Working Paper

The Interaction between Technology and Economy: National Strategies for Constrained Economic Environments

The Case of Japan 1955-1992

Chihiro Watanabe

WP-95-16
February 1995

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*Chihiro Watanabe**

Abstract

Over the last two decades, Japan has constructed sophisticated and successful interactions between technology and economic development. These resulted from a combination of industry's efforts and the Government's (chiefly MITI's) attempt to stimulate and induce such efforts. As economic growth and technological development continued in the mid-1980s, concern for the globalizing world economy increased. Consequently, Japanese industrial technology reached a turning point requiring further intensive efforts towards basic and creative technology, overcoming energy and environmental constraints, not only for Japan's sake, but also for the sake of the global community. While MITI has restructured its National R&D Program due to the "bubble economy" and its bursting, the Japanese industry faces a structural stagnation in R&D activities which may have negative implications for these historically successful interactions between technology and economic development.

This paper demonstrates the source of the interactions, the role of policy and its mechanism, and the current fear regarding their future.

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1. Introduction

The remarkable development of the Japanese economy has largely been attributed to the driving force of industrial development and consistent efforts to increase technological innovation [25]. To date, a number of studies have identified the sources supporting Japanese industry's technological advancement [7,25]. None, however, has taken the perspective of the complement and substiution relationship between technology and other production factors as an inducing system for such sources. Similar to an ecosystem, Japan constructed an elaborate system between internal technology and external technology[1] [46] which can be distinctly observed in a "virtuous cycle" (i.e. successful stimulating and inducing interaction) between technology and economic development. MITI (Japan's Ministry of International Trade & Industry-- responsible for industrial technology policy) stimulated and induced industry's efforts by establishing a sophisticated policy system which has strengthened dynamism conducive to technological development [36,38].

As economic growth and technological advancement continued in the mid-1980s, concern for the globalizing world economy increased. Consequently, Japanese industrial technology reached a turning point in which it called for the following improvements: (i) further intensive efforts in basic and creative technology, (ii) greater attention to overcoming energy and environmental constraints while maintaining sustainable growth, and (iii) the need for greater international contribution to innovative R&D and critical global issues [23,47]. Following the rise and fall of the "bubble economy," along with a change in Japan's technological paradigm, Japanese industry has been facing a structural stagnation in R&D activities which may result in the deconstruction of the cycle between technology and economic development. As an ecosystem demonstrates, once such a cycle begins to deconstruct, remediation of the system becomes impossible. Thus far, Japan has paid limited attention to this possibility, leading to insufficient empirical analyses of impacts of the above deconstruction and the stagnation of R&D activities on the Japanese manufacturing industry.

This paper analyzes the source of the virtuous cycle between technology and economic development in the Japanese manufacturing industry as well as the role of policy and its mechanism. In addition, it reviews such exercises and examines the fear regarding the cycle's deconstruction. Section 2 attempts to provide a new theoretical framework of the above analysis and data construction. Section 3 demonstrates empirical analyses consisting of (i) an empirical review of Japan's path with respect to economic development and technology's contribution to paving such a path, (ii) an empirical analysis of policy contribution and its mechanism, (iii) an empirical analysis of the background which urged Japan's industrial technology program at a turning point, and (iv) demonstration of paradigm change in Japan's industrial technology by introducing empirical analyses of the current state of Japan's industrial technology, the impacts of the current stagnation of R&D activities, and the structural background of the stagnation. Section 4 briefly summarizes the perspective of the new technology policy and its implications for further R&D in a globalizing world economy.

2. Theoretical Framework of the Analyses and Data Construction

2.1 Theoretical Framework of the Analyses

[1] Internal technology means qualification of the R&D environment and consists of quality and quantity of resources for R&D. External technology consists of the "economic environment," "physical and natural environment" (such as energy resources and geographical conditions), "social and cultural environment" (such as education, ethics of labor and entrepreneur, custom and tradition, and preference of consumer) and "policy system." [4]

In order to analyze interactions between technology and economy in constrained economic environments, the following approaches focused on interactions between technology and other production factors which may face certain constraines are essential:

(i) measurement of technology as an endogenous production factor in a consistent way;

(ii) measurement of the service price of technology and internal rate of return to R&D investment; and

(iii) analysis of complement and substitution relations between technology and other production factors.

2.1.1 General Framework

First of all, it is assumed that there exists in the Japanese manufacturing industry the following twice differentiable aggregate production function which relates the flow of output Y to the services of five inputs: labor (L), capital (K), materials (M), energy (E) and technology (T):

$$Y = F(L, K, M, E, T) \tag{1}$$

where technology is endogenous techological improvement efforts[2] and materials are all other intermediate inputs except energy.

Next, the following cost function exists corresponding to the production function (1):

$$C = C(Y, Pl, Pk, Pm, Pe, Pt) \tag{2}$$

where C is gross cost, and Pl, Pk, Pm, Pe, and Pt are prices of labor, capital, materials, energy, and technology respectively.

Following Griliches's postulate, in order to avoid duplication between technology (technology knowledge stock) and other production factors, the respective services of input for R&D (Lr, Kr, Mr, and Er)are deducted from respective other production factors (L, K, M and E) and cost/price factors (Pl, Pk, Pm and Pe).[3]

2.1.2 Measurement of Technology Knowledge Stock

Given R&D expenditure in the period t (R_t), time lag of R&D to commercialization

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[2] In this case, endogenous technological improvement means technological improvement generated by technological knowledge stock arising from R&D investment efforts, while exogeous technological improvement means technological improvements generated by autonomous productivity increases.

[3] See data construction, sources and also tabulated outcome of the calculation in Section 2.2.

(m), and rate of obsolescence of technology (ρ), technology knowledge stock in the period t (T_t) can be measured by the following equations:

$$T_t = R_{t-m} + (1-\rho)T_{t-1} \tag{3}$$

Given the increasing rate of Rt in the initial period (dRt/dt/Rt = g), technology knowledge stock in the initial period (T_o) can be measured as follows:

$$T_o = \frac{R_{1-m}}{(g+\rho)} \tag{4}$$

Equation (4) can be developed as follows:

$$\begin{aligned}
T_n &= R_{n-m} + (1-\rho)\ T_{n-1} = R_{n-m} + (1-\rho)\ \left[R_{n-1-m} + (1-\rho)\ T_{n-2}\right] \\
&= \left[\frac{1+(1-\rho)}{(1+g)}\right] R_{n-m} + (1-\rho)^2 T_{n-2} \\
&= \left[\frac{1+(1-\rho)}{(1+g)}\right] R_{n-m} + (1-\rho)^2\left[R_{n-2-m} + (1-\rho)T_{n-3}\right] \\
&= \left[\frac{1+(1-\rho)}{(1+g)} + \frac{(1-\rho)^2}{(1+g)^2}\right] R_{n-m} + (1-\rho)^3 T_{n-3} = \cdots \\
&= \left[1 + \frac{(1-\rho)}{(1+g)} + \frac{(1-\rho)^2}{(1+g)^2} + \cdots + \frac{(1-\rho)^{n-1}}{(1+g)^{n-1}}\right] R_{n-m} + (1-\rho)^n T_n \\
&\fallingdotseq \left[\frac{1}{1-(1-\rho)/(1+g)}\right] R_{n-m} = \frac{(1+g)}{(g+\rho)} R_{n-m} = \frac{R_{n+1-m}}{(g+\rho)}
\end{aligned}$$

$$T_o = \frac{R_{1-m}}{(g+\rho)}$$

Time lag of R&D to commercialization and rate of obsolescence of technology were estimated as follows:

On the basis of an intensive assessment of the outcomes of a questionnaire for major Japanese firms (undertaken in April 1990, supported by AIST of MITI[4]) the following

[4] Questionnaire was sent to 700 major Japanese firms and 500 responses were received. Out of the responses, 360 valid samples for time lag and 276 for technology life time (both for manufacturing industry) were obtained (both samples were well-balanced for the sectors and stages of technologies as summarized in the following table.

Questions included (i) the time duration of R&D by stages (basic, applied and development research) for specific leading technologies where research and commercialization were undertaken during the 1970s and 1980s, and (ii) the lifetime of specific leading technologies which were in use during the 1970s and 1980s and have been replaced either by new technology or improved technology and products.

Tex.Cerm.Paper	Chemistry	Iron&Steel	Machinery	Others	Total

findings were obtained:

(i) Time Lag of R&D to Commercialization (m)

Basic research to commercialization	5.6 years	(average of 79 samples)
Applied research to commercialization	3.6 years	(average of 125 samples)
Development research to commercialization	2.0 years	(average of 156 samples)
Average of all stages	3.3 years	(agr. average of 360 samples)

(ii) Lifetime of Technology - Rate of Obsolescence of Technology (ρ)

Replaced by new technology	13.5 years	(average of 119 samples)
Replaced by improved technology and products	7.7 years	(average of 157 samples)
Total Average	10.2 years	(average of 276 samples)

Assuming that technology depreciates and becomes obsolete over time > ρ: 9.8%

2.1.3 Simultaneous Measurement of the Service Price of Technology and Internal Rate of Return to R&D Investment

Pt (the service price of technology)

$$= (1-gs)(Rls * Dl + Rms * Dm + Res * De) + Rks * Pstc \tag{5}$$

Pstc (the service price of technology capital)

$$= \frac{Dk(r+\rho)(1-gs)}{(1-ct)} \tag{6}$$

$$\because \frac{Dk(1-gs)}{(1-ct)} = \int_0^\infty Pstc * e^{-(r+\rho)t} dt = \frac{Pstc}{(r+\rho)}$$

where Rls, Rks, Rms and Res are shares of R&D expenditures for labor costs, tangible fixed

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Time Lag						
B>C	7	16	9	33	14	79
A>C	11	23	12	52	27	125
D>C	17	28	15	68	28	156
Total	35	67	36	153	69	360
Lifetime						
by new tech.	12	29	11	40	27	119
by impr. tech.	8	24	11	79	35	157
Total	20	53	22	119	62	276

assets, materials, and energy respectively; Dl, Dk, Dm and De are wage index, investment goods deflator, wholesale price indices of materials and energy respectively; gs and ct are ratios of government financial suppot and corporate tax respectively; r and ρ are rates of internal return to R&D investment and obsolescence of technology respectively.

Internal rate of return to R&D investment (r) can be calculated as follows:

$$e^{mr}=\int_0^\infty \frac{(\sigma V)}{(\sigma T)}e^{-(r+\rho)t}dt=\frac{(\sigma V)}{(\sigma T)}/(r+\rho) \tag{7}$$

where m; time lag from R&D to commercialization, V; production by value added.

Equation (7) is derived from the following:

Given a unit of resource, the value of the resource in m years is represented as e^{mr}, this value is due to the value added created by this increment, which is calculated as

$$\int_0^\infty \frac{(\sigma V)}{(\sigma T)}e^{-(r+\rho)t}dt.$$

When Tayler expansion is made to the primary term in connection with e^{mr}, the following formula can be obtained:

$$e^{mr}\fallingdotseq\frac{1+mr}{1!}=1+mr=\frac{(\sigma V)}{(\sigma T)}/(r+\rho) \tag{8}$$

Production function can be estimated as follows:

$$Y = F(L,K,M,E,T) \tag{1}$$

$$V = G(L,K,T) \tag{9}$$

In order to avoid duplication between technology knowledge stock and other production factors, the respective services of input for R&D (Lr, Kr, Mr, and Er) are deducted from L, K, M and E.

Given that all services of input for R&D related to L, K, M and E are incorporated in T and all duplications are avoided, T can be treated as a production factor,not a shift parameter; furthermore, provided that production factor prices are decided competitively, the marginal product of T or rate of return to R&D investment($\sigma V/\sigma T$) in equation (8) can be calculated as follows:

$$\frac{\sigma V}{\sigma T}=[\frac{GTC\#}{(GLC+GCC+GTC\#)}]*\frac{(V)}{(T)} \tag{10}$$

where GLC and GCC are gross labor cost and gross capital cost respectively (all service costs for technology are deducted), and GTC# is gross technology cost with its potential contributability to production.

While gross technology cost (GTC) as the total sum of R&D expenditure and payment for technology imports represents only R&D investment similar to capital investment, GTC# represents its potential contributability to production as well.

The ratio of GTC and technology knowledge stock (T) Pt' can be defined as "capital price of technology", and the ratio of capital price of technology and service price of technology (Ptϕ) represents "potential contributability of technology to production" (PCT).

$$PCT = \Phi = \frac{Pt'}{Pt} \tag{11}$$

GTC#/(GLC+GCC+GTC#) in equation (10) is equivalent to elasticity of technology in production function (9) and, by taking PCT, can be calculated in a way to be able to represent potential contributability of technology as follows:

$$\frac{GTC\#}{(GLC+GCC+GTC\#)} = \frac{\phi GTC}{(GLC+GCC+\phi GTC)} = \frac{\frac{(Pt')}{(Pt)} * GTC}{[GLC+GCC+\frac{(Pt')}{(Pt)} * GTC]} \tag{12}$$

By substituting equation (10) for $\sigma V/\sigma T$ in equation (8) the following equation can be obtained:

$$1+mr = \frac{\frac{(Pt')}{(Pt)} * GTC * V}{[GLC+GCC+\frac{(Pt')}{(Pt)} * GTC] * [T * (r+\rho)]} \tag{13}$$

By synchronizing equations (5) and (6) Pt can be presented in the following equation:

$$Pt = (1-gs)[(Rls * Dl + Rms * Dm + Res * De) + Rks * Dk(r+\rho)/(1-ct)] \tag{14}$$

Given that production (V), its factor (T) and respective costs (GLC, GCC and GTC), composition of R&D expenditure (Rls, Rks, Rms and Res) and respective deflators (Dl, Dk, Dm and De), ratios of government support (gs) and corporate tax (ct), rate of obsolescence of technology (ρ), and time lag from R&D to commercialization (m) are given exogenously, the service price of technology (Pt) and rate of internal return to technology investment (r) can be measured simultaneously by equations (13) and (14).

2.1.4 Substitution of Technology for Constrained Production Factors

By applying measured technology knowledge stock and service price of technology to the analysis of the substitution among production factors by means of translog production/cost functions, trends and mechanism of technology substitution for constrained production factors (eg. energy and environmental capacity) can be analyzed.

Production function

$$Y = F(L, K, M, E, T) \quad (1)$$

Corresponding cost function

$$C = C(Y, Pl, Pk, Pm, Pe, Pt) \quad (2)$$

The cost function (2) is brought near ln Y = ln Pl = ln Pk = ln Pm = ln Pe = ln Pt= 0, and when Taylor expansion is made to the secondary term in connection with ln Y, ln Pl, ln Pk, ln Pm, ln Pe and ln Pt, the following formula is obtained:

$$\begin{aligned}
\ln C = {} & \\
& \ln A_0 + \ln Y + Al \ln Pl + Ak \ln Pk + Am \ln Pm + Ae \ln Pe + At \ln Pt \\
& + 1/2[\ln Pl(Bll \ln Pl + Blk \ln Pk + Blm \ln Pm + Ble \ln Pe + Blt \ln Pt) \\
& + \ln Pk(Bkl \ln Pl + Bkk \ln Pk + Bkm \ln Pm + Bke \ln Pe + Bkt \ln Pt) \\
& + \ln Pm(Bml \ln Pl + Bmk \ln Pk + Bmm \ln Pm + Bme \ln Pe + Bmt \ln Pt) \\
& + \ln Pe(Bel \ln Pl + Bek \ln Pk + Bem \ln Pm + Bee \ln Pe + Bet \ln Pt) \\
& + \ln Pt(Btl \ln Pl + Btk \ln Pk + Btm \ln Pm + Bte \ln Pe + Btt \ln Pt)] \quad (15)
\end{aligned}$$

Under the assumption of the symmetrical nature of coefficients and of the linear homogeneity of the cost funct., the following restrictions are imposed on coefficients in (15):

$$\begin{aligned}
& Al + Ak + Am + Ae + At = 1 \\
& Bll + Blk + Blm + Ble + Blt = 0 \\
& Bkl + Bkk + Bkm + Bke + Bkt = 0 \\
& Bml + Bmk + Bmm + Bme + Bmt = 0 \\
& Bel + Bek + Bem + Bee + Bet = 0 \\
& Btl + Btk + Btm + Bte + Btt = 0 \\
& Bij = Bji \ (i,j = L, K, M, E, T) \quad (16)
\end{aligned}$$

When ln Pl, ln Pk, ln Pm, ln Pe and ln Pt are used here to differentiate (15) and Scheppard's adjustment ($\sigma C/\sigma Pi = Xi$, $Xi = L, K, M, E, T$) is adopted, the following equation is obtained:

$$Ml=\frac{\sigma lnC}{\sigma lnPl}=\frac{Pl}{C}*\frac{\sigma C}{\sigma Pl}=\frac{PlL}{C}=Al+(BlllnPl+BlkllnPk+BlmlnPm+BlelnPe+BltlnPt)$$
$$Mk=\frac{\sigma lnC}{\sigma lnPk}=\frac{Pk}{C}*\frac{\sigma C}{\sigma Pk}=\frac{PkK}{C}=Ak+(BkllnPl+BkklnPk+BkmlnPm+BkelnPe+BktlnPt)$$
$$Mm=\frac{\sigma lnC}{\sigma lnPm}=\frac{Pm}{C}*\frac{\sigma C}{\sigma Pm}=\frac{PmM}{C}=Am+(BmllnPl+BmklnPk+BmmlnPm+BmelnPe+BmtlnPt) \quad (17)$$
$$Me=\frac{\sigma lnC}{\sigma lnPe}=\frac{Pe}{C}*\frac{\sigma C}{\sigma Pe}=\frac{PeE}{C}=Ae+(BellnPl+BeklnPk+BemlnPm+BeelnPe+BeelnPt)$$
$$Mt=\frac{\sigma lnC}{\sigma lnPt}=\frac{Pt}{C}*\frac{\sigma C}{\sigma Pt}=\frac{PtT}{C}=At+(BtllnPl+BtklnPk+BtmlnPm+BtelnPe+BttlnPt)$$

The left sides in equation (17) are measured as follows:

$$Ml=\frac{PlL}{C}=\frac{GLC}{C},\ Mk=\frac{PkK}{C}=\frac{GCC}{C},\ Mm=\frac{PmM}{C}=\frac{GMC}{C},$$
$$Me=\frac{PeE}{C}=\frac{GEC}{C},\ Mt=\frac{PtT}{C}=\frac{Pt}{Pt'}*\frac{GTC}{C} \quad (18)$$

where GXC/C (X=L,K,M,E,T) is cost share.

Elasticity of substitution among production factors can be measured by Allen partial elasticity of substitution as follows:

$$\sigma\ ij=\frac{(Bij+Mi^2-Mi)}{Mi^2} \qquad (i,j=L,K,M,E,T)\ (i=j)$$
$$\sigma\ ij=\frac{(Bij+Mi*Mj)}{Mi*Mj} \qquad (i,j=L,K,M,E,T)\ (i\neq j) \quad (19)$$

2.2 Data Construction and Assessment

2.2.1. General Concept

Production: Y = f[(L-Lr), (K-Kr), (M-Mr), (E-Er), T],
T = h (Lr,Kr,Mr,Er)

Gross Cost: C = c (Y, Pl, Pk, Pm, Pe, Pt) = (GLC-GTCl) + (GCC-GTCk) + (GMC - GTCm) + (GEC-GTCe) + GTC
GTC = GTCl + GTCk + GTCm + GTCe
(under the assumption of the linear homogeneity of cost function)

Prices: Pl = (GLC-GTCl)/(L-Lr), Pk = (GCC-GTCk)/(K-Kr), Pm = (GMC-GTCm)/(M-Mr), and Pe = (GEC-GTCe)/(E-Er).

2.2.2 Data Construction

Y (production) = (1985 gross cost*1) 1985 gross cost: gross cost at 1985 fixed prices
L (labor) = (number of employed persons*1) x (working hours*2),
K (capital) = (capital stock*3) x (operating rate*4),
M (materials: intermediate inputs except energy) = (1985 intermediate inputs1) - (1985 gross energy cost*5,*6,*7),
E (energy) = (final energy consumption*7), and
T (technology) = GTCt-m + (1-ρ)Tt-1,
GTCt-m: gross technology cost in time t-m
m: time lag from R&D to commercialization*8
ρ: rate of obsolescence of technology*8

Lr (labor for technology) = (number of researchers*9) x (working hours*10)
Kr (capital stock of R&D: KR) x (operating rate*11)
KRt = GTCkt + (1-ρkr)KRt-1
ρKr: rate of obsolescence of capital stock for R&D (inverse of the average of lifetime of tangible fixed assets for R&D*11)
Mr (materials for R&D*8,*9)
Er (energy for R&D*8)

GLC (gross labor cost) = (income of employed persons*1 + income of unincorporated enterprise*12)
GCC (gross capital cost) = (gross domestic product*1 - gross labor cost)
GMC (gross materials cost) = (intermediate input) - (gross energy cost)
GEC (gross energy cost) = expenditures for fuels and electricity*5
GTC (gross technology cost) = R&D expenditure and payment for technology import*11
GTCl (R&D expenditure for labor)*9
GTCk (R&D expenditure for capital)*8,*9
GTCm (R&D expenditure for materials)*8,*9
GTCe (R&D expenditure for energy)*8

Sources of data
*1 Annual Report on National Accounts (Economic Planning Agency)
*2 Year Book of Labor Statistics (Ministry of Labor)
*3 Statistics of Enterprisers' Capital Stock (Economic Planning Agency)
*4 Annual Report on Indices on Mining and Manufacturing (MITI)
*5 Industrial Statistics (MITI)
*6 Economic Statistics Annual (The Bank of Japan)
*7 Comprehensive Energy Statistics (Agency of Natural Resources & Energy)
*8 Report on the Promotion of Research Industry (Institute of Economic Research, Japan Society for the Promotion of Machine Industry, 1990)
*9 Report on the Survey of Research & Development (Management and Coordination Agency)
*10 Survey on Researchers for the Promotion of Basic and Leading Science & Technology (Institute for Future Technology, 1990)
*11 Corporate Tax Law (MITI)
*12 Quarterly Report on Unincorporated Enterprise (Management and Coordination Agency)

2.2.3 Assessment of the Constructed Data

Outcomes of the calculation for input data (production, cost, and price) are presented in Appendix II (Basic Data), ratios of duplication of technology to other production factors are presented in Table 1, and input data avoiding duplication are presented in Table 2.

