58	−0.02	0.835	2.05	−333
	(−4.56)	(−4.69)	(−5.47)	(−1.74)	(−1.80)			
	[0]	[m(T)]	[1]	[0]	[1]			
5. 93/10–97/3	−0.0032	0.97	0.09	−0.2	0.03	0.711	2.17	−438
	(−2.67)	(−4.61)	(−3.09)	(−1.48)	(−1.91)			
	[0]	[m(T)]	[1]	[0]	[1]			

Table 3
Trends in technology contribution to minimize discrepancies between changes in wages and productivity in Japan's electrical machinery industry (1983–1997)

	$\lvert\Delta W/W - \Delta(Y/L)\rvert = a + b_1\Delta T/T + b_2 t$			
	b_1	b_2	adj. R^2	DW
1. 83/2–85/6	− 16.66 (− 8.94) *1	− 0.01 (− 8.40) *1	0.804	2.77
2. 85/6–86/11	− 14.97 (− 1.47) *20	0.01 (1.14) *30	0.468	2.70
3. 86/11–91/2	− 3.30 (− 1.46) *15	0.00 (1.01) *30	0.491	1.08
4. 91/2–93/10	− 2.58 (− 1.85) *10	—	0.561	1.81
5. 93/10–97/3	36.46 (2.22) *5	0.04 (2.28) *5	0.442	2.34

Y/L: Productivity $(= IIP/(EP * H))$; *t*: time trend.
* 1, * 5, * 15, * 20, and * 30 indicate significance at the 1, 5, 15, 20, and 30% level, respectively.

analyses in Fig. 12 and Table 1. Noteworthy is the dramatic change since 1993, which coincides with similar results in Tables 1 and 2.

On the basis of the above results with respect to an assessment of technology contribution to achieving wage increases without inflation by identifying the elasticity of technology

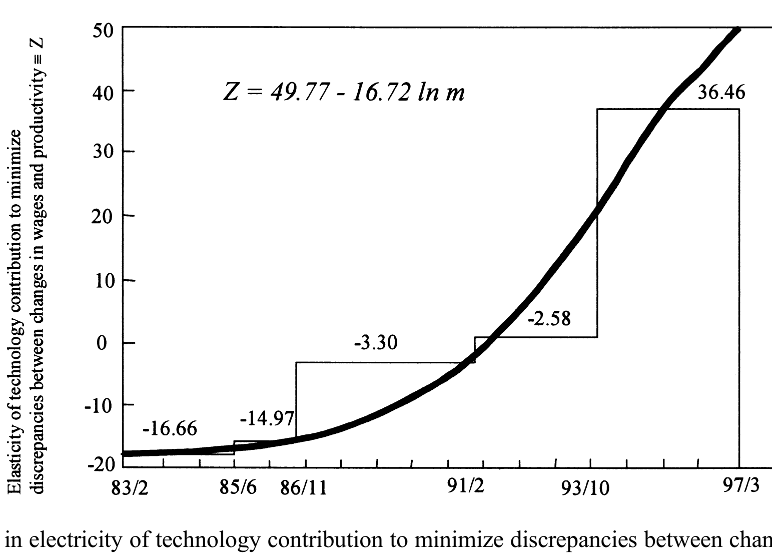


Fig. 14. Trends in electricity of technology contribution to minimize discrepancies between changes in wages and productivity in Japan's electrical machinery industry (1983–1997).

contribution to minimizing the discrepancy between changes in wages and productivity in five periods, Fig. 14, based on an approach similar to Fig. 13, analyzes trends in this elasticity. Fig. 14 demonstrates a similar result, decreasing (increased elasticity of technology contribution to minimize the discrepancies: *Z*) from 1986, accelerating from 1991, and finally resulting in a dramatic decrease from 1993.

Utilizing this estimated elasticity, Fig. 15 analyzes trends in the discrepancy between changes in wages and productivity, and the technology contribution to minimizing this discrepancy. Looking at Fig. 15 we note that technology continues to minimize this discrepancy until June 1991 as the value $b_1\ \Delta T/T(=0.020Z(\Delta T/T))$ remained negative. At this time the trend changes. This change can be attributed to a collapse of the hierarchical system caused by a stall in technology's substitution for labor.