Fig. 1 compares trends in prices of labor, capital, materials and energy to deflators of respective production factors. Table 3 summarizes correlations between calculated prices and deflators of respective production factors which suggest statistically significant. This demonstrates the reliability of outcomes of calculation with respect to fundamental data for input.

Table 1 Ratios of Duplication of Technology to Other Production Factors in the Japanese Manufacturing Industry (1955-1992) - %

YEAR	Labor	Capital	Materials	Energy
1955	1.340	1.400	0.250	0.500
1956	1.360	1.400	0.250	0.500
1957	1.370	1.350	0.250	0.500
1958	1.400	1.350	0.300	0.700
1959	1.470	1.350	0.300	0.700
1960	1.420	1.350	0.300	0.700
1961	1.170	1.350	0.300	0.800
1962	1.190	1.350	0.350	0.800
1963	1.300	1.400	0.350	0.800
1964	1.380	1.400	0.350	0.800
1965	1.390	1.447	0.353	0.818
1966	1.351	1.340	0.377	0.842
1967	1.297	1.211	0.382	0.909
1968	1.402	1.124	0.492	1.045
1969	1.486	1.088	0.519	1.091
1970	1.610	1.069	0.561	1.192
1971	1.829	1.113	0.584	1.227
1972	1.759	1.171	0.618	1.320
1973	1.807	1.197	0.566	1.264
1974	1.844	1.234	0.498	1.207
1975	2.115	1.238	0.517	1.292
1976	2.076	1.201	0.527	1.258
1977	2.083	1.160	0.560	1.304
1978	2.106	1.133	0.606	1.350
1979	2.131	1.128	0.637	1.899
1980	2.247	1.146	0.612	1.417
1981	2.337	1.198	0.720	1.588
1982	2.483	1.290	0.830	1.662
1983	2.513	1.401	0.932	1.914
1984	2.688	1.501	1.012	1.981
1985	2.767	1.578	1.163	2.223
1986	2.958	1.687	1.307	2.385
1987	3.071	1.823	1.435	2.547
1988	3.266	1.936	1.524	2.614
1989	3.373	2.006	1.590	2.742
1990	3.498	2.069	1.692	2.849
1991	3.435	2.137	1.689	2.882
1992	3.510	2.208	1.700	2.900

Table 2 Input Data Avoiding Duplication in the Japanese Manufacturing Industry (1955-1992)

(1) Programs (example)

```
SMPL 55 92;
GENR Rls=RELS/100;GENR Rks=REKS/100;GENR Rms=REMS/100;
GENR Res=REES/100;
GENR GS=1-GVS/100;GENR TR=1-CTR/100;
GENR m=3.3;GENR q=0.098;
FRML EQPT P=GS*[(Rls*Dl+Rms*Dm+Res*De)+Rks*Dk*(R+q)/TR];
IDENT EQR R=[(-1-m*q)+SQRT((1+m*q)*(1+m*q)+4*m*(A-q))]/(2*m);
IDENT EQA A=PT/P*Mt*V/((Ml+Mk)+PT/P*Mt)/T;
IDENT EQB B=A*T/V;
SIML(TAG=Z,ENDOG=(P,R,A,B))EQPT EQR EQA EQB;
PRINT P R B;
```

```
SMPL 56 92;
PARAM Al Ak Am Ae At Bll Blk Blm Ble Blt Bkk Bkm Bke Bkt Bmm Bme Bmt;
PARAM Bee Bet Btt;
GENR M1=Ml/100;GENR M2=Mk/100;GENR M3=Mm/100; GENR M4=Me/100;
GENR M5=Mt/100*Pz/Pt';
FRML EQL M1=Al+Bll*LOG(Pl/Pz)+Blk*LOG(Pk/Pz)+Blm*LOG(Pm/Pz)+Ble*LOG(Pe/Pz);
FRML EQK M2=Ak+Blk*LOG(Pl/Pz)+Bkk*LOG(Pk/Pz)+Bkm*LOG(Pm/Pz)+Bke*LOG(Pe/Pz);
FRML EQM M3=Am+Blm*LOG(Pl/Pz)+Bkm*LOG(Pk/Pz)+Bmm*LOG(Pm/Pz)+Bme*LOG(Pe/Pz);
FRML EQE M4=Ae+Ble*LOG(Pl/Pz)+Bke*LOG(Pk/Pz)+Bme*LOG(Pm/Pz)+Bee*LOG(Pe/Pz);
LSQ EQL EQK EQM EQE;
SET At=1-Al-Ak-Am-Ae;
SET Blt=-Bll-Blk-Blm-Ble;
SET Bkt=-Blk-Bkk-Bkm-Bke;
SET Bmt=-Blm-Bkm-Bmm-Bme;
SET Bet=-Ble-Bke-Bme-Bee:
SET Btt=-Blt-Bkt-Bmt-Bet:
GENR Stl=Blt/M1/M5+1;
GENR Stk=Bkt/M2/M5+1;
GENR Stm=Bmt/M3/M5+1;
GENR Ste=Bet/M4/M5+1;
GENR Sle=Ble/M4/M1+1;
GENR Ske=Bke/M4/M2+1;
GENR Sme=Bme/M4/M3+1;
GENR Slk=Blk/M1/M2+1;
GENR See=Bee/M4/M4-1/M4+1;
GENR Stt=Btt/M5/M5-1/M5+1;
GENR Eel=M1*Sle;
GENR Eek=M2*Ske;
GENR Eem=M3*Sme;
GENR Eee=M4*See;
GENR Eet=M5*Ste;
GENR Etl=M1*Stl;
GENR Etk=M2*Stk;
GENR Etm=M3*Stm;
GENR Ete=M4*Ste;
GENR Ett=M5*Stt;
PRINT Bet Bke Bme Stl Stk Stm Ste Sle Ske Sme Slk See Stt;
PRINT Eel Eek Eem Eee Eet Etl Etk Etm Ete Ett;
```

PT = Pz = Pt (the service price of technology)

Pt' (capital price of technology)

(2) Cost Share (%) and Prices (index: 1985 = 100)

YEAR	Ml	Mk	Mm	Me	Mt	Pl	Pk	Pm	Pe	Pt
1955	13.03	14.46	67.76	4.11	0.65	4.11	44.80	41.42	23.13	37.73
1956	11.99	14.28	69.24	3.87	0.62	4.40	53.28	45.85	24.70	39.58
1957	11.43	14.55	69.32	4.10	0.61	4.64	63.08	46.91	27.76	40.47
1958	13.66	14.47	67.02	4.20	0.66	4.91	58.00	42.96	27.20	35.62
1959	12.49	15.31	67.75	3.79	0.66	5.33	60.09	43.59	25.57	37.30
1960	11.75	16.55	67.46	3.55	0.68	5.92	70.36	43.55	24.63	41.44
1961	11.73	17.16	67.11	3.28	0.72	6.90	75.71	44.57	23.51	45.71
1962	12.98	16.61	66.33	3.32	0.76	7.93	70.85	43.37	23.55	45.09
1963	13.26	17.21	65.53	3.22	0.78	8.89	70.57	44.11	22.99	44.74
1964	13.20	17.90	65.10	2.99	0.80	10.01	69.43	44.80	21.27	44.68
1965	14.04	17.35	64.77	3.07	0.77	11.22	65.73	43.29	21.04	38.58
1966	13.78	17.13	65.44	2.86	0.80	12.29	67.35	44.31	19.87	39.34
1967	13.63	17.45	65.48	2.59	0.86	13.70	74.80	45.43	18.81	44.58
1968	13.93	18.04	64.55	2.50	0.98	16.00	78.88	45.32	18.56	52.41
1969	13.69	18.15	64.81	2.34	1.02	18.58	81.28	46.19	17.48	58.70
1970	13.52	18.42	64.70	2.24	1.12	22.29	86.50	46.54	17.35	68.45
1971	14.76	18.10	63.64	2.39	1.12	25.81	81.45	47.30	18.41	61.76
1972	15.37	17.97	63.13	2.32	1.21	29.91	78.68	47.79	19.25	62.66
1973	15.22	17.29	63.99	2.36	1.15	36.38	83.99	57.92	21.62	64.37
1974	15.37	14.54	65.63	3.35	1.10	48.42	87.74	76.90	38.62	65.42
1975	16.69	13.37	64.77	3.99	1.18	56.72	86.82	78.41	50.48	60.47
1976	16.04	13.91	64.77	4.13	1.15	60.61	89.74	82.84	57.50	60.03
1977	16.39	13.91	64.39	4.13	1.19	66.80	91.85	83.70	62.57	60.48
1978	16.49	15.15	63.49	3.64	1.23	70.93	96.30	81.20	58.25	60.88
1979	15.72	14.48	65.02	3.49	1.29	74.90	93.36	88.26	60.48	67.00
1980	14.56	13.40	66.15	4.61	1.29	79.50	96.19	101.48	97.39	73.72
1981	15.17	13.60	65.27	4.52	1.45	85.30	100.63	101.75	105.01	80.76
1982	15.58	14.09	64.42	4.33	1.59	89.51	103.33	102.56	107.82	84.60
1983	15.94	14.20	64.14	3.98	1.74	91.96	100.17	100.98	106.73	89.31
1984	15.85	14.69	63.99	3.65	1.81	95.19	100.09	101.27	99.20	93.14
1985	16.20	15.15	63.09	3.54	2.03	100.00	100.00	100.00	100.00	100.00
1986	17.55	15.75	61.50	3.02	2.18	105.10	97.83	89.59	85.35	95.39
1987	17.80	16.55	60.82	2.51	2.32	107.46	97.30	87.71	69.60	93.79
1988	17.30	16.82	61.21	2.29	2.38	109.47	96.06	87.66	64.63	95.37
1989	17.02	16.58	61.79	2.12	2.49	116.01	95.12	90.95	62.89	99.36
1990	17.07	16.41	61.80	2.13	2.59	125.80	92.92	92.83	66.65	102.88
1991	17.41	16.44	61.40	2.13	2.62	133.27	92.36	92.62	69.28	100.90
1992	18.69	16.06	60.48	2.10	2.67	139.83	87.45	90.39	66.54	91.09

(3) Composition of R&D Expenditure (%) and Respective Deflators (1985 = 100)

YEAR	RELS	REKS	REMS	REES	DL	DK	DM	DE;
1955	31.00	44.46	20.00	4.54	5.52	22.82	40.40	21.20
1956	32.00	43.72	20.00	4.28	6.00	20.40	46.00	22.50
1957	33.00	42.47	20.00	4.53	6.24	21.51	47.00	24.40
1958	34.00	41.36	20.00	4.64	6.48	22.89	43.80	23.00
1959	34.61	41.14	20.05	4.20	6.96	23.16	45.00	22.40
1960	32.38	43.71	19.98	3.93	7.56	24.38	44.20	22.00
1961	33.57	43.21	19.58	3.64	8.40	27.66	43.70	21.10
1962	37.18	38.83	20.32	3.67	9.12	34.43	40.30	20.40
1963	39.98	36.09	20.36	3.57	10.08	40.45	40.00	20.30
1964	39.93	36.89	19.87	3.31	11.16	42.20	40.30	20.10
1965	43.94	32.03	20.63	3.40	12.12	51.17	39.70	20.40
1966	44.72	30.61	21.50	3.17	13.57	53.17	41.00	20.20
1967	42.37	34.59	20.17	2.87	15.37	50.41	42.00	20.30
1968	41.54	33.80	21.89	2.77	17.65	51.05	41.80	20.40
1969	40.81	36.16	20.43	2.60	20.53	51.87	42.80	20.00
1970	40.37	36.66	20.48	2.49	24.13	52.64	44.70	20.30
1971	43.62	33.35	20.38	2.65	27.49	56.93	43.40	21.80
1972	46.70	31.08	19.64	2.58	31.69	62.21	43.80	21.80
1973	46.40	33.28	17.70	2.62	39.26	69.75	56.90	22.90
1974	51.45	27.29	17.53	3.73	49.46	90.72	74.10	37.70
1975	53.43	25.18	16.94	4.44	55.22	98.08	74.70	45.90
1976	53.17	24.51	17.73	4.59	61.94	100.72	81.10	50.10
1977	52.24	24.90	18.26	4.60	67.35	98.65	83.20	53.50
1978	51.33	25.56	19.06	4.05	71.31	96.04	81.40	50.30
1979	49.37	27.63	19.11	3.89	76.47	103.62	88.30	55.00
1980	47.23	28.80	18.83	5.14	82.11	101.42	104.60	91.70
1981	45.30	29.49	20.16	5.05	86.67	101.65	103.20	102.10
1982	44.03	30.87	20.26	4.84	90.64	102.28	102.70	107.70
1983	44.40	31.05	20.09	4.46	93.40	101.26	101.70	104.50
1984	42.94	32.12	20.85	4.09	97.00	102.77	101.90	100.10
1985	41.23	33.93	20.86	3.98	100.00	100.00	100.00	100.00
1986	41.82	33.85	20.93	3.40	101.44	95.96	93.10	85.60
1987	41.84	34.52	20.82	2.82	103.12	97.64	90.50	74.70
1988	41.13	34.93	21.36	2.58	107.80	98.07	91.30	69.90
1989	39.87	36.32	21.42	2.39	114.05	101.23	94.30	69.60
1990	39.10	36.73	21.76	2.41	120.05	103.53	94.50	73.50
1991	39.01	37.65	20.93	2.41	124.13	100.46	95.00	73.50
1992	41.53	36.18	19.91	2.38	125.57	97.50	92.80	71.30;

(4) Gross Cost, Value Added, Technology Knowledge Stock, and Ratios of Government Support and Corporate Tax (%)

YEAR	GCN	V	T	GVS	CTR;
1955	8505.10	6031.80	623.70	10.50	40.00
1956	11043.20	7072.10	735.70	10.00	40.00
1957	13165.00	7866.10	843.80	9.86	40.00
1958	12230.00	8129.40	968.30	9.00	38.00
1959	15081.10	9106.00	1139.60	7.29	38.00
1960	19187.10	10744.10	1351.80	6.18	38.00
1961	23407.00	13039.30	1566.90	6.43	38.00
1962	24924.70	14125.40	1796.30	5.89	38.00
1963	28255.70	16819.30	2110.80	5.08	38.00
1964	32800.90	19612.50	2515.00	5.80	38.00
1965	34636.70	20560.20	2966.00	5.26	37.00
1966	39934.60	23226.50	3445.80	4.00	35.00
1967	48436.30	27262.20	3965.10	3.22	35.00
1968	56235.50	31221.20	4471.00	3.61	35.00
1969	67284.10	36178.50	4978.80	3.35	35.00
1970	80378.50	41865.50	5620.00	3.17	36.75
1971	84233.20	43920.00	6507.60	3.87	36.75
1972	93010.30	48158.80	7630.50	2.85	36.75
1973	118288.10	54785.10	9014.20	3.52	36.75
1974	146532.60	53108.60	10517.60	3.13	40.00
1975	144486.60	52313.30	11994.50	3.41	40.00
1976	165550.70	57183.90	13501.10	2.51	40.00
1977	177399.30	59388.30	14852.90	2.44	40.00
1978	185646.80	61132.80	16013.50	1.98	40.00
1979	207584.80	66756.20	17065.80	2.26	40.00
1980	242496.30	71481.90	18094.20	2.87	40.00
1981	250840.50	74792.50	19161.50	3.20	42.00
1982	254090.60	78130.10	20326.20	3.00	42.00
1983	259644.30	81520.70	21624.50	2.90	42.00
1984	279496.10	88425.80	23129.60	2.70	43.30
1985	287810.30	94672.60	24864.30	2.60	43.30
1986	275271.20	92112.60	26807.40	3.10	43.30
1987	274714.60	98860.20	29009.10	3.10	42.00
1988	296560.00	107999.40	31578.80	2.80	42.00
1989	322245.70	116619.40	34467.40	2.60	40.00
1990	348072.00	125492.40	37412.00	2.70	37.50
1991	366078.00	133420.80	40512.50	2.80	37.50
1992	351620.40	130991.60	43910.50	2.80	37.50;

GCN, V, T : billion yen

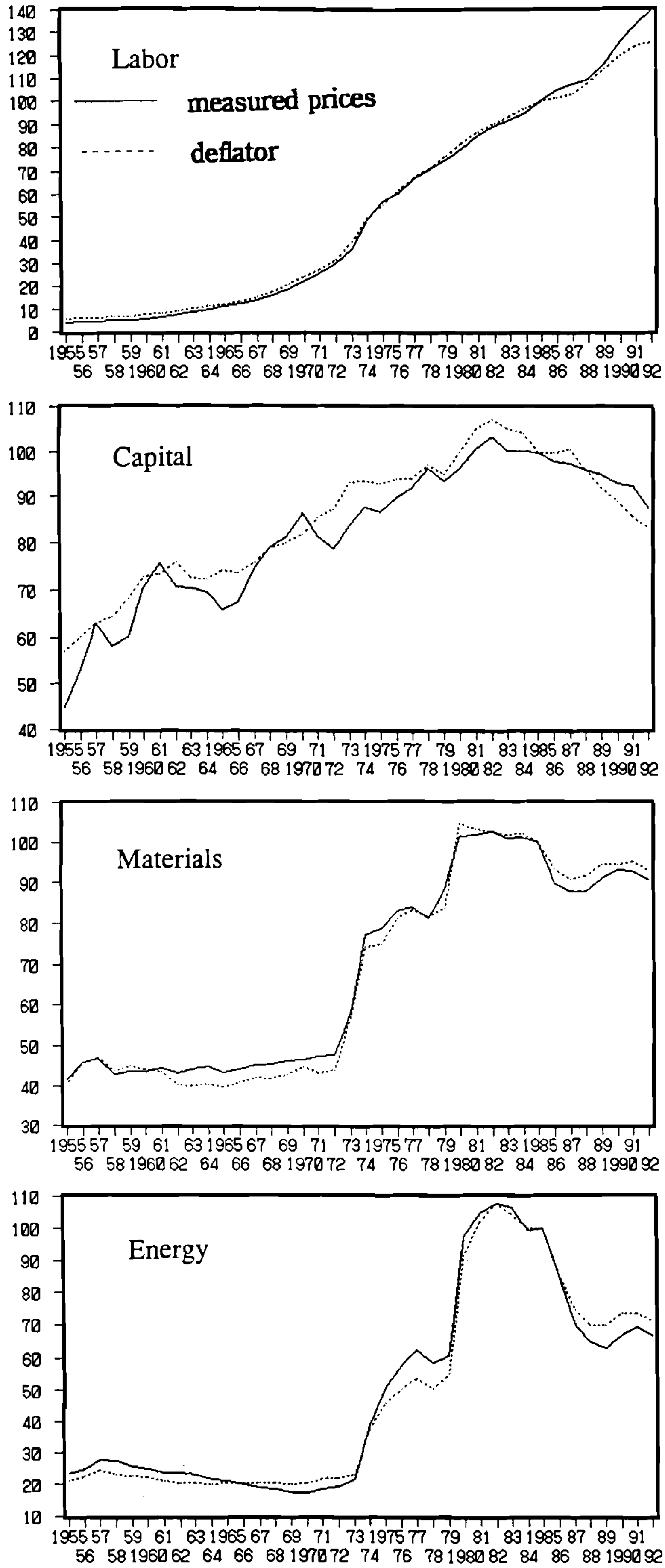

Fig. 1 Trends in Prices and Deflators of Labor, Capital, Materials and Energy in the Japanese Manufacturing Industry (1955-1992) - Index: 1985 = 100

Table 3 Correlations between Calculated Prices and Deflators of Labor, Capital, Materials and Energy in the Japanese Manufacturing Industry (1955-1992)

Labor	$\ln Pl$	$= -0.74 + 1.08 \ln LDEF$ (47.22)	adj.R^2 0.984	DW	1.59
Capital	$\ln Pk$	$= -6.63 + 1.14 \ln KDEF$ (20.53)	adj.R^2 0.919	DW	0.91
Materials	$\ln Pm$	$= 0.10 + 0.89 \ln MDEF$ (27.61)	adj.R^2 0.955	DW	1.83
Energy	$\ln Pe$	$= -6.98 + 0.99 \ln EDEF$ (24.08)	adj.R^2 0.943	DW	1.92

2.3 Empirical Results of the Measurement of Fundamental Structure

2.3.1 Technology Knowledge Stock

Empirical results of the measurement of the technology knowledge stock taking Japanese manufacturing industry over the period 1955-1992 are summarized in Table 4.

Table 4 Trends in Technology Knowledge Stock in the Japanese Manufacturing Industry (1955-1992) - 1985 constant prices (billion yen)

YEAR	T
1955	623.7
1956	735.7
1957	843.8
1958	968.3
1959	1139.6
1960	1351.8
1961	1566.9
1962	1796.3
1963	2110.8
1964	2515.0
1965	2966.0
1966	3445.8
1967	3965.1
1968	4471.0
1969	4978.8
1970	5620.0
1971	6507.6
1972	7630.5
1973	9014.2
1974	10517.6
1975	11994.5
1976	13501.1
1977	14852.9
1978	16013.5
1979	17065.8
1980	18094.2
1981	19161.5
1982	20326.2
1983	21624.5
1984	23129.6
1985	24864.3
1986	26807.4
1987	29009.1
1988	31578.8
1989	34467.4
1990	37412.0
1991	40512.5
1992	43910.5

2.3.2 The service price of technology and internal rate of return to R&D investment

Empirical results of the measurement of the service price of technology and internal rate of return to R&D investment taking Japanese manufacturing industry over the period 1955-1992 are summarized in Table 5.

Table 5 Trends in Service Price of Technology, Internal Rate of Return to R&D Investment and Rate of Return to R&D Investment (Marginal Productivity of Technology) in the Japanese Manufacturing Industry (1955-1992)

	technology price (1985 capital tech. price=100)	internal rate of return	rate of return to R&D invest.
1955	14.50039	0.22418	0.56051
1956	15.17078	0.22312	0.55757
1957	15.61905	0.21483	0.53461
1958	14.83593	0.18182	0.44772
1959	15.38419	0.17671	0.43491
1960	16.01628	0.18869	0.46520
1961	16.93875	0.21109	0.52440
1962	17.58235	0.19668	0.48595
1963	18.62039	0.18733	0.46171
1964	18.96596	0.18097	0.44557
1965	19.09798	0.13067	0.32728
1966	20.33478	0.12798	0.32141
1967	21.52500	0.15082	0.37267
1968	23.57001	0.18098	0.44560
1969	25.42309	0.20218	0.50046
1970	28.49505	0.23063	0.57874
1971	28.79631	0.18656	0.45975
1972	31.34381	0.17350	0.42694
1973	36.44583	0.14417	0.35738
1974	46.23367	0.09308	0.24977
1975	49.22974	0.06651	0.20062
1976	54.30429	0.05002	0.17246
1977	57.14359	0.04210	0.15957
1978	58.42367	0.03517	0.14863
1979	62.36423	0.04952	0.17163
1980	68.76235	0.05820	0.18620
1981	71.62645	0.07172	0.20988
1982	73.31712	0.07938	0.22385
1983	74.52961	0.09004	0.24392
1984	76.24859	0.09734	0.25809
1985	76.82673	0.11603	0.29597
1986	73.92110	0.10217	0.26766
1987	73.45994	0.10361	0.27054
1988	75.55594	0.10669	0.27675
1989	78.21811	0.11369	0.29111
1990	80.26114	0.11919	0.30261
1991	80.56562	0.11365	0.29103
1992	80.46414	0.08732	0.23871

2.3.3 Trends in Complement and Substitution of Technology and Other Production Factors

Using the above data, by means of equations described in Section 2.1.4, the translog cost function for the Japanese manufacturing industry over the period 1956-1992, imposing linear homogeneity in prices are estimated. Table 6 shows all estimated parameters statistically significant at the 1% level except parameters Bme (Bem) which is at the 20% level.

Table 6 Estimated Translog Cost Function for the Japanese Manufacturing Industry over the Period 1956-1992

$$M_l = 0.1608 + 0.0232 \ln (P_l/P_t) + 0.0092 \ln (P_k/P_t) - 0.0263 \ln (P_m/P_t) - 0.0062 \ln (P_e/P_t)$$

(91.89) (13.82) (5.40) (-10.60) (-5.80)

$$M_k = 0.1440 + 0.0092 \ln (P_l/P_t) + 0.0663 \ln (P_k/P_t) - 0.0636 \ln (P_m/P_t) - 0.0089 \ln (P_e/P_t)$$

(74.13) (5.40) (13.77) (-12.21) (-3.16)

$$M_m = 0.6350 - 0.0263 \ln (P_l/P_t) - 0.0636 \ln (P_k/P_t) + 0.1042 \ln (P_m/P_t) - 0.0031 \ln (P_e/P_t)$$

(265.55) (-10.60) (-12.21) (15.58) (-1.01)

$$M_e = 0.0386 - 0.0062 \ln (P_l/P_t) - 0.0089 \ln (P_k/P_t) - 0.0031 \ln (P_m/P_t) + 0.0184 \ln (P_e/P_t)$$

(32.65) (-5.80) (-3.16) (-1.01) (10.17)

On the basis of the estimated function, the estimated Allen partial elasticities of substitution are computerized as summarized in Table 7.

Table 7 Trends in Allen Partial Elasticity of Substitution in the Japanese Manufacturing Industry (1956-1992)

	σ TL	σ TK	σ TM	σ TE
1956	1.30988	-7.88842	-5.74617	-0.59227
1957	1.32813	-7.80567	-5.80187	-0.51711
1958	1.23514	-6.58304	-5.02517	-0.26834
1959	1.25970	-6.23755	-5.01893	-0.41939
1960	1.28592	-5.93470	-5.26096	-0.56954
1961	1.28212	-5.58805	-5.19939	-0.67330
1962	1.22954	-5.12769	-4.64701	-0.48834
1963	1.20512	-4.39894	-4.21808	-0.40090
1964	1.19698	-3.96218	-4.02118	-0.44221
1965	1.16499	-3.56101	-3.49623	-0.25140
1966	1.15495	-3.25818	-3.10204	-0.23820
1967	1.15601	-3.16274	-3.08252	-0.36160
1968	1.14382	-2.79375	-2.90185	-0.32904
1969	1.14600	-2.76192	-2.87709	-0.41659
1970	1.14007	-2.51215	-2.67977	-0.40213
1971	1.11455	-2.19117	-2.34011	-0.17329
1972	1.09491	-1.77320	-1.90506	-0.04284
1973	1.08910	-1.67929	-1.66418	0.04704
1974	1.07390	-1.66853	-1.17568	0.43770
1975	1.05507	-1.34842	-0.78400	0.61796
1976	1.05291	-1.08442	-0.64741	0.65917
1977	1.04791	-0.92862	-0.53327	0.68465
1978	1.04536	-0.68673	-0.48120	0.65918
1979	1.04678	-0.73483	-0.42181	0.65056
1980	1.05040	-0.87075	-0.39461	0.73601
1981	1.04526	-0.72462	-0.32245	0.74808
1982	1.04113	-0.55358	-0.25051	0.75457
1983	1.03815	-0.46289	-0.19188	0.74661
1984	1.03760	-0.38574	-0.17072	0.72924
1985	1.03495	-0.27660	-0.12816	0.73476
1986	1.02978	-0.13364	-0.06842	0.71297
1987	1.02730	-0.00299	-0.00441	0.67893
1988	1.02707	0.04892	0.03821	0.66086
1989	1.02647	0.07190	0.08352	0.64761
1990	1.02560	0.09031	0.11105	0.65975
1991	1.02424	0.12297	0.13581	0.67137
1992	1.02003	0.20368	0.22181	0.70434

a T: technology, L: labor, K: capital, M: materials, and E: energy.

	σ LE	σ KE	σ ME	σ LK
1956	-0.33470	-0.61506	0.88425	1.53877
1957	-0.32155	-0.49617	0.89087	1.55468
1958	-0.07948	-0.46863	0.88982	1.46670
1959	-0.30831	-0.53821	0.87921	1.48241
1960	-0.48473	-0.51916	0.87049	1.47437
1961	-0.60969	-0.58576	0.85910	1.45829
1962	-0.43714	-0.61853	0.85916	1.42787
1963	-0.45049	-0.61062	0.85301	1.40423
1964	-0.56916	-0.66765	0.84066	1.39041
1965	-0.43684	-0.67568	0.84402	1.37869
1966	-0.57144	-0.82182	0.83429	1.39079
1967	-0.75435	-0.97485	0.81712	1.38785
1968	-0.77837	-0.97903	0.80781	1.36708
1969	-0.93327	-1.10153	0.79549	1.37126
1970	-1.04498	-1.16317	0.78600	1.37041
1971	-0.75561	-1.06325	0.79609	1.34529
1972	-0.73680	-1.14088	0.78824	1.33399
1973	-0.72419	-1.18737	0.79463	1.35054
1974	-0.20280	-0.83240	0.85893	1.41278
1975	0.07000	-0.67311	0.87999	1.41339
1976	0.06512	-0.55364	0.88406	1.41345
1977	0.08508	-0.55364	0.88337	1.40462
1978	-0.03179	-0.61851	0.86580	1.36925
1979	-0.12885	-0.76618	0.86332	1.40526
1980	0.07732	-0.44485	0.89830	1.47281
1981	0.09679	-0.45195	0.89487	1.44712
1982	0.08197	-0.46295	0.88881	1.42022
1983	0.02379	-0.57927	0.87850	1.40755
1984	-0.07051	-0.66462	0.86721	1.39619
1985	-0.07993	-0.66423	0.86113	1.37586
1986	-0.16850	-0.87647	0.83301	1.33373
1987	-0.38618	-1.14861	0.79683	1.31314
1988	-0.56326	-1.31722	0.77873	1.31702
1989	-0.71640	-1.53927	0.76324	1.32689
1990	-0.70333	-1.55353	0.76439	1.32931
1991	-0.67007	-1.54887	0.76285	1.32229
1992	-0.57792	-1.64645	0.75580	1.30732

A cost function is well-behaved if it is concave in input prices and if its input demand functions are strictly positive. The fitted cost shares are checked based on the parameter estimates of the cost function and the positivity conditions were confirmed at each annual observation. Concavity of the cost is satisfied if the Hessian matrix is negative, and this postulation is satisfied in the translog cost function when the Allen partial elasticities of substitution (σii: i=L,K,M,E,T) is negative. All σii were confirmed negative at each annual observation except σtt for the early period of observation. Although further careful analysis on these trends is requested, this was considered that technology development was consistently forwarded despite its prices in the Japanese manufacturing industry which has changed to price consciousness in accordance with increase in its technology knowledge stock.

This question with respect to satisfaction of concavity of technology cost (especially in the 1950s and 1960s when technological development efforts in Japan's manufacturing industry were strongly promoted despite its cost) remains unsolved. In the analyses of the following section (empirical analyses) this unsolved question was recognized and primary analyses were focused in the period after 1970s by making multi empirical cross evaluation.

3. Empirical Analyses

3.1 The Role of Technology: Japan's Path

The Japanese economy has shown tremendous growth due to the motivating influence of industrial development. Japan's GDP share was 4.1% in 1960, 6.4% in 1970, and 9.1% in 1980. It increased to 14.8% in 1990 as illustrated in Fig. 2 and currently shares more than 18%.

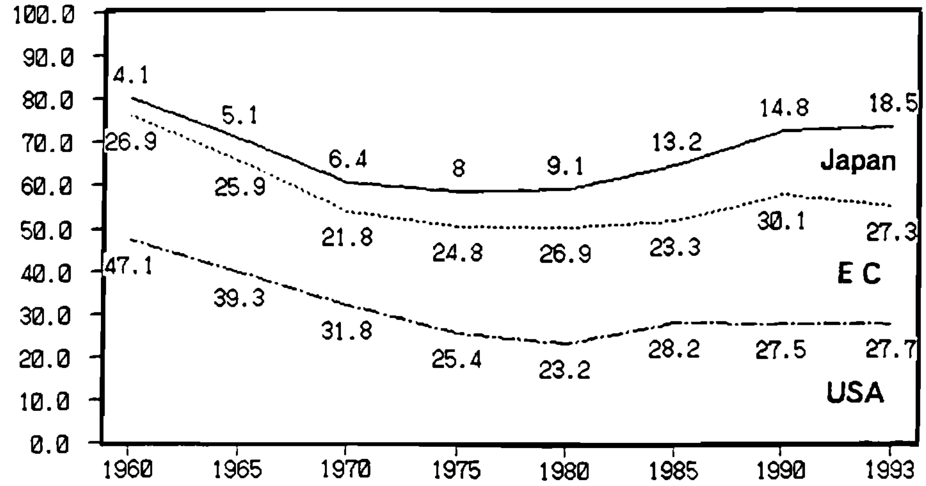

Fig. 2 Trends in GDP Share in the World (1955–1993) – %

Source: National Accounts (United Nation, Annual issues)
a All current prices base (figures in 1955 are by GNP).

Whereas agriculture, forestry, fisheries and mining generally stagnated in the post-war period, the manufacturing industry took a leading role in stimulating Japan's economy as a whole as illustrated in Fig. 3 [35].

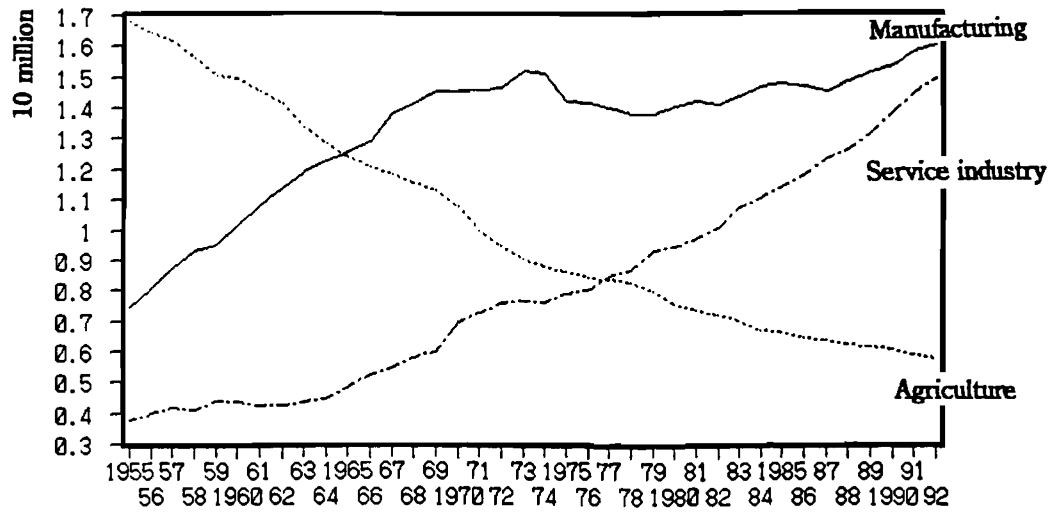

Fig. 3 Trends in Number of Employed Persons in Japan (1955–1992)

Source: Annual Report on National Accounts (Economic Planning Agency, Annual issues)

The manufacturing industry displayed distinctive dynamism and initiative in shedding obsolete equipment, facilities and technology, and venturing into new lines of activity, all of which rapidly enhanced technology and productivity levels, as illustrated in Fig. 4. These efforts resulted in the attainment of levels outmatching other competitors and recognition for being among the world's most advanced nations [23].

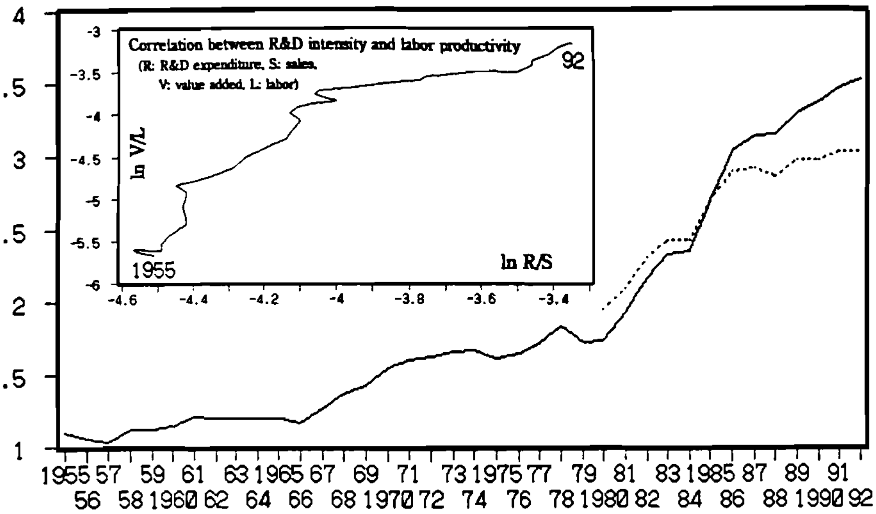

Fig. 4 Trends in R&D Intensity in the Japanese Manufacturing Industry (1955–1992)

a R&D intensity: R&D expenditure per sales at current prices bases (%).

(------ indicates 1985 fixed prices bases for reference)

Such remarkable improvement has mainly resulted from private industry's vigorous efforts to invest in R&D. The marginal productivity of Japanese industry's capital investment has exceeded those levels found in the USA and European countries [58]. In addition, the marginal productivity of its R&D investment (rate of return to R&D investment) has proven to be much higher than capital investment as illustrated in Fig. 5, and has maintained an extremely high level in comparison to other advanced countries as shown in Fig. 6.

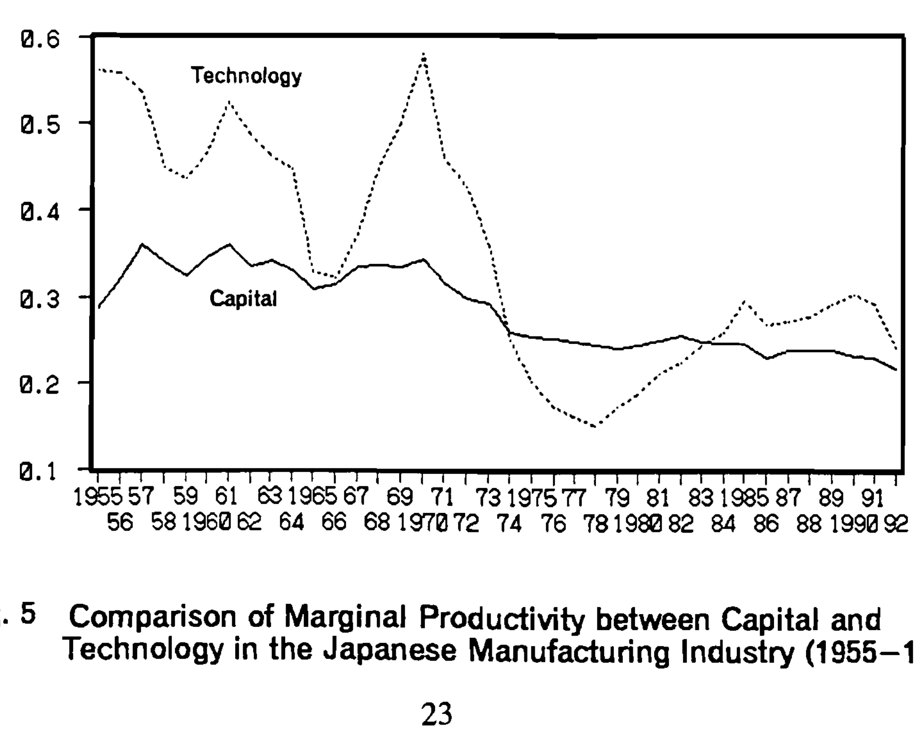

Fig. 5 Comparison of Marginal Productivity between Capital and Technology in the Japanese Manufacturing Industry (1955–1992)

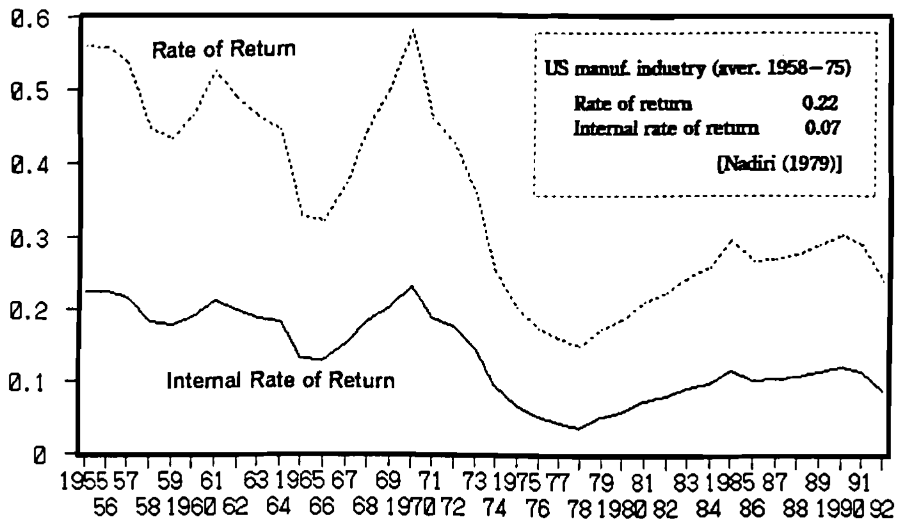

Fig. 6 Trends in Internal Rate of Return to R&D Investment and Rate of Return to R&D Investment (Marginal Productivity of Technology) in the Japanese Manufacturing Industry (1955–1992)

This high level of rate of return to R&D investment in Japan's industry induced further efforts by private industry to increase R&D investment. It is important to note that these efforts in R&D investment were incorporated with capital investment as illustrated in Fig. 7.