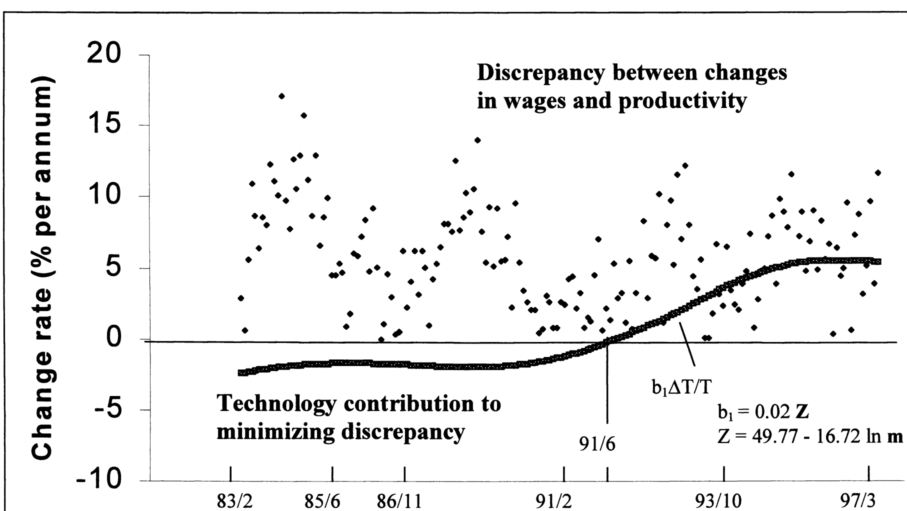


Fig. 15. Trends in discrepancy between changes in wages and productivity, and technology contribution to minimize discrepancies in Japan's electrical machinery industry (1983–1997).

$$|\Delta W/W - \Delta(Y/L)(Y/L)| = 0.114 + 0.020Z(\Delta T/T) - 0.001t \quad \text{adj.R}^2 \quad \text{DW}$$

$$(5.48)^{*} \qquad (6.06)^{*} \quad 0.352 \quad 1.44$$

* Significant at the 0.1% level.

$$Z = 49.77 - 16.72\ln m \quad (\text{Fig. } 14),$$

$$\text{m} = m^{\#} - \frac{m^{\#}}{1+e^{-(aT+b)}} \quad (\text{Fig. } 13).$$

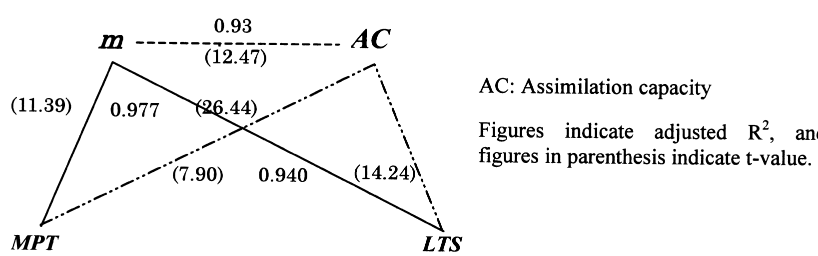
where m is the time lag between technology knowledge stock formation and its impact on wages; $m^{\#}$ is the ceiling of time lag; T is the technology knowledge stock; and a and b are coefficients.

4. Collapse of the cultivation system of assimilation capacity

As analyzed in Section 3, a collapse of the hierarchical system of technology waves due to the stagnation of substitution for labor in a subtle hierarchical system of technology resulted in a breakdown of "technolabor homeostasis," one of the notable aspects of Japan's unique technomanagerial system. This breakdown has a significant impact on assimilation capacity which assesses, selects, and internalizes technology spillover embodying technology into its own production system, and is thus closely relevant to "technolabor homeostasis."

Fig. 16 shows the governing factors of both assimilation capacity (*AC*) and the time lag of technology knowledge stock formation and its impact on wage (*m*), which can be considered an important proxy of the hierarchical system of technology waves. Looking at Fig. 16, we note that both *AC* and *m* are governed by technology substitution for labor (*LTS*) and marginal productivity of technology (*MPT*). Fig. 16 also shows that both have a strong correlation.

Table 4 demonstrates that the assimilation capacity of Japan's electrical machinery industry is strongly governed by both marginal productivity of technology and technology substitution



	adj. R^2	DW
1977-97		
$\ln m = -6.37 + 1.17 \ln MPT + 14.30 \ln LTS$ (11.39) (26.44)	0.977	1.32
1981-95		
$\ln AC = -3.71 + 0.97 \ln MPT + 4.25 \ln LTS$ (7.90) (14.24)	0.940	2.38
1981-95		
$\ln m = 1.33 + 2.44 \ln AC$ (12.47)	0.931	2.15

Fig. 16. Scheme of the technology wave function in Japan's electrical machinery industry (1977–1997).[a] Assimilation capacity (*AC*) is measured by the following equation:

$$AC = \left(1 - \frac{1}{\phi}\right) \cdot \frac{T_i}{T_s'} \quad 0 < AC < \frac{T_i}{T_s},$$

where T is its own technology stock; T_s is stock of spillover technology; and ϕ is the ratio of prices of spillover technology and own technology stock.

Table 4
Governing factors of assimilation capacity in Japan's leading manufacturing industries (1981–1995)

Electrical machinery	adj. R^2	DW
$\ln ACem = -3.71 + 0.97 \ln MPTem + 4.25 \ln LTSem$	0.940	2.38
(7.90) (14.24)		
Chemicals		
$\ln ACch = -12.10 + 2.73 \ln MPTch + 3.62 \ln LTSch$	0.971	1.57
(12.23) (20.25)		
Primary metals		
$\ln ACpm = -6.33 + 1.69 \ln MPTpm + 0.52 \ln LTSpm$	0.948	2.55
(9.55) (4.49)		

AC: assimilation capacity; *MPT*: marginal productivity of technology; and *LTS*: elasticity of technology substitution for labor.

for labor. Table 4 suggests that this is not specific to the electrical machinery industry. This pattern can also be observed in other leading manufacturing sectors such as chemical and primary metals.

Therefore, because of stagnation trends in R&D activities, which result in stagnation of the marginal productivity of technology and a subsequent decrease in technology substitution for labor, the assimilation capacity of these leading industries has decreased dramatically, as illustrated in Fig. 17.

The marginal productivity of technology, technology substitution for labor, assimilation capacity, and utilization of technology spillover create a cyclical structure, as illustrated in Fig. 18 [29]. As can be seen, a decrease in assimilation capacity results in a stagnation of technology spillover leading to GDP stagnation, which leads to a further decrease in assimilation capacity through a decrease in marginal productivity of technology and technology substitution for labor. The collapse of technolabor homeostasis can be attributed to the vicious cycle of R&D investment, assimilation capacity, technology spillover, TFP

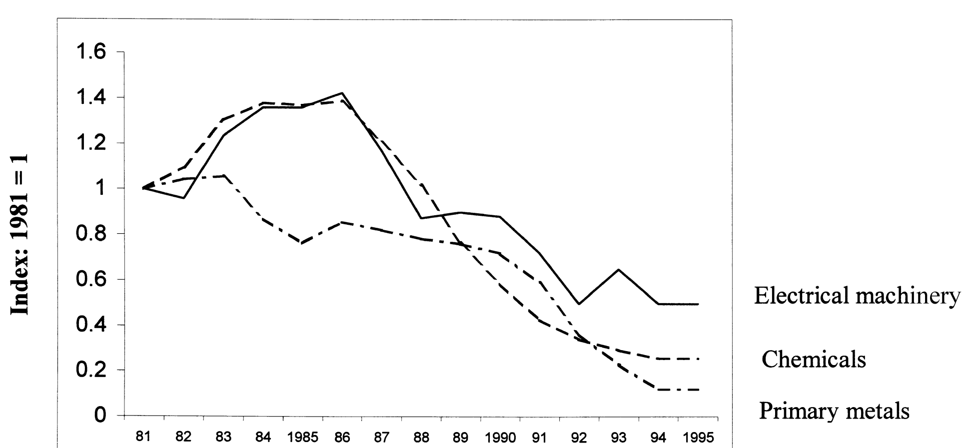


Fig. 17. Trends in assimilation capacity of Japan's major manufacturing industries (1981–1995)—index: 1981 = 1.