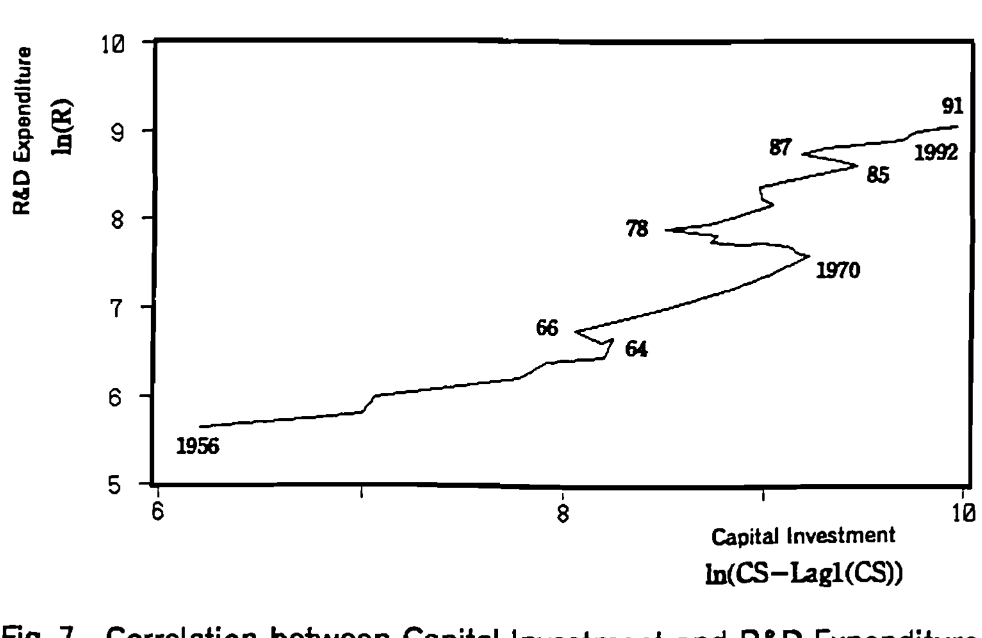

Fig. 7 Correlation between Capital Investment and R&D Expenditure in the Japanese Manufacturing Industry (1956–1992)
– 1985 fixed prices

a Correlation between R&D expenditure (R) and capital investment (CS–Lagl(CS) where CS: capital stock) in the period 1957–1970 is as follows:

	adj.R^2	DW
$\ln(R) = -0.41 + 0.76 \ln(CS - Lagl(CS))$ (14.74)	0.974	1.13

Thus, through the support of the complementary relationship between R&D and capital investments, Japan's manufacturing industry displayed distinctive dynamism and initiative in shedding obsolete equipment, facilities and technology, resulting in the rapid enhancement of its technology and productivity levels.

Despite many handicaps, Japan achieved sustainable development by focusing its efforts on improving the productivity of the relatively scarce resources in each respective era [10]. Scarce resources included capital in the 1950s, labor in the 1960s, environmental capacity from the mid-1960s to the start of the 1970s, and energy following the first energy crisis in 1973 as illustrated in Fig. 8. While many have attributed this achievement to the complementary relationship between R&D and capital investment, technology in fact provided the strongest contribution through its substitution for scarce resources (constrained production factors). Looking at Fig. 5 we note that the marginal productivity of technology fell below the productivity of capital from 1973-1983. Nevertheless, industry's efforts in consistent R&D investment were sustained as observed in Fig. 4. This is considered due to a result of industry's efforts to substitute technology (which is relatively constraints free production factor) for energy, a crucially constrained production factor during the period 1973-1983 as illustrated in Figs. 1 and 8.

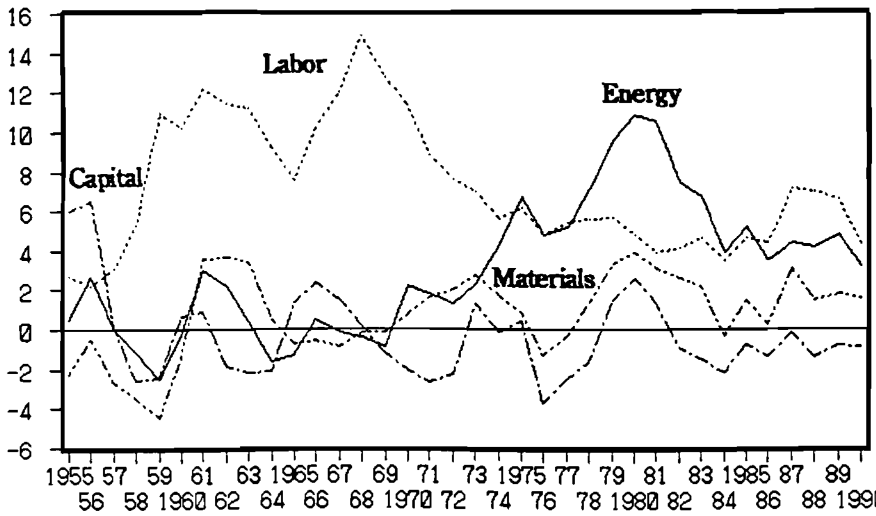

Fig. 8 Trends in Change Rate of Productivity of Production Factors in the Japanese Nanufacturing Industry (1955–1990)
– 3 years' moving average (%)

a Productivity is measured by the ratio of value added and respective production factor.

Fig. 9 illustrates trends in substitution and complement among labor, capital, energy and technology (technology knowledge stock) in Japan's manufacturing industry from 1956-1992. Looking at Fig. 9, we note that technology and capital were consistently complementary by the late 1980s; technology consistently substitutes for labor; while energy and technology were independent or slightly complementary until 1973 at which point technology began to substitute for energy. These trends demonstrate the above hypothesis.

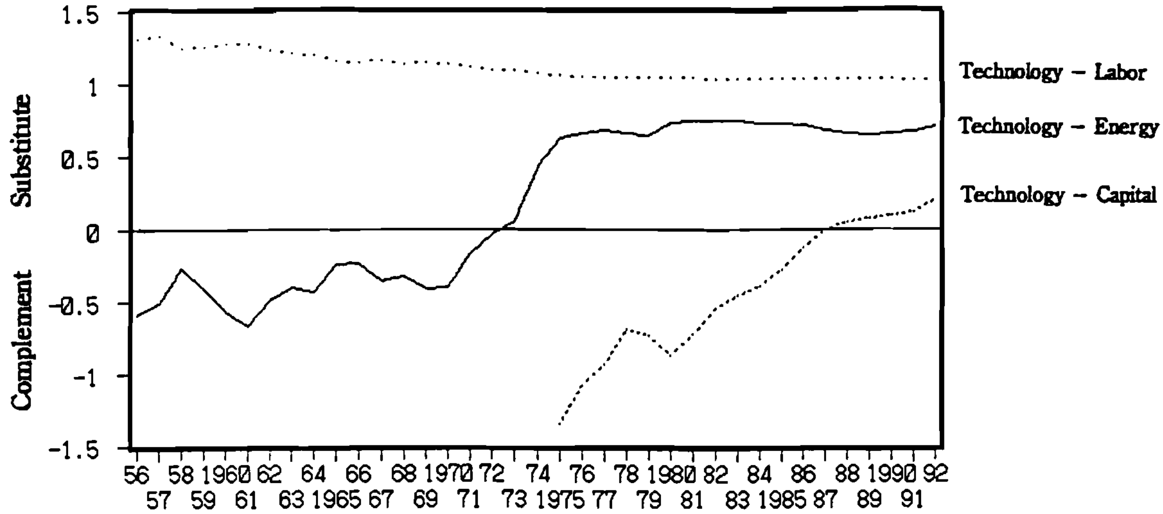

Fig. 9 Trends in Substitution and Complement among Labor, Capital, Energy and Technology in the Japanese Manufacturing Industry (1956–1992) – Allen Partial Elasticity of Substitution

Figs. 10, 11 and 12 illustrate trends in unit energy consumption (manufacturing industry: 1955-1992), SOx emissions (Japan's total: 1965-1989) and CO_2 discharge (manufacturing industry: 1970-1990). Fig. 10 demonstrates a dramatic decrease in unit energy consumption after the first energy crisis in 1973, while Figs. 11 and 12 demonstrate that SOx and CO_2 discharges were kept to a minimum despite an increase in production.

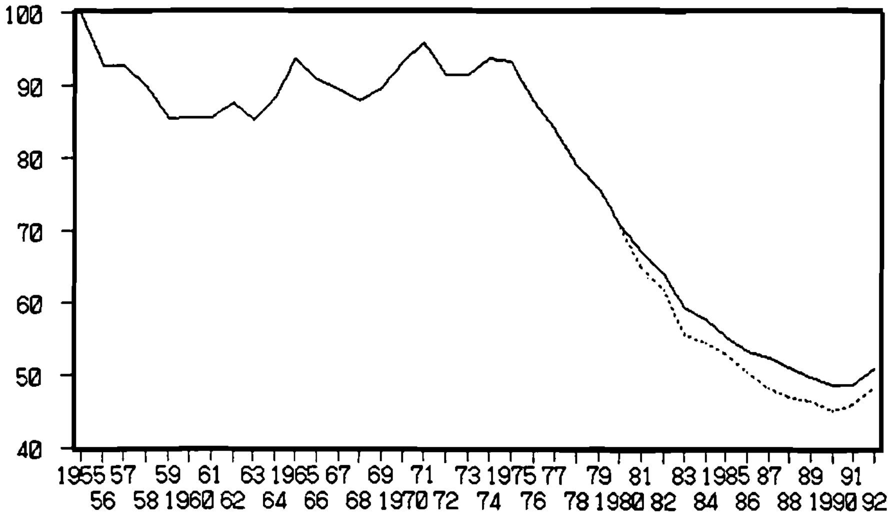

Fig. 10 Trends in Unit Energy Consumption in the Japanese Manufacturing Industry (1955–1992) – Index: 1955=100

a Unit energy consumption: energy consumption per IIP (Production weight. ---- illustrates value added weight for reference).

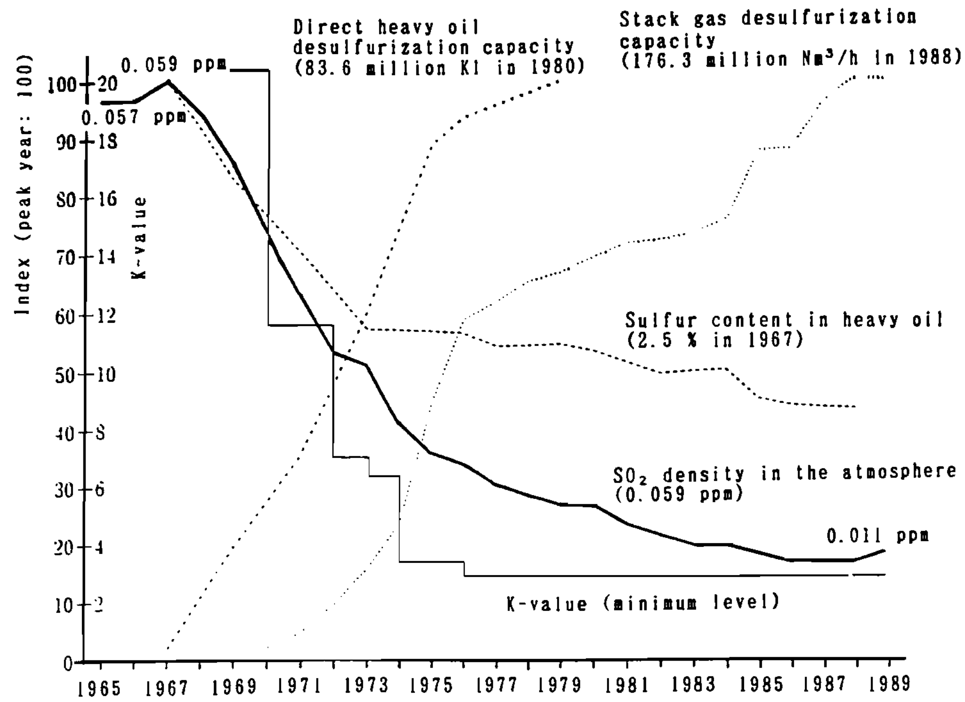

Fig. 11 Trends in Japan's Efforts to Decrease SOx Emissions (1965–1989)

a Figures in parentheses indicate peak levels.

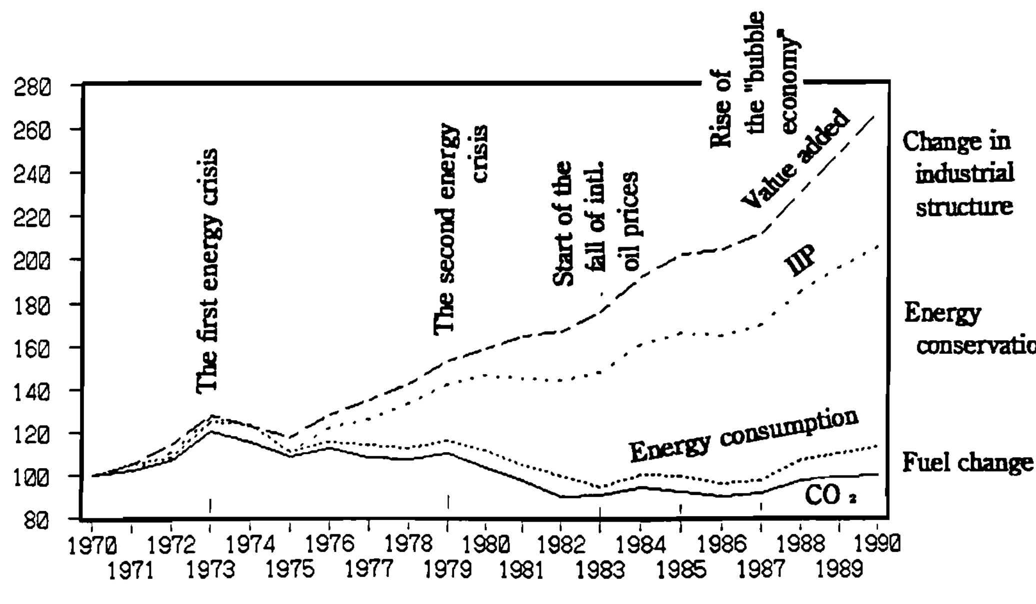

Fig. 12 Trends in Production, Energy Consumption and CO_2 Discharge in the Japanese Manufacturing Industry (1970–1990)
– Index: 1970=100

Figs. 13 and 14 analyze factors producing change in SOx and CO_2 discharges which indicate that efforts to improve dependency on energy or decrease in unit energy consumption (55% and 60% from 1974-1990 respectively) largely contributed to reductions in SOx and CO_2 discharges.

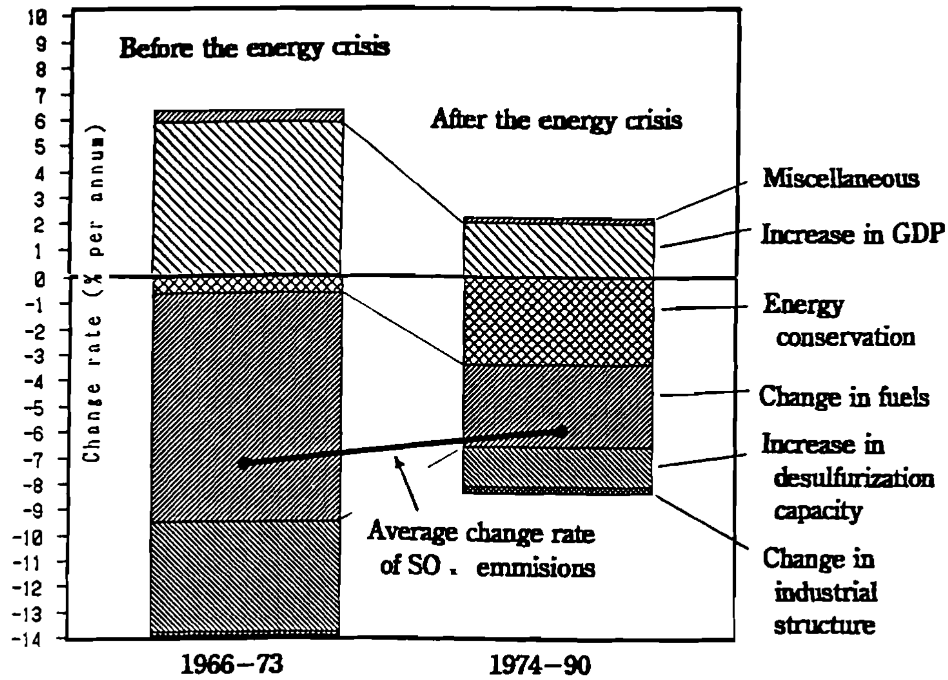

Fig. 13 Factors Contributing to Change in SOx Emissions in Japan (1966–1990)

a Magnitude of contribution is measured by the following equation (1965–1990):

$$\ln SOx = 14.99 - \underset{(-23.42)}{0.24} \ln DSF + \underset{(12.84)}{1.41} \ln E/Y \quad adj.R^2\ 0.99 \quad DW\ 1.24 \qquad ①$$

$$SOx = (SOx/E)*(E/Y)*(Y/V)*V$$
$$\ln SOx = \ln (SOx/E) + \ln (E/Y) + \ln (Y/V) + \ln V \qquad ②$$

(① + ②)/2

$$\ln SOx = 7.49 + 0.50\ln(SOx/E) + 1.20\ \ln(E/Y) + 0.50\ln(Y/V) - 0.12\ln(DSF) + 0.50\ln V$$

$$\blacktriangle\ SOx = 0.50\ \underbrace{\blacktriangle\ (SOx/E)}_{\text{change in fuels}} + 1.20\ \underbrace{\blacktriangle\ (E/Y)}_{\text{energy conservation}} + 0.50\ \underbrace{\blacktriangle\ (Y/V)}_{\text{change in ind. struct.}} - 0.12\ \underbrace{\blacktriangle\ (DSF)}_{\text{desulf. capacity}} + 0.50\ \underbrace{\blacktriangle\ V}_{\text{change in prod.}} + \underbrace{\eta}_{\text{misc.}}$$

where E: energy, Y: production, V: value added (GDP), DSF: desulfurization capacity.

b Contribution of respective factors to reducing SOx emissions in each year is as folows (average change rate: %):

	▲SOx	▲(SOX/E)	▲(E/Y)	▲(Y/V)	▲(DSF)	▲V	η
1966-69	-2.51	-8.56	-0.35	0.26	0	6.14	0
1970-73	-12.25	-9.27	-0.87	-0.54	-8.25	5.78	0.90
1974-78	-10.44	-5.55	-2.08	-0.15	-4.20	1.37	0.17
1979-82	-7.61	-2.70	-6.27	-0.68	-0.26	2.26	0.04
1983-86	-5.08	-2.66	-3.57	-0.26	-0.68	1.96	0.13
1987-90	-0.05	-1.37	-1.82	-0.04	-0.36	3.06	0.48
1966-73	-7.38	-8.91	-0.61	-0.14	-4.13	5.96	0.45
1974-90	-6.07	-3.21	-3.36	-0.28	-1.54	2.12	0.20
1979-90	-4.25	-2.24	-3.89	-0.33	-0.43	2.43	0.21

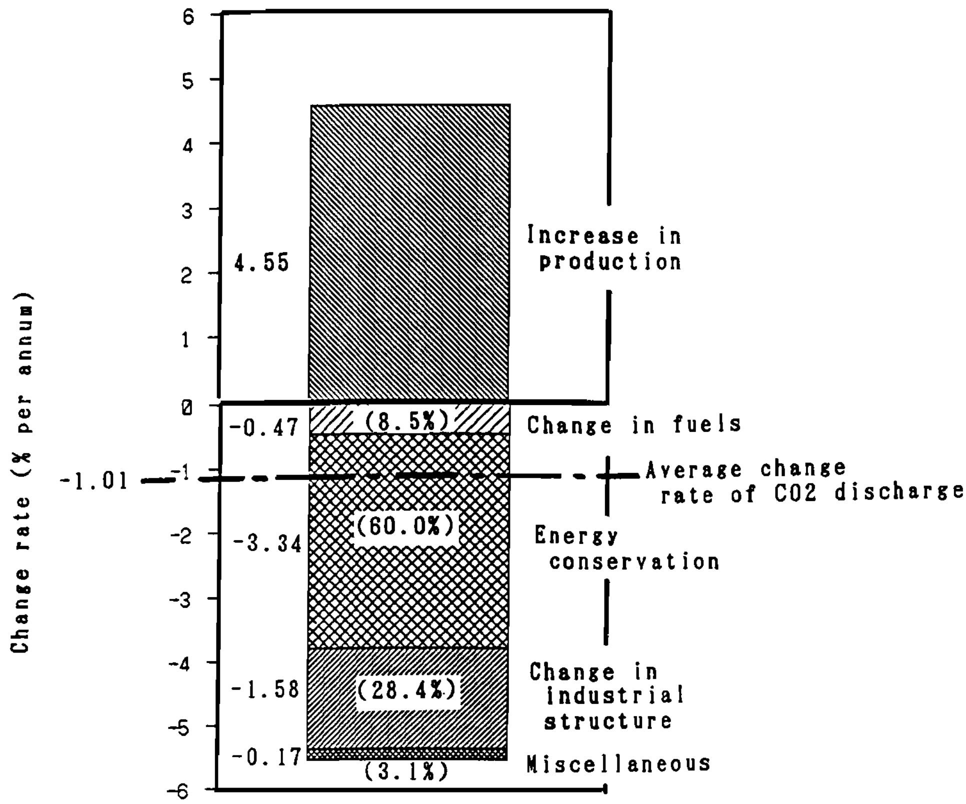

Fig. 14 Factors Contributing to Change in CO_2 Discharge in the Japanese Manufacturing Industry (1974–1990)

a Figures in parentheses indicate shares of contribution to reducing CO_2 discharge.

b Magnitude of contribution is measured by the following equation:

$$C = C/E \cdot E/I \cdot (V/I)^{-1} \cdot V$$

where C: CO_2, E: energy consumption, I: IIP (production weight) and V: Value added.

$$\underbrace{\blacktriangle C/C}_{} = \underbrace{\blacktriangle (C/E)/(C/E)}_{\text{change in fuels}} + \underbrace{\blacktriangle (E/I)/(E/I)}_{\text{energy conservation}} - \underbrace{\blacktriangle (V/I)/(V/I)}_{\text{change in industrial structure}} + \underbrace{\blacktriangle V/V}_{\text{change in production}} + \underbrace{\eta}_{\text{misc.}}$$

Fig. 15 analyzes factors contributing to the decrease in unit energy consumption in Japan's manufacturing industry from 1975-1990, which indicate that the substitution of technology for energy contributed to 35.5% of the reduction of unit energy consumption; the high level of R&D intensity, which exceeds most other advanced countries (see Fig. 16), produced 37.6%; and energy price increases contributed to 26.9%. The first factor represents the outcome of efforts aimed at overcoming energy constraints by means of energy conservation technology, technologies for improving energy productivity and oil alternative technologies. The second factor represents both the above objective efforts and other efforts in line with the complementary tie between capital investment and R&D investment. The last factor represents similar effects as autonomous energy efficiency improvement (AEEI). This demonstrates that Japanese manufacturing industry's efforts in R&D investment were primarily initiated by technology's complement to capital and substitution for constrained production factors such as labor, energy and environmental capacity, which thereby enhanced its technology and productivity levels.