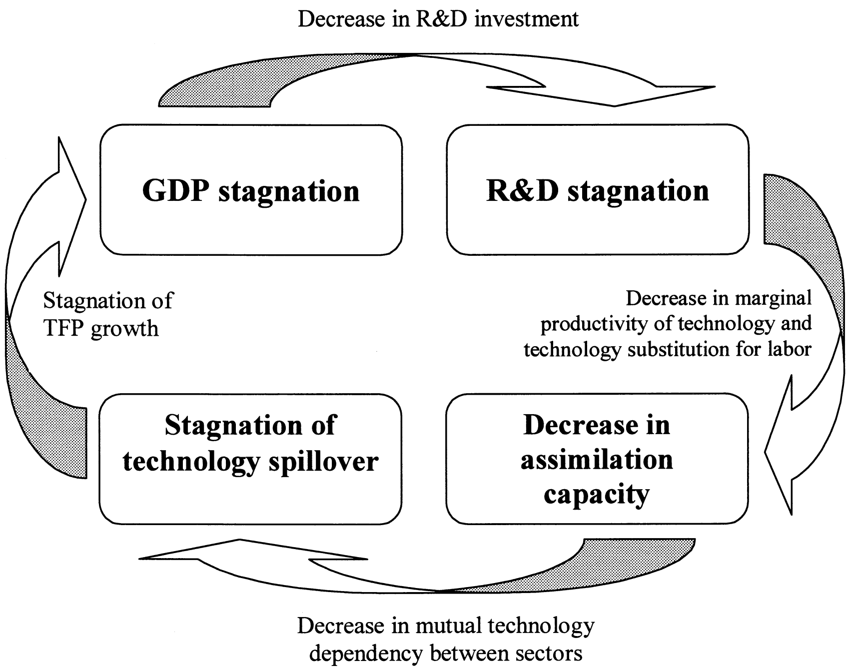


Fig. 18. The vicious cycle among R&D investment, assimilation capacity, technology spillover, TFP and production.

[total factor productivity, which represents technology improvement: see Eq. (A7) in Appendix] and production.

Currently, nearly all industrialized countries suffer R&D stagnation of some description [2,24,25]. On the other hand, rapid advancement of informatization and globalization stimulate global technology spillover [29].

Under each circumstances, the critical success factor is the ability to utilize global technology spillover for sustainable competitive advantage. This depends largely on assimilation capacity [26].

5. Implications

The Japanese electrical machinery industry was analyzed to demonstrate hierarchical order in a technometabolism based on the subtle balance between several waves of technological innovation. This work shows that the collapse of Japan's "virtuous cycle" is due to a stall in the four waves of technological innovation described earlier.

Key postulates can be summarized as follows: remediation of "Technolabor homeostasis" by recovering technology substitution for labor, through increasing systems redundancy, by means of stimulating mutual interaction between (a) optimal R&D investment, (b) learning exercise, and (c) improvement of assimilation capacity for effective utilization of technology spillover.

Appendix. Model synthesis and data construction

Technology Incorporating Wage Profile Function (TIWPF)

The production function is generally seen in the following way:

$$Y = f(L, K) \tag{A1}$$

where Y is the production (value added); L is the labor; and K is the capital stock.

The following cost function exists corresponding to the production function in (A1)

$$C = C(Y, P_l, P_k) \tag{A2}$$

where C is the gross cost; and P_l and P_k are prices of labor and capital, respectively.

Based on the assumptions concerning the competitive circumstances of prices and the linear homogeneity of production factors, the following equations are obtained:

$$\frac{\partial Y}{\partial L} = \frac{P_l}{P_y}, \frac{\partial Y}{\partial K} = \frac{P_k}{P_y} \tag{A3}$$

$$Y = \frac{\partial Y}{\partial L} L + \frac{\partial Y}{\partial K} K \tag{A4}$$

where P_y means prices of production (GDP deflator).

Substituting P_l/P_y and P_k/P_y for $\partial Y/\partial L$ and $\partial Y/\partial K$ in Eq. (A4) we obtain

$$P_l = P_y \frac{Y}{L} - P_k \frac{K}{L} \tag{A5}$$

Because $\psi = \psi\ (P_y,\ P_l,\ P_k)$ and $JR = h\ (K/L)$, prices of labor P_l can be expressed by the following equation[11]:

$$P_l = P\left(\psi, Y/L, P_y, JR\right) \tag{A6}$$

where ψ is the technology improvement (represented by Total Factor Productivity, TFP); and JR is the active openings ratio.

---

[11] $\psi = TFP = Y - X = \sum v_j p_j - \sum w_i q_i$

where

$$X = X(L, K), \sum w_i q_i = P_y, \text{and} \sum v_j p_j = P(P_l, P_k),$$

Correlation between active openings ratio (JR) and capital labor ratio (K/L) in Japan's manufacturing industry over the period 1981–1991 can be demonstrated as follows:

$$\ln JR = 4.11 + 1.51 \ln K/L - 0.25\ D \quad \text{adj. } R^2\ 0.933 \text{ DW } 1.72,$$
$$(10.85)(-4.14)$$

where D is the dummy variable (1985, 86, 87 = 1, other years 0).

Technology improvement ψ can be attributed to technology knowledge stock (T) and institutional change with a time trend (λt, where t is the time trend) as follows:

$$\psi = \psi(T, \lambda t) \tag{A7}$$

$$T_t = R_{t-m} + (1-\rho)T_{t-1} \tag{A8}$$

where T_t is the technology knowledge stock in time t; R_{t-m} is the R&D expenditure in time $t-m$; m is the lead time between R&D and commercialization; and ρ is the rate of obsolescence of technology.

Wage is defined as a crystal of socio-economic products reflecting sociowelfare demand for employees and the "imperfectness" of the real economy in the marketplace while centering on prices of labor.

Therefore, we define the wage profile function as follows:

$$W = W(P_l, SW, Adj) \tag{A9}$$

where SW is the social-welfare factors; and Adj is the adjustment of the imperfectness of the real economy in the marketplace.

To reflect sociowelfare factors and imperfectness of the real economy into the wage profile function, based on a theoretical analysis of factors governing the prices of labor, we postulated the following technology incorporating wage profile function (TIWPF):

$$W_t = W\left[\lambda_{t-m_1}t, T_{t-m_2}, (IIP/(EP*H))_{t-m_3}, JR_{t-m_4}, CPI_{t-m_5}\right] \tag{A10}$$

Eq. (A10) can be developed using a simple Cobb-Douglas type function as follows:

$$W_t = Ae^{\lambda t-mlt}T^{\alpha}_{t-m_2}\left[IIP\Big/(EP*H)^{\beta}_{t-m_3}[JR]^{\gamma}_{t-m_4}[CPI]^{\delta}_{t-m_5}\right] \tag{A11}$$

where A is the scale factor; IIP is the index of industrial production; EP is the employed persons: H is the work hours; JR is the active openings ratio; CPI is the consumer price index; and m_i (i=1–5); time-lag, α, β, γ, δ are elasticities of respective governing factors.

By taking the logarithm we obtain the following linear equation:

$$\ln W_t = \ln A + \lambda_{t-m1}t + \alpha \ln T_{t-m_2} + \beta \ln(IIP/(EP*H))_{t-m_3} + \gamma \ln JR_{t-m_4} + \delta \ln CPI_{t-m_5} \tag{A12}$$

To avoid seasonal variation, by taking the balance between W_t and W_{t-s} (s indicates a time span of the same period in the preceding year) the following equation is obtained:

$$\ln \frac{W_t}{W_{t-s}} = s\lambda_{t-m_1} + \alpha a \ln \frac{T_{t-m_2}}{T_{t-s-m_2}} + \beta \frac{[IIP/(EP * H)]_{t-m_3}}{[IIP/(EP * H)]_{t-s-m_3}} + \gamma g \ln \frac{JR_{t-m_4}}{JR_{t-s-m_4}} + \delta d \ln \frac{CPI_{t-m_5}}{CPI_{t-s-m_5}} \quad \text{(A13)}$$

Data construction

W is the wage indices by industry (contractual cash earnings): Annual Report on the Monthly Labor Survey (Ministry of Labor).

T is the R&D expenditure (R): Report on the Survey of Research and Development (Management and Coordination Agency); lead time between R&D and commercialization (m) and rate of obsolescence of technology (ρ): Watanabe [24].

IIP is the index of industrial production: Yearbook of Indices of Industrial Production (MITI).

EP is the regular employment indices by industry: Annual Report on the Monthly Labor Survey (Ministry of Labor).

H is the hours worked indices (total hours worked): Annual Report on the Monthly Labor Survey (Ministry of Labor).

JR is the active opening ratio: Monthly Labor Statistics and Research Bulletin (Ministry of Labor).

CPI is the consumer price index: Annual Report on the Consumer Price Index (Management and Coordination Agency).

References

[1] C. Watanabe, K. Wakabayashi, The perspective of techno-metabolism and its insight into national strategies, Res. Eval. 6 (2) (1997) 69–76.

[2] OECD, Technology Productivity and Job Creation, OECD, Paris, 1998.

[3] C. Watanabe, The feedback loop between technology and economic development: an examination of Japanese industry, Technol. Forecast. Soc. Change. 49 (2) (1995) 127–145.