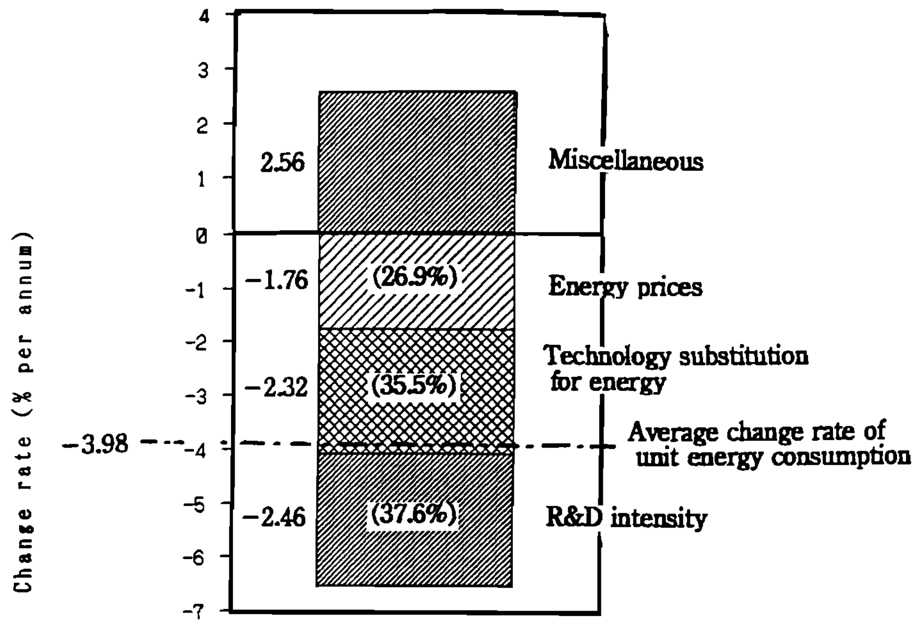

Fig. 15 Factors Contributing to Change in Unit Energy Consumption in the Japanese Manufacturing Industry (1975–1990)

a Magnitude of contribution is measured by the following equation:

σ te = (Bte − Mt · Me)/(Mt · Me) = 1 + Bte(GC/GTC)(Pt'/Pt)(GC/GEC)

σ te − 1 = Bte(GC/R)(Pt'/Pt)(GC/E · Pe) = Bte(S/R)(GC/S)(IIP/E)(GC/IIP)(1/Pe)(Pt'/Pt)

E/IIP = Bte · (σ te − 1) $^{-1}$ (R/S) $^{-1}$ (Pe) $^{-1}$ (GC/IIP)(GC/S)(Pt'/Pt)

ln E/IIP = ln Bte − ln (σ te − 1) − ln R/S − ln Pe + ln (GC/IIP) + ln (GC/S)(Pt'/Pt)

ln(Gc/IIP) = 5.476 $+ \underset{(21.407)}{0.437}$ ln(Pe)   1970−1990   adj.R^2 0.958   DW 0.32

▲ E/IIP = − ▲ (σ te − 1) − ▲ R/S − (▲ Pe − ▲ (GC/IIP)) + η

= − ▲ (σ te − 1) − ▲ R/S − 0.563 ▲ Pe + η

where σ te: substitution of technology for energy; Bte: coefficient; Mt and Me: cost share of technology and energy respectively; GC: gross cost; GTC: gross technology cost; Pt': capital price of technology (Pt'=GTC/T T: technology stock)); Pt: service price of technology; GEC: gross energy cost; R: R&D expenditure inc. technology imports (= gross technology cost); E: energy consumption; Pe: prices of energy; S: sales; IIP: index of industrial production; η : miscellaneous.

b Contribution of respective factors to reducing unit energy consumption is as follows (average change rate: %):

▲ E/IIP (unit energy consumption): −3.98
▲ (σ te − 1) (substitution of technology for energy): −2.32
▲ R/S (R&D intensity): −2.46
▲ Pe (energy prices): −1.76
η (miscellaneou)s: 2.56

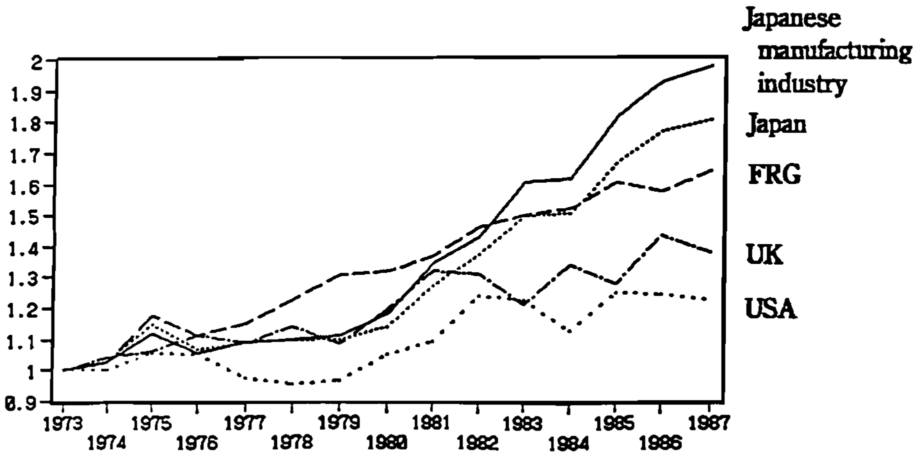

Fig. 16 Comparison of Trends in R&D Intensity in Japan, the USA, FRG, and the UK Industry (1973–1987) – Index: 1973 = 1

a R&D intensity: R&D expenditure per production where production is represented by IIP
All are 1980 constant prices.

3.2 Policy Contribution and its Mechanism

Japan has adopted different industrial policies throughout its economic development, all of which reflect the international, natural, social, cultural and historical environment of the post-war period [35]. In the late 1940s and 1950s, Japan made every effort to reconstruct its war-ravaged economy, laying the foundation for viable economic growth by introducing "priority production system" which allocated limited raw materials, capital and foreign exchange for strategic industries leading the consolidation of the economic foundation and the rationalization of industrial productivity. During the decade of the 1960s, Japan actively sought to open its economy to foreign competition by liberalizing trade and the flow of international capital. In the process, it achieved rapid economic growth led by the heavy and chemical industries. On the other hand, the heavy concentration of such highly material-intensive and energy-intensive industries led to serious environmental pollution problems [34]. This necessitated a reexamination of its industrial policy which led to a shift towards a knowledge-intensive industrial structure that would place a lesser burden on the environment by depending less on energy and materials and more on technology [21]. In the 1980s, intensive efforts continued for the attainment of greater creative knowledge (Table 8).

Table 8 Trends in Japan's Industrial Structure Policy in the Post-War Era

1950s	Priority production system
1960s	Heavy and chemical industrial structure
1970s	Knowledge-intensive industrial structure
1980s	Creative knowledge-intensive industrial structure
1990s	Creation of human-values in the global age

Industrial technology policy initiated by MITI focused on inducing industry's challenge in order to respond to the above historical demands[5] [37] (Table 9). Thus, Japan succeeded in constructing a virtuous cycle between technological development and economic growth in the face of numerous constraints [10].

[5] A survey of manufacturing firms involved in MITI's energy R&D program projects regarding their expectations for R&D projects (AIST of MITI, 1993) indicated that aside from supplementing industry's own R&D activities, a significant number of firms expressed the strong expectation that such projects will induce industry's R&D in relevant fields.

1966–	The National R&D Program (Large–Scale Project)	Leading technology (big, risky)
1974–	R&D on New Energy Technology (The Sunshine Project))	Oil–substituting energy technology (renewable energy and energy conversion)
1976–79	VLSI Project (Very large scale integrated circuit)	Innovative computer technology
1976–	R&D on Medical & Welfare Equipment Technology	Medical and welfare technology
1978–	R&D on Energy Conservation Technology (The Moonlight Project)	Technologies for improving energy productivity
1981–	The R&D Program on Basic Technologies for Future Industries ("Jisedai" Project)	Basic and fundamental technology
1982–91	Fifth Generation Computer Project	Innovative computer technology (concept/system)
1985–	The Comprehensive Promotion of Private–sector R&D in Fundamental Technology (Key Technology Center Project)	Fundamental technology initiated by private-sector
1989–	The Designated Research Frame in the Global Environmental Field	Basic technology for global environment
1990–	The R&D Program for Global Environmental Industrial Technology	Global environmental technology

Table 9 Chronology of MITI Initiated R&D Programs

Fig. 17 illustrates trends in Japan's governmental support for R&D investment by industry. Looking at Fig. 17, we note that Japan's governmental R&D funding in industry shared 5 to 10% of industry's total R&D expenditures by the mid-1960s, however, decreased as its economic growth left industry's principal initiatives; currently that share has decreased to only 3%. Interestingly enough, Japan's governmental support for R&D investment by industry is extremely small in comparison to other advanced countries as summarized in Table 10.

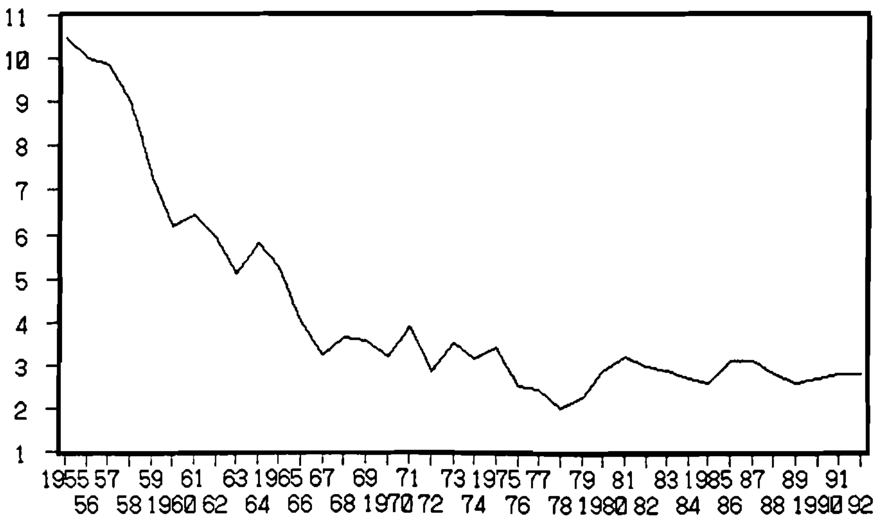

Fig. 17 Trends in Japan's Government Support for R&D Investment by Industry (1955–1992)

a Ratio of government R&D funds in industry's R&D expenditure (%)

Sources: Wakasugi (1986), AIST of MITI and White Paper on Japanese Science & Technology (annual issues).

Table 10 Comparison of Government R&D funds in Industry in 5 Countries [a]

Japan (1992)	USA (1992)	Germany (1991)	France (1988)	U K (1990)
2.7	29.9	22.7	21.2	18.6 %

Inducing Impacts of MITI's Energy R&D on Energy R&D Initiated by the Japanese Manufacturing Industry (1976–1990) [b]

	adj.R^2	DW	D
Energy R&D Total $\ln(ERT) = 3.43 + 0.45 \ln(SSML) + 0.24 \ln(nSM) - 0.65\ D$ (4.21) (1.31) (−5.67)	0.978	0.96	1976=1
Energy Conservation R&D $\ln(ERS) = 3.84 + 0.72 \ln(ML+SSH) - 1.43\ D$ (12.82) (−8.36)	0.975	1.28	1976=1
Renewable Energy R&D $\ln(ERR) = 0.09 + 0.98 \ln(SSR)$ (17.59)	0.957	1.75	

ERT, ERS and ERR: Energy R&D total, energy conservation R&D, and renewable energy R&D initiated by manufacturing industry respectively.

SSML: R&D undertaken by both the Sunshine Projects (R&D on new energy technology) and the Moonlight Project (R&D on energy conservation technology); nSM: MITI's other energy R&D.

ML: R&D on energy conservation undertaken by the Moonlight Project; SSH: Hydrogen R&D undertaken by the Sunshine Project.

SSR: R&D on renewable energy undertaken by the Sunshine Project.

a Source: White Paper on Japanese Science and Technology (1993).

b Source: C. Watanabe (1993).

This observation implies the effectiveness of Japan's R&D policy system. Indeed, MITI has established a sophisticated policy system (Fig. 18) in its comprehensive industrial policy (Fig. 19). Its policy system, in coordination with other related industrial policies, aims at inducing technology complementation with capital as well as substitution for constrained production factors such as labor, energy and environmental capacity. The mechanism for such inducement in MITI's policy system can be summarized as follows [38] (Fig. 20):

Basic Principle

- Activate Free Competition in the Marketplace
- Stimulate the Competitive Nature of Industry
- Induce the Vitality of Industry

Approach

- Leading-edge Technology Foresight
- Maintain Close Cooperation with Related Industrial Policies
- Depend on an Active and Flexible Approach
- Best Utilize Innovative Human Resources in National Research Laboratories and Universities.
- Organize Tie-ups between Industries, Universities and Government

Policy Formation/Implementation

- Vision: Penetration, Identification, Providing Direction, Instilling Confidence, Developing General Consensus
- Action:
  - Incentive: National Research Laboratory, R&D Program, Investment, Conditional Loans, Financing, Tax Exemption
  - Stimulation: R&D Consortium, Publication, Open Tender
  - Regulation: IPR, Monopoly, Accounting
- Dissemination: Diffusion, Transfer, Demonstration, Public Procurement

Fig. 18 Basic Scheme of MITI's Industrial Technology Policy

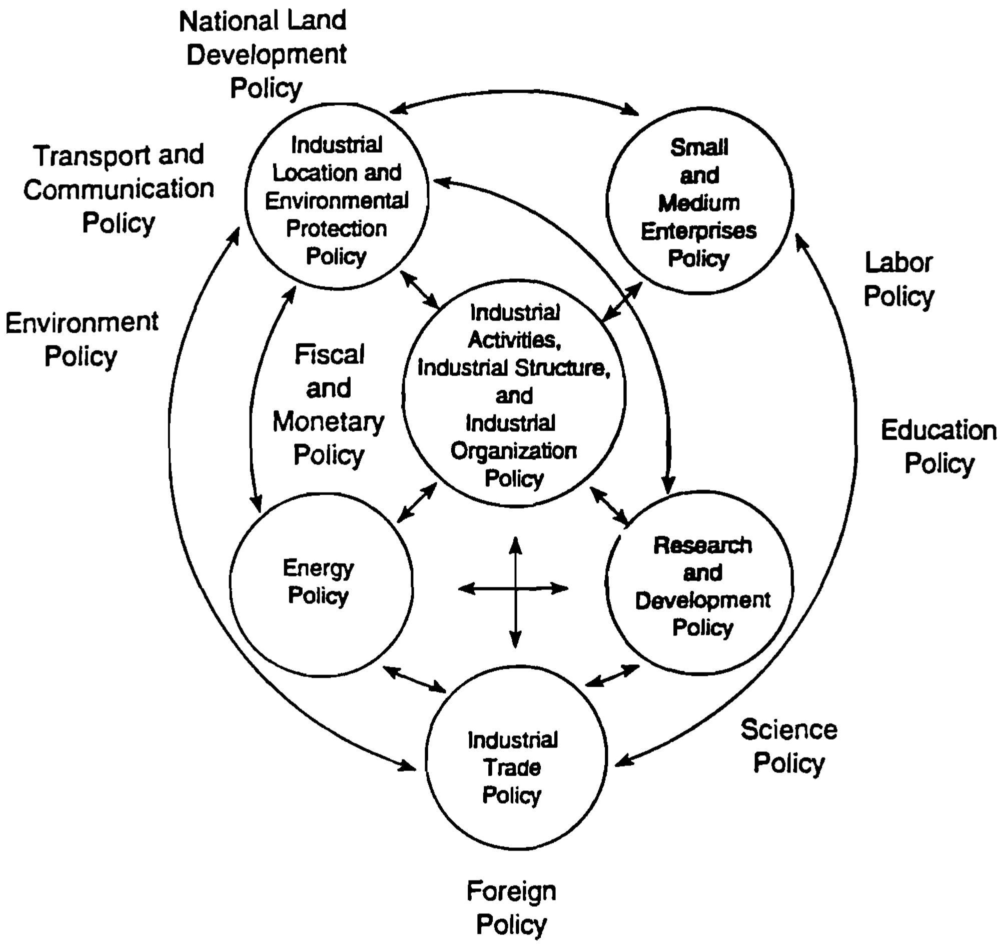

Fig. 19 Relationship of Major Industrial Policies

(i) Identification of future prospects for social and economic needs;
(ii) Selection of strategic areas with high innovative potential;
(iii) Formulation and publication of visions[6];
(iv) Provision of policy measures, including formulation of National R&D Program[7] projects which induce industry to increase its R&D intensity;
(v) As the degree of R&D intensity increases, the potential for further technological challenge increases;
(vi) Expectations for the outcome of technological development among industries increase;
(vii) Inducement of further investment in R&D activities; and
(viii) Buildup of dynamism conducive to technological development.

---

[6] "Visions" are government reports, often produced at the onset of a new decade and after a great deal of cross-sector consultation, that outline the ministry's vision for the future and guide the thinking of both the ministry and related industry. Their effect appears to be providing a vehicle for creating consensus, setting long-term goals, and instilling confidence in various sectors.

[7] "National R&D Program" in this paper means "R&D Programs under a National Initiative" initiated by MITI's Agency of Industrial Science and Technology (AIST) since 1966 (see Section 3.3).

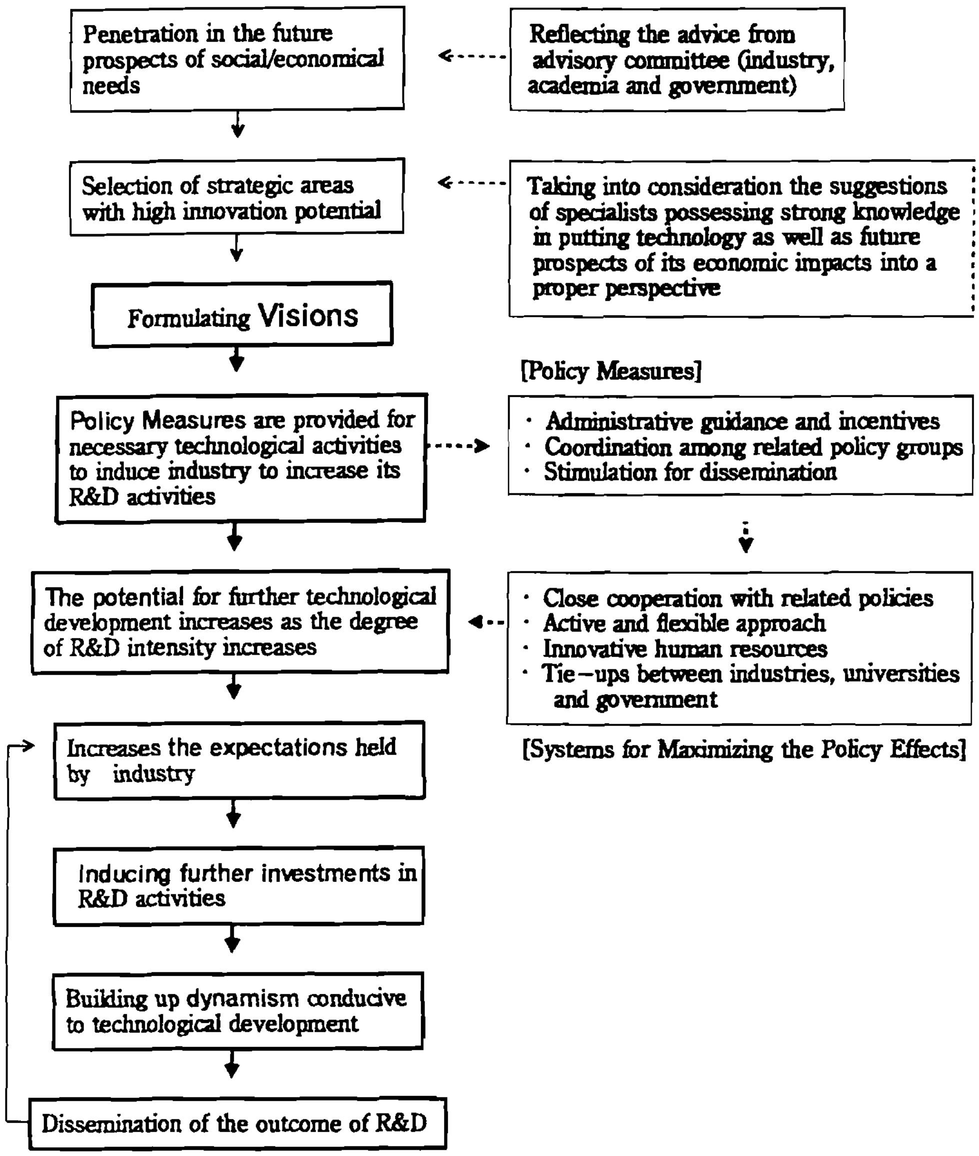

Fig. 20 Mechanism of the Total System of MITI's Industrial Technology Policy

3.3 Japan's Industrial Technology Program at a Turning Point

Although its level of research ability in basic technology is relatively low, the source of Japan's leading high technology has been steadily shifting from an imported base to an indigenous base [23] (Fig. 21). A new stream of technological innovation suggests that it is necessary to not only build on existing technology, but also to initiate creative technological innovation which will induce broad new technologies based on new scientific inventions and discoveries, whose results could be used to resolve global problems [13].