[4] C. Watanabe, M Hemmert, The interaction between technology and economy: has the “virtuous cycle” of Japan’s technological innovation system collapsed? in: M. Hemmert, C. Oberlander (Eds.), Technology and Innovation in Japan, Routledge, New York, 1998, pp. 37–57.

[5] A.G. Tansley, The use and abuse of vegitational terms and concepts, J. Ecol. 16 (1935) 284–307.

[6] A. Koestler, The Ghost in the Machine, Hutchinson & Co., London, 1967.

[7] C. Freemen (Ed.), Long Waves in the World Economy, , Butterworths, London, 1983.

[8] J. Delbeke, Recent long-wave theories: a critical survey, in: C. Freeman (Ed.), Long Waves in the World Economy, Butterworths, London, 1983, pp. 1–12.

[9] G.O. Mensch, Stalemate in Technology — Innovation Overcome the Depression. Ballinger Publishing Company, Cambridge, MA, 1979 (Original title; Das Technologische Patt. Umschau Vertag, Frankfurt, 1975).
[10] G.O. Mensch, Stalemate in Technology, 1925–1935: The Interplay of Stagnation and Innovation, Discussion Paper. International Institute of Management, Berlin, 1977, pp. 60–74.
[11] J.W. Forrester, Growth cycles, De Econ. 125 (4) (1977) 525–543.
[12] C. Freeman, The Kondratiev Long Waves, Technical Change and Unemployment, in: Structural Determinants of Employment and Unemployment 2, OECD, Paris, 1977, p. 183.
[13] C. Freeman, J. Clark, L. Soete, Unemployment and Technical Innovation—A Study Of Long Waves And Economic Development, France Pinter, London, 1982.
[14] W.W. Rostow, The World Economy—History and Prospect, University of Texas Press, Austin, 1978.
[15] J.J. van Duijn, The long wave in economic life, De Econ. 125 (4) (1977) 544–575.
[16] J.J. van Duijn, The Long Wave in Economic Life, George Allen & Unwin, London, 1983.
[17] J.J. van Duijn, Fluctutions in innovations over time, in: C. Freeman (Ed.), Long Waves in the World Economy, Butterworths, London, 1983, pp. 19–30.
[18] T. Modis, Predictions, Simon and Schuster, New York, 1992.
[19] B.C. Twiss, Managing Technological Innovation, fourth ed, Pitman, London, 1992.
[20] D.S. Price, Little Science, Big Science, Columbia University Press, New York, 1963.
[21] E.M. Rogers, Diffusion of Innovations, The Free Press, New York, 1983.
[22] C. Watanabe, Trends in the substitution of production factors to technology, Res. Policy 21 (6) (1992) 481–505.
[23] C. Watanbe, The Interaction between Technology and Economy: National Strategies for Constrained Economic Environments. IIASA Working Paper, WP 95-16, 1995.
[24] C. Watanabe, Systems option for sustainable development, Res. Policy. 28 (7) (1999) 719–749.
[25] OECD, Technology and Industrial Performance, OECD, Paris, 1997.
[26] C. Watanabe, Restructuring a techno-managerial strategy based on the perspective of techno-betabolism, FRI Rev. 3 (3) (1999) 79–83.
[27] K.G. Abraham, J.C. Haltiwanger, Real wages and business cycle, J. Econ. Lit. 33 (1995) 1215–1264.
[28] T. Miyazawa, A. Noda, A method for data synchronization and optimal dead-time estimation in multiple linear regression model, J. Jpn. Ind. Manage. Assoc. 50 (2) (1999) 76–87.
[29] C. Griffy-Brown, C. Watanabe, Technology spillovers and informatization in Japan, Int. J. Technol. Manage. 17 (4) (1999) 362–386.

Chihiro Watanabe is Professor, Dept. of Industrial Engineering & Management, Tokyo Institute of Technology, Tokyo, Japan; and Senior Advisor to the Director on technology, International Institute for Applied Systems Analysis (IIASA), Laxenburg, Austria.

Bing Zhu is a Visiting Fellow, Dept. of Industrial Engineering & Management, Tokyo Institute of Technology, Tokyo, Japan, and Research Fellow, International Institute for Applied Systems Analysis (IIASA), Laxenburg, Austria.

Toshinori Miyazawa is a Post Ph.D. student, Dept. of Industrial Engineering & Management, Tokyo Institute of Technology, Tokyo, Japan.