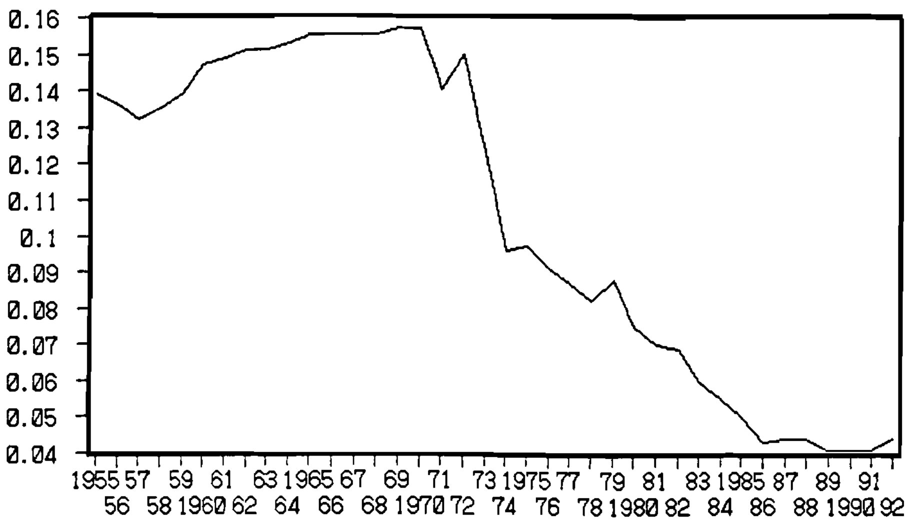

Fig. 21 Trends in the Ratio of Technology Import to R&D Expenditure in the Japanese Manufacturing Industry (1955–1992)

At the same time, with economic growth and technological advancement, Japan is requested to make a significant contribution to the international community through the R&D process, its outcome, and its ripple effects [23]. Furthermore, confronting economic stagnation and mounting concern for future sustainable development due to malevolent CO_2 discharge resulting from energy use, we are moving in a new direction that recognizes the critical role technology must play in (i) revitalizing the world's economy and (ii) providing a solution which can simultaneously overcome energy and environmental constraints while maintaining sustainable growth [44]. Finding such a simultaneous solution is the only survival strategy for Japan as it faces crucial energy and environmental constraints.

Under these conditions, Japan's industrial technology programs have reached a crucial point in which the following requests have been made (Fig. 22):

(i) Further intensive efforts related to basic and creative technology,
(ii) Greater attention to developing science and technology that provide a solution for simultaneously overcoming energy and environmental constraints while maintaining sustainable growth, and
(iii) A greater international contribution to innovative R&D and common global critical issues through the R&D process, its outcome and its ripple effect [15].

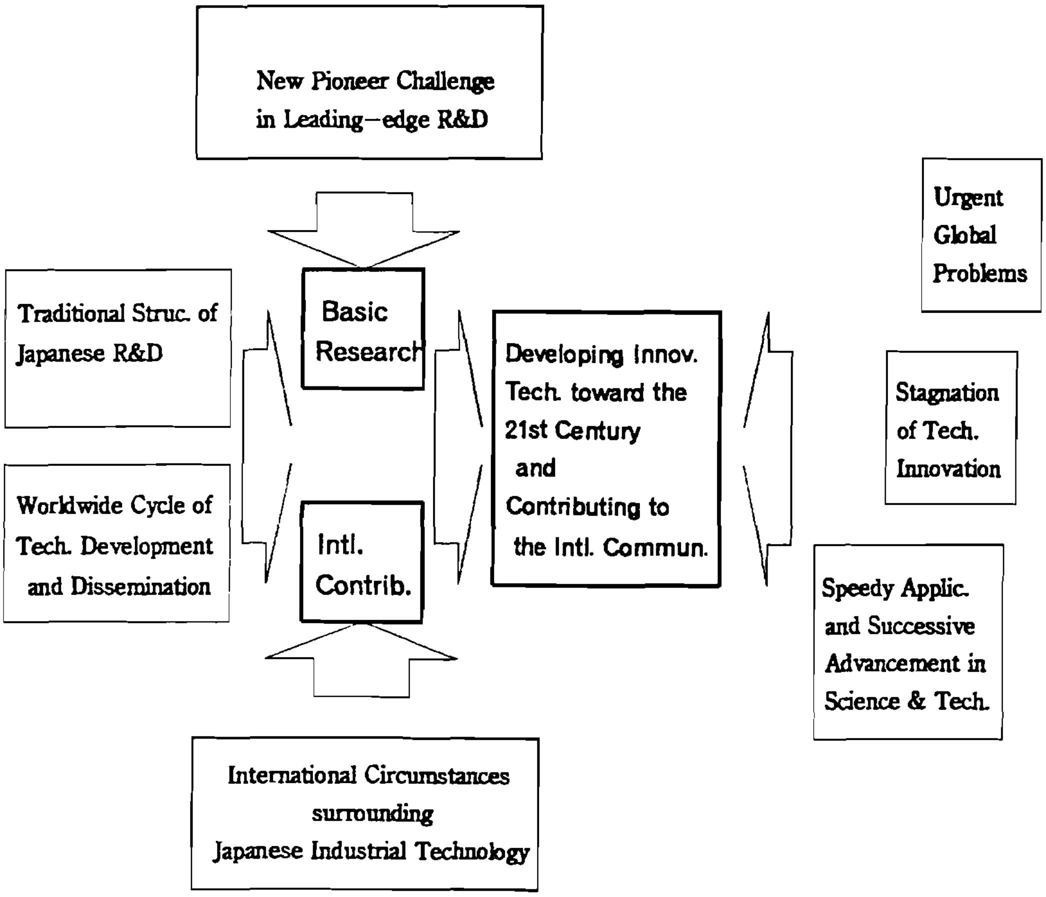

Fig. 22 Trends and Future Tasks in Japanese Industrial Technology at a Turning Point in the Late 1980s

In the latter half of the 1980s several concerned ministries in Japan accepted these recommendations in response to the critical nature of the period. In March 1986 the Science and Technology Council proposed "General Guidelines for Science & Technology" [29] stressing (i) promotion of creative science & technology, (ii) balanced development of science & technology in harmony with social progress, and (iii) development of science and technology from a broad international point of view. MITI, in its first white paper on industrial technology (September 1988) [23], stressed (i) a more aggressive approach to basic and creative technology and (ii) greater international contribution through the R&D process, its outcome and its ripple effect (Table 11).

Although MITI has established a sophisticated policy system which has built up dynamism conducive to technological development, the policy system has been aimed at its own effectiveness and does not necessarily take into full account the redundancy of the broader system [25]. In addition, it was primarily oriented to the rapid development and application of industrial technology for commercial use in the marketplace rather than for the accumulation of scientific inventions and discoveries with a view to international contribution [25].

Table 11 Chronological Background Leading to Restructuring of MITI's National R&D Programs (1986–1992)

1986 March **General Guidelines for Science & Technology**
(Science & Technology Council → Cabinet Approval)

① Promotion of creative science & technology
② Balanced development of science & technology in harmony with social progress
③ Development of science & technology from a broad international point of view

1988 Sept. **White Paper on Industrial Technology: Trends and Future Tasks in Japanese Industrial Technology** (MITI)

① More aggressive approach to basic and creative technology
② Greater international contribution through the R&D process, its outcome and its ripple effect

1990 July **MITI's Vision for the 1990s** (Industrial Structure Council)

① Strengthening basic and creative R&D
② Promoting international R&D efforts
③ Developing science & technology in harmony with man and nature
④ Developing technology for regional vitalization

1992 April **General Guidelines for Science & Technology**
(Science & Technology Council → Cabinet Approval)

① Contribute to maintaining mankind's coexistence with Earth
② Increase technological knowledge stock
③ Contribute to constructing a society with a safe and enjyoiablea life

Facing the above mentioned turning point, MITI's new task became the structuring of a new policy system which encourages forefront efforts in industrial technology to promote R&D on both basic technology and energy and environmental technologies so as to strengthen transnational interdependency [40].

After several extensive studies by the Science and Technology Council and MITI during the late 1980s, MITI's Industrial Structure Council suggested the following direction for Japanese industrial science and technology policy in the 1990s, as summarized in Table 12:

(i) Strengthening basic and creative R&D,
(ii) Promoting international R&D efforts,
(iii) Developing science and technology in harmony with man and nature, and
(iv) Developing technology for regional vitalization.

Table 12 **Basic Direction of Japanese Industrial Science & Technology Policy in the 1990s Indicated by MITI's Vision for the 1990s**

1. Strengthening basic and creative R&D

(i) Fostering centers of excellence open to the world through cooperation among industry, government and universities
(ii) Identifying seeds of new technological innovation
(iii) Stimulating research on basic technology by industry

2. Promoting international R&D efforts

(i) International R&D scheme for solving global problems
(ii) Promotion of international cooperative research
(iii) Promotion of technology transfer for the sustainable growth of developing countries

3. Developing science & technology in harmony with man and nature

(i) R&D to assist aged people
(ii) R&D related to human beings, including the analysis of human feeling
(iii) R&D to preserve nature and to improve the standard of living

4. Developing technology for regional vitalization

(i) Foundation of a regional advanced R&D system
(ii) Strengthening regional policy planning and coordination functions
(iii) Attracting young researchers to regional R&D centers

After outlining this general direction in MITI's "Vision for the 1990s" (published in July 1990 [13]), MITI's advisory councils[8] (Fig. 23) made further efforts to construct a new concept on which to base MITI's industrial technology policy.

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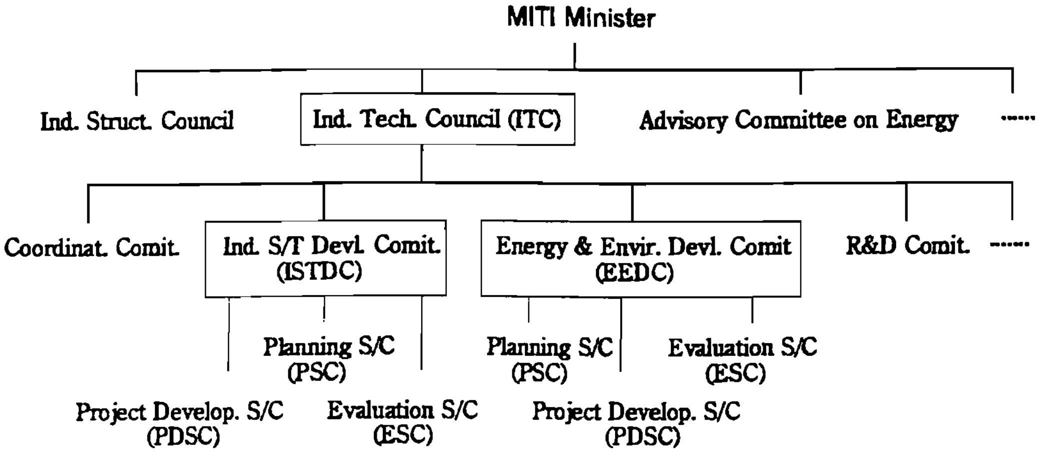
[8] Advisory councils have played an important role in MITI's policy making/implementation by advising MITI, representing policy requirements in respective sectors, and developing general consensus. These councils generally consist of representatives from industry, academia, government agencies, the consumer sector, mass media, and workers.



Composition of Members

	Chairman	Members: Industry	Academia	Gov. Agency	Consumers	Massmedia	Workers	Others	Total Number
ITC	Ex Prof.	7	12	6	1	1	1	1	29
CoordC	Ex Prof.	8	10	3	1	1	1	3	27
ISTDC	Prof.	12	21	1	1	2		1	38
EEDC	Ex Gov.Ag.	11	17	3	1	7		1	40
PSC	Ex MITI	7	11	3		1		2	24 [a)]
PDSC	Prof.		13	1	4		2		20 [b)]
ESC	Prof.	4	10	3	1	2		1	21 [c)]

a) Demonstrates a case of Planning Subcommittee of ISTDC.
b) Demonstrates a case of Medical & Welfare Apparatus R&D Project Development Sub-committee.
c) Demonstrates a case of Evaluation Subcommittee of EEDC.

Fig. 23 Scheme of MITI's Advisory Committees Advising National R&D Programs

The Industrial Technology Council (ITC), an advisory council to MITI's Minister, proceeded to make comprehensive and extensive studies as summarized in Table 13. Through such studies ITC's Coordination Committee (responsible for coordinating ITC's advisory committees) proposed its "Principal Direction of Industrial Science and Technology" in June 1992, which stressed the significance of fostering the COE's (Center of Excellence) and international contribution by means of industrial science and technology [15]. In the process of its study, the Committee proposed reorganizing MITI's national research laboratories and restructuring MITI's National R&D Programs[9].

[9] R&D budgets for national research laboratories and National R&D Programs amount to 15% and 30% of MITI's total R&D budgets respectively.

Table 13 Chronological Background Leading to Restructuring of MITI's National R&D Programs in 1992

1992 June **Principal Direction of Japan's Industrial Science & Technology: Promoting Techno-Globalism and Fostering the COE**
(Advisory Committee *(coordination)* of Industrial Technology Council)

> ① Foster the COE
> - Reorganization of National Research Laboratories
> - Restructuring of National R&D Programs
> - Dramatic increase in public R&D investment
>
> ② International contribution by means of industrial science & technology
> - Aggressive efforts for international cooperation and exchanges
> - Further efforts to opening a broader door for international participation in National R&D Programs

1992 June **R&D Subjects Expected to be Challenged in the Field of Industrial Science & Technology**
(Advisory Committee *(ind. science & tech. devel.)* of Ind. Tech. Council)

> ① Recognize the change in circumstances surrounding technological development and identify technologies expected to be developed
>
> ② Realize the current state and future direction of ind. science & tech. by fields
>
> ③ Identify R&D subjects to be challenged in each field

1992 Nov. **Proposals for a New Earth: Policy Triad for the Envir., Economy and Energy**
(Joint Special Committees on Energy and Environment of Industrial Structure Council, Advisory Committee for Energy and Industrial Technology Council)

> ① Comprehensive approach integrating industry, energy, environment and technology policies
>
> ② Contribution of technological breakthroughs for fundamental solution of global environmental problems
>
> ③ Internationally cooperative approach

1992 Dec. **A Comprehensive Approach to the New Sunshine Program: Sustainable Growth through a Simultaneous Solution of Energy and Environmental Constraints**
(Advisory Committee *(energy and envir. tech. devel.)* of Ind. Tech. Council)

> ① Identify principal role of energy & environmental technology and the basic direction of Japan's approach
>
> ② Pursue a comprehensive approach by integrating R&D programs on energy and environmental technologies
>
> ③ Identify R&D projects to be challenged on a priority basis

As indicated in Fig. 20, key components for maximizing MITI's policy effectiveness include: (i) close cooperation with related policies (see Fig. 19), (ii) an active and flexible approach, (iii) innovative human resources and (iv) ties between industries, universities and government research laboratories. AIST's (Agency of Industrial Science and Technology of MITI) national research laboratories with 2200 researchers have made significant contributions to systems like "MITI's Innovative Human Resources Center," while networks among industries, universities and such laboratories depend greatly on National R&D Programs.

MITI's typical industrial technology policy includes National R&D Programs which in responding to Japan's social and economic needs:

(i) challenge R&D activities in the pre-competitive stage that cannot be carried out by the private sector alone because of the high risks involved and the long lead time required before commercialization can take place;

(ii) are undertaken by the most suitable research organizations from the private sector, academic bodies and government research institutes, thereby ensuring non-discriminatory opportunities for potential participants both in Japan and from foreign countries; and

(iii) are open and systematic due to periodic reviews and evaluations.

In order to meet the new responsibility of rebuilding its policy system, ITC's Coordination Committee has proposed restructuring its existing R&D programs along with reorganizing AIST's national research laboratories. Basically this policy system is grounded on the principle of "techno-globalism" which focuses on vitalizing creative R&D and distributing and transferring the R&D process, its outcome and its ripple effect to the international community, thereby strengthening transnational interdependency in industrial science and technology [47].

In line with the proposal made by ITC's Coordination Committee, ITC's advisory committees responsible for (i) industrial science and technology (non-energy/environmental technologies) and (ii) energy and environmental technologies undertook intensive studies. In June 1992 they proposed (i) "R&D Subjects Expected to be Challenged in the Field of Industrial Science and Technology" [16] and in December 1992 (ii) "A Comprehensive Approach to R&D on Energy and Environmental Technologies" [17]. The latter, in particular, was based on a comprehensive study conducted by joint special committees on energy and environment of the Industrial Structure Council, the Advisory Committee for Energy, and the ITC, which introduced "Proposals for a New Earth: Policy Triad for the Environment, Economy and Energy" in November 1992 [14].

Through these extensive studies, especially in the "Principle Direction of Japan's Industrial Science and Technology," a strong recommendation emerged for restructuring the six existing National R&D Programs[10] into two comprehensive programs on (i) basic and creative R&D together with mission-oriented R&D and (ii) R&D on energy and environmental technologies.

As a result of this recommendation, several relevant advisory committees undertook further intensive studies. After a thorough review of R&D projects initiated by National R&D Programs on non-energy/environmental technologies, the advisory committee responsible for industrial science and technology identified 55 R&D subjects in seven fields to be challenged by the new program, as summarized in Table 14. The seven fields consist of: (i) new

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[10] The National R&D Program (Large-Scale Project), the R&D Program on Basic Technologies for Future Industries ("Jisedai" Project), the R&D Program on Medical and Welfare Equipment Technology, the Sunshine Project (R&D on New Energy Technology), the Moonlight Project (R&D on Energy Conservation Technology), and the Global Environmental Technology Program.

materials, (ii) biotechnology, (iii) electronics/information/communications, (iv) machinery/aerospace,(v) human/life/society, (vi) natural resources, and (vii) medical/welfare.

Table 14 Scheme of Identification of R&D Subjects to be Challenged by ISTFP and NSS

Industrial Science & Technology Frontier Program (ISTFP)

	MITI's R&D Budget up to FY 1992 a)	Significant Subjects b) (New Priorities) A	B c)	New Challenge
New Materials	53 (7)	9	1	i) Identify dual
Biotech./Chemistry	52 (7)	4	2	objective: basic/
Elect./Inf./Communic.	89 (8)	6	5	creative and
Machinery/Aerospace	107 (6)	9	3	mission oriented
Human, Life & Society	28 (3)	1	6	ii) Extensive pre-project study:
Natural Resources	50 (4)	2	2	leading research
Medical & Welfare	12 (31)	2	3	
TOTAL	¥391 bil.(66)	33	22	

a) Figures in parentheses indicate number of projects completed by the end of FY 1992.
b) Figures indicate number of candidate subjects.
c) A: Subjects for basic and creative R&D which are expected to contribute to further development of the economy and society by building a new technology paradigm;
B: Subjects for mission oriented R&D which are expected to contribute to attaining social goals meeting public demand and securing an economic/scientific base.

New Sunshine Program (NSS)

	MITI's R&D Budget up to FY 1992	Significant Subjects a) (Overall Assessment)	A	B	C	D b)	New Challenge
New Energy	440	Renewable Energy	8	4	8	4	i) Contribute to the achivement
		H-Effic. Use of Fos. Fuels	6	8	3		of the goal of "New Earth 21".
Energy Conservation	140	Energy Transp. and Storage	5	6	2		ii) Accelerate to construct a
Envir. Protection	20	Envir. Protection	8	15	7	4	virtually spin cycle/challenge
		Innov. Synthetic System		6	1	2	to innovative synthetic projects
		Fundamental R&D		3			
TOTAL	¥ 600 bil.	100	27	42	21	10	

a) Figures indicate number of canditate subjects.
b) A: Subjects which Japan and other advanced nations (AN) should challenge over the short/medium term.
B: Subjects which Japan and other AN should challenge for technological breakthroughs over the medium/long term.
C: Subjects which are expected to contribute to relax energy and environmental constraints in developing nations over the short/medium term.
D: Subjects for worldwide challenge over the medium/long term.

Based on an intensive review of R&D projects initiated by National R&D Programs on new energy R&D, energy conservation R&D and environmental protection R&D, the advisory committee responsible for energy and environmental technologies identified 100 R&D subjects in six fields by classifying (i) subjects which Japan and other advanced nations should challenge over the short/medium term, (ii) subjects which Japan and other advanced nations should challenge for technological breakthroughs over the medium/long term, (iii)subjects which are expected to contribute to relaxing energy and environmental constraints in developing nations over the short/medium term, and (iv) subjects for worldwide challenge over the medium/long term as summarized in Table 14. The six fields include: (i) renewable energy, (ii) highly-efficient use of fossil fuels, (iii) energy transportation and storage, (iv) environmental protection, (v) innovative synthetic system, and (vi) fundamental R&D.

Considering intensive and extensive studies as well as ITC's recommendation, MITI has decided to consolidate six existing R&D National Programs into the following two comprehensive programs by identifying (i) the basic nature, (ii) objective field, (iii) R&D subjects, and (iv) approach to R&D for each respective program [54](Fig. 24):

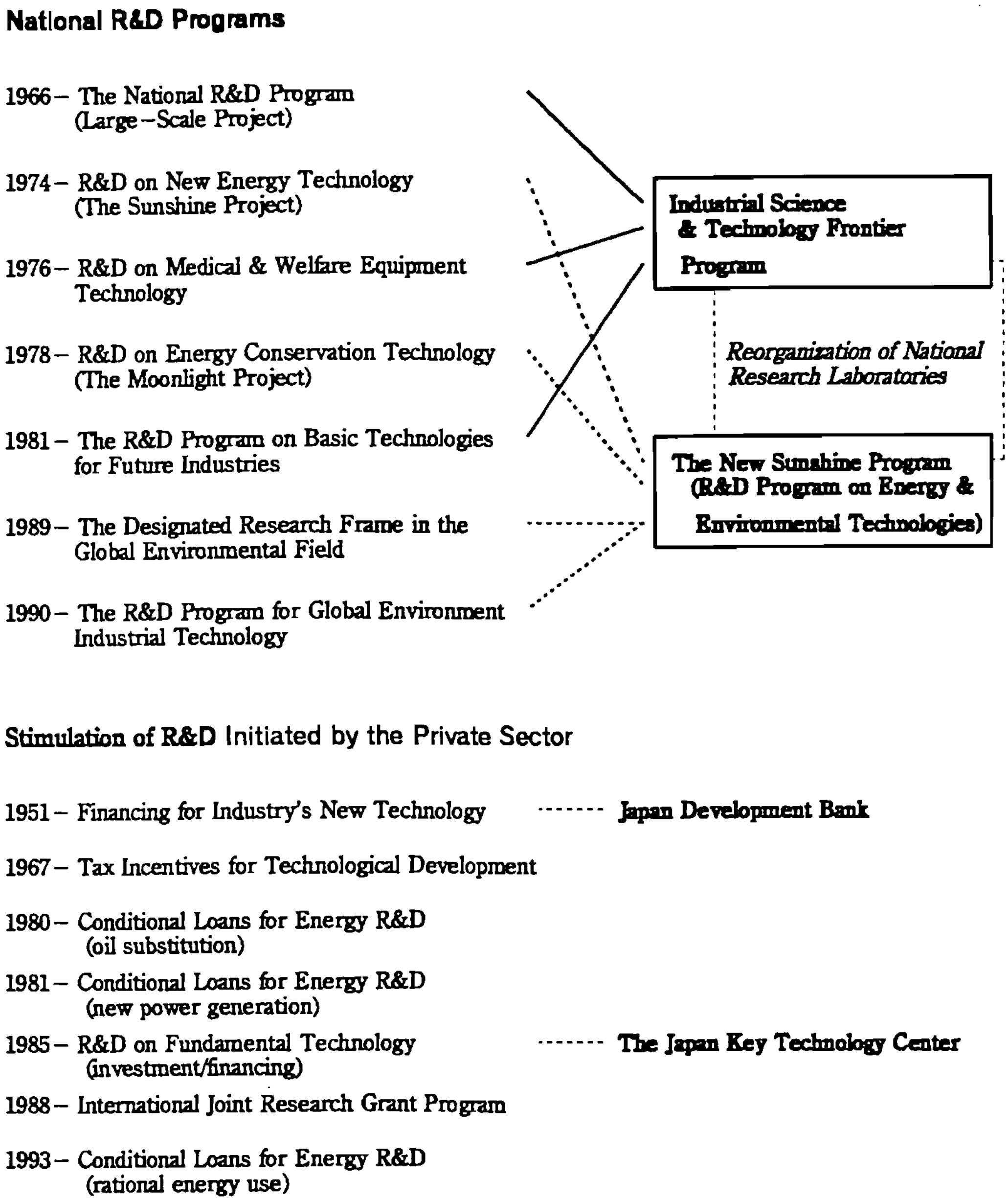


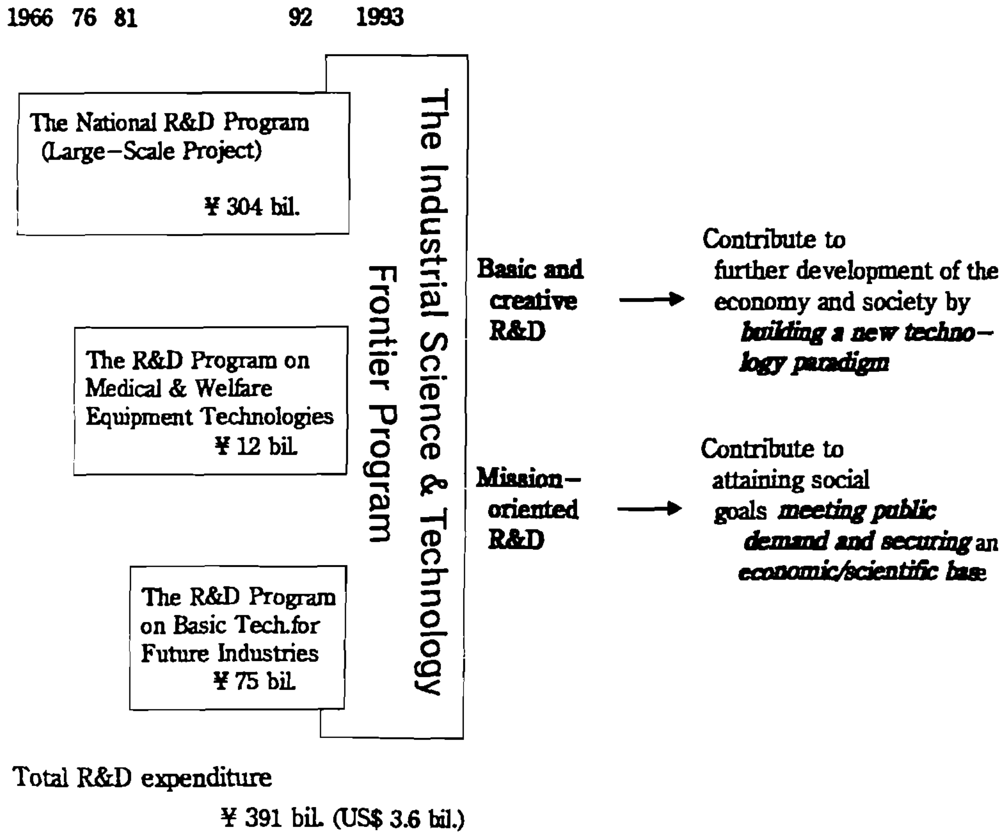
Fig. 24 Scheme of Restructuring of National R&D Programs

(i) Industrial Science and Technology Frontier Program

This program entails restructuring the National R&D Program (Large-Scale Project: 1966), the R&D Program on Basic Technologies for Future Industries (1981) and the R&D Program on Medical and Welfare Equipment Technology (1976) by introducing:

a. Fundamental and creative R&D which will contribute to further development of the economy and society by building a new technology paradigm with a new concept, philosophy and approach and also by making technological breakthroughs, and

b. Mission-oriented R&D to attain the social goal of meeting public demand and a quality of life common to the international community, in addition to realizing real human life [3] (Fig. 25).



a. Total R&D expenditure indicates accumulation of MITI's R&D budget up to FY 1992.

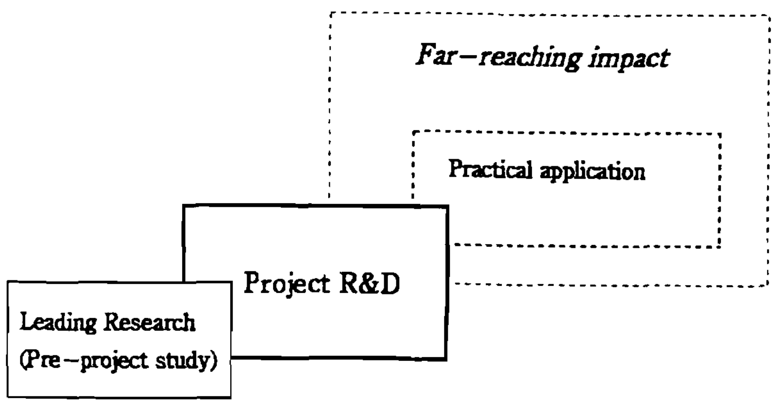


Fig. 25 Basic Concept of the Industrial Science & Technology Frontier Program

(ii) The New Sunshine Program

Based on the recognition of the two-sided nature of the global environment issue and energy consumption, this program aims at a comprehensive approach for overcoming global energy and environmental constraints while maintaining sustainable growth through the integration of the Sunshine Project, (R&D on New Energy Technology: 1974), the Moonlight Project (R&D on Energy Conservation Technology: 1978) and the Global Environment Technology Program (1989) [17] (Fig. 26).

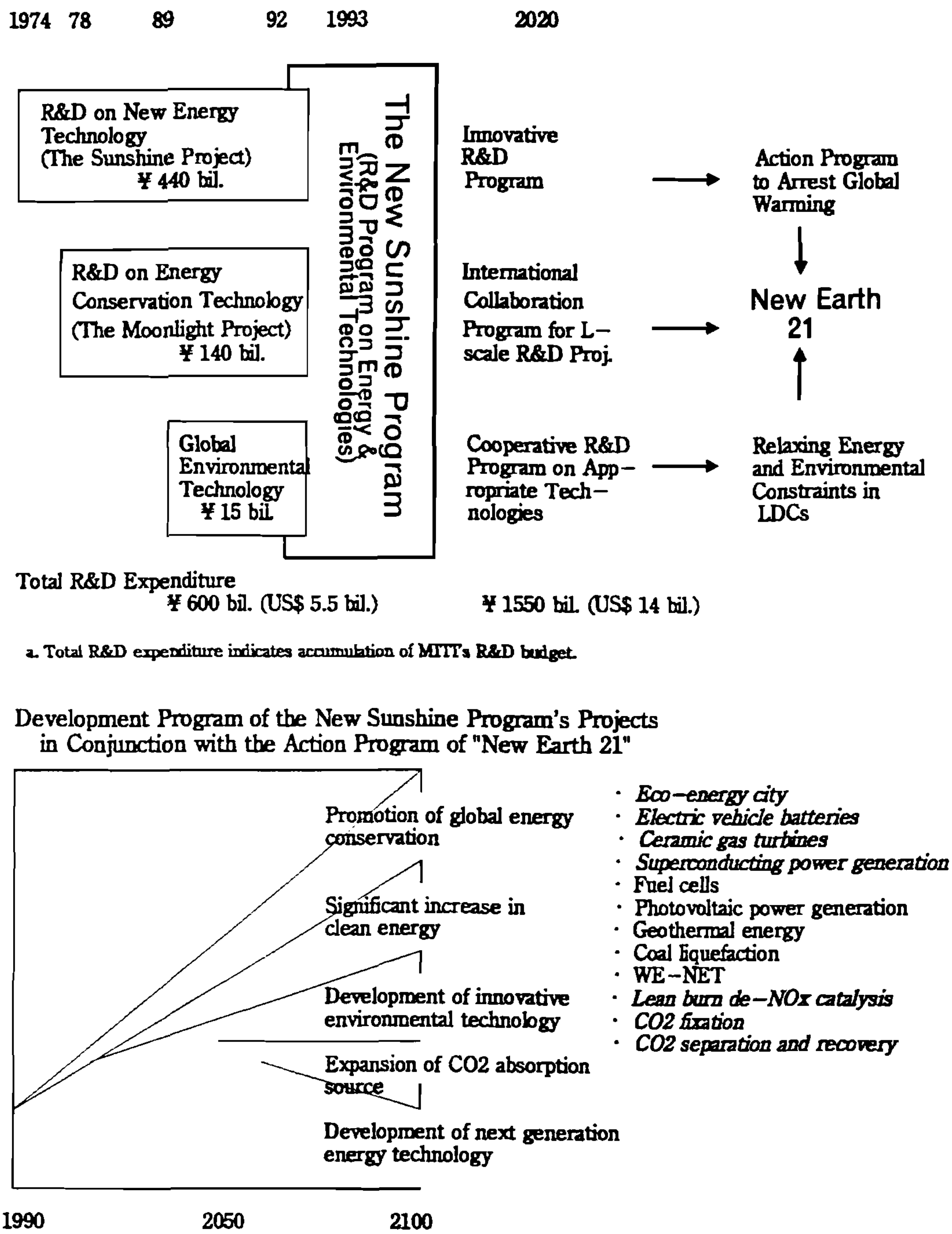


Fig. 26 Basic Concept of the New Sunshine Program

The reorganization of AIST's national research laboratories[11], which includes creating the National Institute for Advanced Interdisciplinary Research and extensively reviewing policy programs for stimulating industry R&D activities, is expected to maximize the effectiveness of such a restructuring (Fig. 24).

[11] Since 1993 sixteen research laboratories in MITI's AIST have been reorganized into fifteen research institutes.

3.4 Paradigm Change in Japan's Industrial Technology

MITI's intensive efforts to restructure its long lasting National R&D Programs by creating both the Industrial Science and Technology Program and the New Sunshine Program, together with the reorganization of AIST's national research laboratories, are expected to appropriately meet the national demands concerning Japan's industrial technology at a turning point. Unfortunately, as this expectation has emerged, Japan's industrial technology has had to face the impacts of an unexpected paradigm change in the late 1980s brought on by the fall of international oil prices (starting in 1983) and the succeeding rise (1987) and fall (1991) of Japan's "bubble economy." Looking closely again at Fig. 9, we note that the degree of technology substitution for energy has decreased since 1983 and the complement relationship between technology and capital has relaxed, transforming into substitution since 1988.

3.4.1 Current State of R&D Activities in the Japanese Manufacturing Industry

Fig. 27 summarizes the average increase rate of R&D expenditure in the Japanese manufacturing industry from 1979-1992 by four 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"), and 1991-1992 (after the bursting of the "bubble economy"). Looking at Fig. 27 we can note a significant decrease in R&D expenditure in Japan's manufacturing industry following the "bubble economy." Recent statistics published by the Management and Coordination Agency reveal that Japan's manufacturing industry first experienced a decrease in R&D expenditure in 1992 (a 2.4% decrease in comparison to the previous year in current prices), which continued in 1993 (similarly a 5.8% reduction). MITI's Industrial Structure Council has warned that such stagnation in R&D investment, previously regarded as a "sacrosanct field," is no longer avoidable.

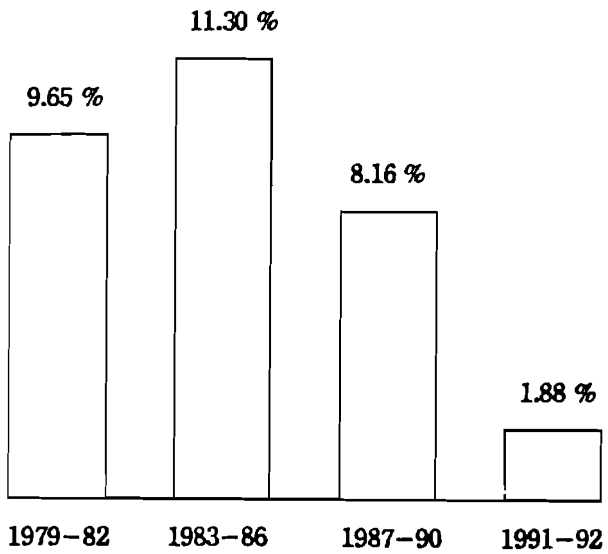


Fig. 27 Average Increase Rate of R&D Expenditure in the Japanese Manufacturing Industry (1979–1992)
– % per annum using 1985 constant prices

Sources 1979–1991: Report on the Survey of Research and Development (Management and Coordination Agency)

1992: Investment Plan of Industry in 1993 (Industrial Structure Council of MITI– June 1993)

R&D strategy in firms can be well demonstrated in their R&D intensity (ratio between R&D expenditure and sales). In addition, in order to assess the state of their virtuous cycle between technology and economic development, trends in sales cannot be overlooked. By identifying contributions of "inducement by production increase" (increase in sales) and "inducement by strategy" (increase in R&D intensity), Fig. 28 analyzes factors contributing to changes in R&D expenditure in the Japanese manufacturing industry during these four periods. Looking at Fig. 28 we can see that the increase in R&D expenditure in the period of the "bubble economy" was largely attributed to "inducement by production increase." After the bursting of the "bubble economy," however, the contribution of "inducement by production increase" decreased dramatically and an increase in R&D expenditure was slightly maintained by the contribution of "inducement by R&D strategy."

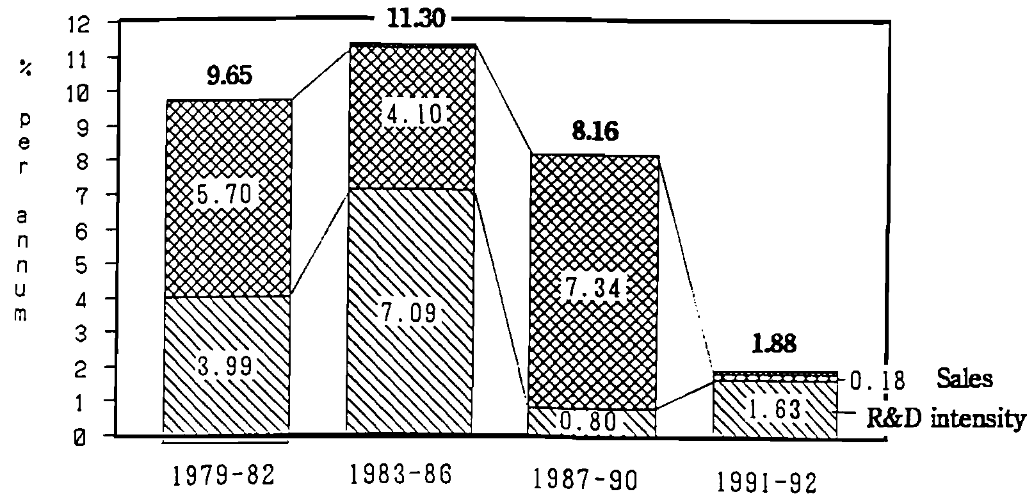


Fig. 28 Factors Contributing to Change in R&D Expenditure in the Japanese Manufacturing Industry (1979–1992)

a Magnitude of contribution is measured by the following equation:

▲R = ▲RS + ▲S where R: R&D expenditure, RS: R&D intensity, and S: sales.

Similar trends can be observed in major sectors of the manufacturing industry as illustrated in Fig. 29.

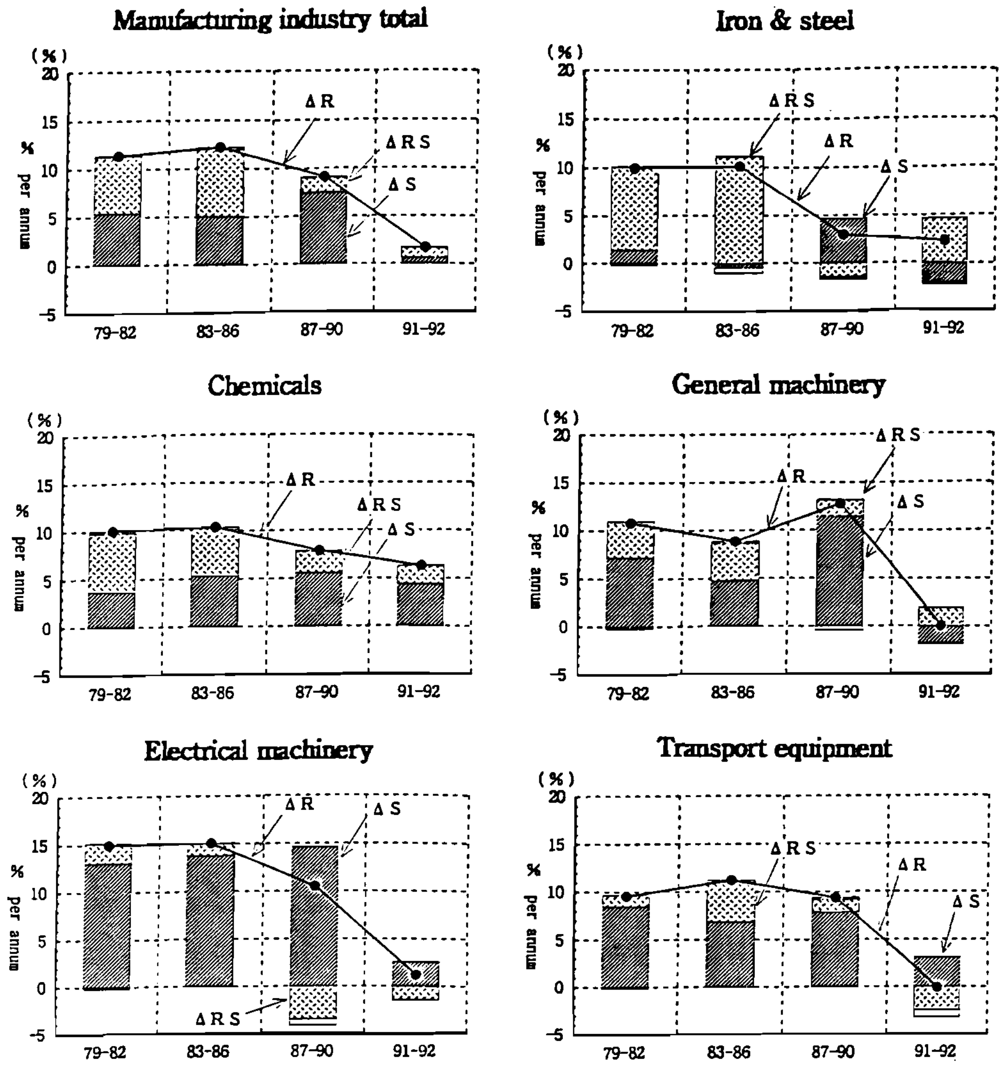


Fig. 29 Factors Contributing to Change in R&D Expenditure in Major Sectors of the Japanese Manufacturing Industry (1970–1992)

a Magnitude of contribution is measured by the following equation:

▲ R = ▲ R/S + ▲ S where R: R&D expenditure, R/S: R&D intensity, and S: sales.

Fig. 30 analyzes factors contributing to changes in sales in the same periods, which indicate that a stagnation of R&D activities in the period of the "bubble economy" led to a stagnation of technology (technology knowledge stock) in the period of the bursting of the "bubble economy," resulting in a decrease in technology's contribution to sales.

These analyses demonstrate the following structural fear of the virtuous cycle's possible deconstruction: a decrease in "inducement by R&D strategy" in the period of the "bubble economy" > stagnation of technology in the period of the bursting of the "bubble economy" > a decrease in the contribution of technology to an increase in sales > a decrease in the "inducement by production increase" > stagnation of R&D expenditure.

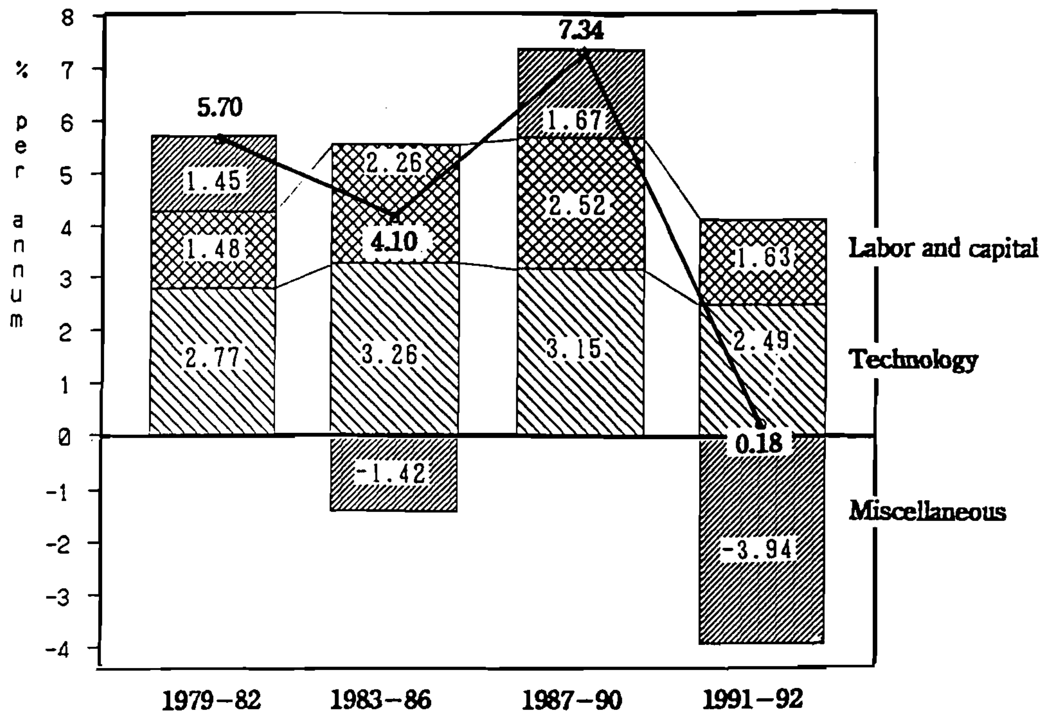


Fig. 30 Factors Contributing to Change in Sales in the Japanese Manufacturing Industry (1979–1992)

a Magnitude of contribution is measured by the following equation:

$$\ln(S/L) = -0.19 + \underset{(2.28)}{0.24} \ln(K/L) + \underset{(4.74)}{0.39} \ln(T/L) \qquad 1974\text{–}92 \qquad \text{adj.}R^2\ 0.983,\ \ DW\ 1.39$$

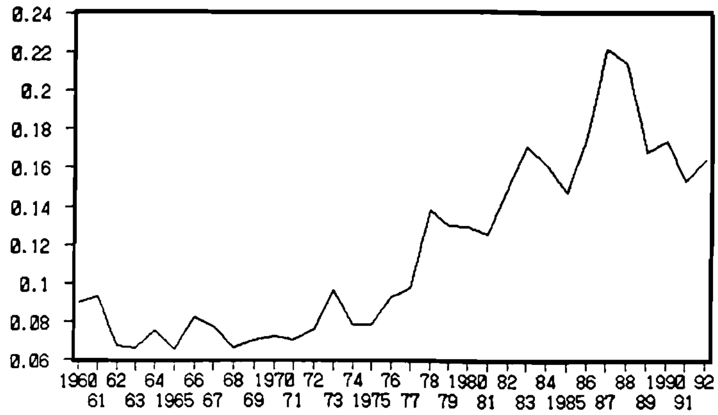
$$\blacktriangle S = 0.37 \blacktriangle L + 0.24 \blacktriangle K + 0.39 \blacktriangle T + \eta$$

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

where S: sales, L: labor, K: capital stock, T: technology stock, η : miscellaneous, R_{t-m}: R&D expenditure in the period t−m, m: time lag of R&D to commercialization, and ρ : rate of obsolescence of technology.

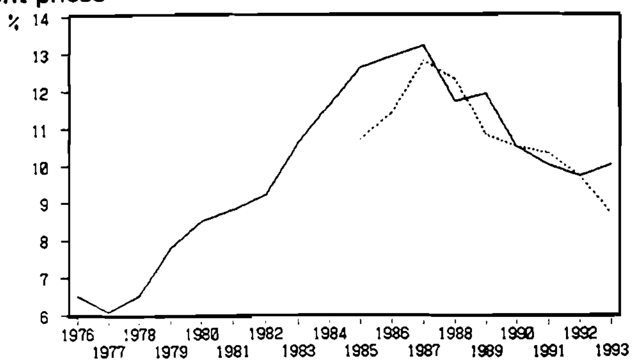
Fig. 31 illustrates trends in R&D investment's share of the total investment in Japan's manufacturing industry from 1960 to 1993. Looking at Fig. 31, we can observe the noteworthy change beginning in 1987 (coincides with the start of the "bubble economy") which indicates that increasing trends turned out to be decreasing trends. This change produces some fear that the complementary relationship between technology and capital, an enduring source of Japan's rapid enhancement of its technological level initiated by industry's vigorous R&D investment, may be deconstructing itself. Indeed, R&D intensity (which represents vigorous R&D investment by means of a contribution of "inducement by R&D strategy" to an increase in R&D expenditure) has a strong correlation to R&D investment's share of the total investment with a one to two year time-lag (see footnote in Fig. 31). Considering the decreasing trend in R&D investment's share of total investment, it is strongly feared that R&D intensity may further decrease due to the bursting of the "bubble economy," thereby leading to the deconstruction of the complement between technology and capital. Analyses on trends in substitution and complementary behavior between capital and technology (see Fig. 9 in Section 3.1) indicate a similar fear.

Historical Trends in R&D Capital Share out of Total Investment (1960–1992)
– 1985 constant prices



a IR = RK/[CS−Lag1(CS)] where IR: R&D capital share out of total investment, RK: expenditurs for tangible fixed assets out of total R&D expendiyure, and CS: capital stock.

Recent Trends in R&D Investment Share out of Total Investment (1976–1993)
– current prices



b Sources: Japan Development Bank (——) and Industrial Structure Council (----).
Shares in 1993 are projections at August and March 1993 respectively.

Fig. 31 Trends in R&D Investment Share out of Total Investment in the Japanese Manufacturing Industry (1960–1993)

c Correlations between R&D investment share out of total investment (IR) and R&D intensity (RS) are as follows (1978–1990):

		$adj.R^2$	DW	D
Manfufact. total	ln(RS) = −0.59 + 0.66 ln(Lag2(IR)) +0.07 D (22.86) (2.58)	0.980	1.59	1990=1
Chemicals	ln(RS) = −0.02 + 0.52 ln(Lag2(IR)) (12.96)	0.933	2.53	
Iron & steel	ln(RS) = 0.07 + 0.30 ln(Lag1(IR)) + 0.21 D (7.36) (4.14)	0.907	1.58	1985–87, 90=1
Ceramics	ln(RS) = −0.16 + 0.48 ln(Lag1(IR)) − 0.32 D (10.87) (−5.39)	0.943	1.68	1978, 79=1
Machinery	ln(RS) = −0.24 + 0.58 ln(Lag2(IR)) + 0.06 D (8.74) (2.66)	0.886	1.51	1986, 90=1

3.4.2 Impacts of Stagnated R&D Activities

A decrease in R&D intensity, presumably due to the deconstruction of the complementary relationship between technology and capital, not only leads to a decrease in the quantity of R&D activities (as discussed in Section 3.4.1) but also significantly influences the quality of R&D activities. Table 15 demonstrates an analysis in respect to such impacts on both basic research and energy and environmental R&D.

Table 15 Impacts of R&D Stagnation on Future R&D Activities in the Japanese Manufacturing Industry

(1) Basic Research

Correlations between *R&D intensity* (RS) and *ratio of R&D expenditures for basic research* (BR) in the Japanese manufacturing industry are analyzed as follows:

		adj.R^2	DW	D
Chemicals (1974–90)	$\ln(BR) = 1.19 + 0.94 \ln(Lag1(RS)) + 0.14\,D$	0.862	1.88	1983, 84=1
	(9.45) (2.87)			
Iron & steel (1977–90)	$\ln(BR) = 1.73 + 0.72 \ln(Lag3(RS)) - 0.30\,D$	0.831	1.65	1986=1
	(7.79) (−3.28)			
General Machinery (1975–90)	$\ln(BR) = -2.36 + 3.76 \ln(Lag0(RS)) - 0.43\,D$	0.858	2.57	1979, 80=1
	(6.40) (−2.06)			
Electrical Machinery (1974–90)	$\ln(BR) = 0.11 + 0.84 \ln(Lag1(RS)) - 0.20\,D$	0.835	1.26	1983, 84=1
	(6.96) (−5.48)			
Transport Equipment (1978–90)	$\ln(BR) = 0.67 + 0.71 \ln(Lag0(RS)) - 0.60\,D$	0.893	1.79	1978, 79=1
	(2.48) (−9.64)			

(2) Energy and Environmental R&D

Correlations between *R&D objectives* and *R&D strategy, R&D intensity (RS) and energy prices (PE)* are analyzed as follows (1976–1990):

	adj.R^2	DW	D
Energy R&D			
$\ln(ERT) = 2.12 + 0.77 \ln(ENERS) + 1.50 \ln(RS) + 0.45 \ln(PE) + 0.12\,D$	0.918	1.54	1990=1
(2.64) (3.70) (1.29) (1.34)			
R&D for Environmental Protection			
$\ln(EVT) = 2.86 + 1.07 \ln(ENVRS) + 2.08 \ln(RS) + 0.21 \ln(PE) - 0.14\,D$	0.847	1.85	1986=1
(7.94) (8.97) (1.57) (−1.77)			
R&D for Information Technology			
$\ln(INT) = 2.75 + 1.53 \ln(INFRS) + 0.87 \ln(RS) + 0.27 \ln(PE)$	0.999	2.44	
(23.10) (6.25) (4.92)			

a ERT, EVT and INT: R&D expenditures for energy R&D, R&D for environmental protection and R&D for information technology respectively.
ENERS, ENVRS and INFRS: The ratio of R&D expenditures for energy, environmental protection and information respectively.

Table 15 (1) summarizes the outcomes of the analysis with respect to correlations between R&D intensity and the ratio of R&D expenditures for basic research in Japan's chemical, iron & steel, general machinery, electrical machinery and transport equipment industries. Examining the table we note that the ratio of R&D expenditures for basic research has a strong correlation to R&D intensity in all the industries examined. Although there have been some indications that full-scale efforts to promote research on basic technology seriously began as Japan's industrial technology approached the technological frontier [23], the data in this table warns us that such efforts have again stagnated[12].

Table 15 (2) compares inducing factors for energy R&D, environmental protection R&D, and information technology R&D (aimed at improving manufacturing processes) in Japan's manufacturing industry during the period 1976-1990. Looking at the table we can note that both environmental protection R&D and energy R&D show sensitivity to the level of R&D intensity, which contrasts with information technology R&D. This analysis corresponds to the analysis of technology substitution for energy in Fig. 9 of Section 3.1 in which the level of substitution began to decrease in 1983 (when international oil prices started to fall), followed by a further decline in 1987 (the start of the "bubble economy"). Currently Japan's economy again faces the prospect of energy and corresponding environmental capacity constraints after the fall of international oil prices and the succeeding "bubble economy" [49][13]. Fears concerning such a prospect have remained relatively minor due to Japan's success in overcoming energy and environmental constraints in the 1960s, the 1970s, and the early 1980s. Contrary to this optimistic view, this analysis warns us of the potential stagnation in challenges to technological breakthroughs for overcoming energy and environmental constraints. Such stagnation could be seen as a result of the dramatic decrease in the level of technology substitution for energy which emerged in 1987.

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[12] A survey undertaken by MITI in March 1993 regarding the focus of R&D by the types of activities to be undertaken by leading Japanese firms in the next few years demonstrates this fear as follows:

(out of 100%)	Increase	Stable	Decrease	Undecided
Total Basic Research	18.8	43.2	14.9	23.0
Applied Research	22.7	49.3	10.7	17.3
Development Research	42.7	34.7	10.7	12.0

[13] A survey undertaken by MITI in June 1993 regarding the change rate of expenditure for R&D for environmental protection in leading Japanese firms demonstrates this fear as follows:

	1990	1991	1992
Change rate of average expenditure(%)	37.7	26.9	14.4

A correlation analysis between R&D intensity (RS) and energy productivity (E/IIP) in the Japanese manufacturing industry (1974-1990) demonstrates a similar fear:

$$\ln(E/IIP) = 2.00 - 0.77 \ln(RS) - 0.39 \ln(PE) \qquad \text{adj.}R^2\ 0.968\ \ DW\ 1.41$$
$$\qquad (-13.24) \qquad (-7.36)$$

(PE) = energy prices

3.4.3 Structural Background of a Stagnation

As analysed in Section 3.4.1, a decrease in R&D intensity in the period of the "bubble economy" triggered fear of a possible deconstruction of the virtuous cycle between technological development and economic growth. R&D intensity has a strong correlation to R&D investment's share of total investment as analysed in Section 3.4.1. Fig. 32 summarizes trends in investment objectives in the Japanese manufacturing industry from 1986-1990. Looking at Fig. 32 we can note that R&D investment's share of total investment decreased dramatically (12.9 % in 1986 to 10.5 % in 1990) with its peak in 1987 (13.2%). This change is believed to be a result of firms' decisions to focus investment on increasing production capacity by means of non-innovative investment (this share increased from 22.8% in 1986 to 32.0% in 1990) rather than R&D investment which required consistent innovative efforts with high-risks during the period of the "bubble economy" [12].

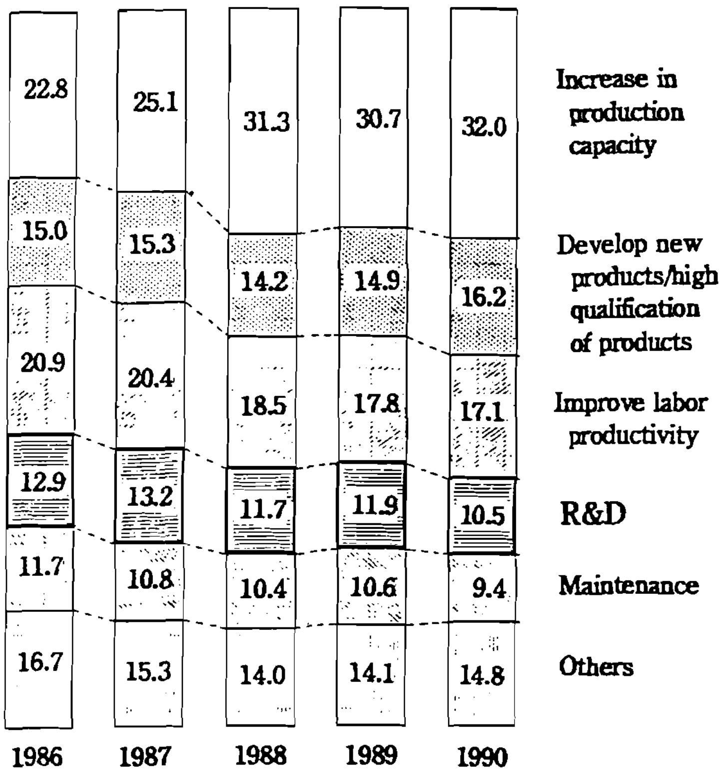

Fig. 32 Trends in Objectives of Investment in the Japanese Manufacturing Industry (1986−1990) %

Source: Japan Development Bank

Another factor leading to a decrease in R&D intensity (stagnating "inducement by R&D strategy") was an illusion between nominal and real prices [43]. Firm strategy is generally developed by examining current figures and increasing trends based on current figures. This behavior can be equally applied to their efforts in maintaining increasing trends in R&D intensity, which is considered to be a symbolic indicator for challenging investment in the future. This indicator is generally measured by current figures (a ratio calculated by current prices). Because this indicator is a ratio, there was an illusion that the ratio represented real R&D efforts. In actuality the ratio does not necessarily represent real R&D efforts due to a discrepancy of deflators between R&D expenditures and sales. As indicated in Fig. 33 a R&D deflator can consist of buildings and land, labor (researchers), materials, machinery, instruments and equipment.

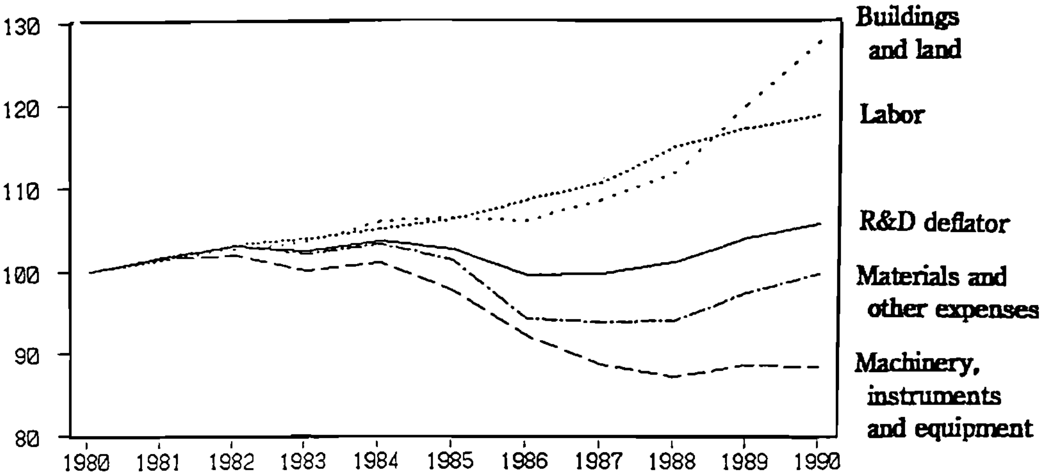

Fig. 33 Trends in R&D Deflator and Its Components in the Japanese Manufacturing Industry (1980–1990)
– Index: 1980=100

Due to a sharp increase in the prices of buildings and land as well as labor during the period of the "bubble economy", the R&D deflator exceeded the sales deflator as illustrated in Fig. 34, causing R&D intensity measured by current prices to be higher than the ratio measured by constant prices (which represent real efforts in challenging R&D).

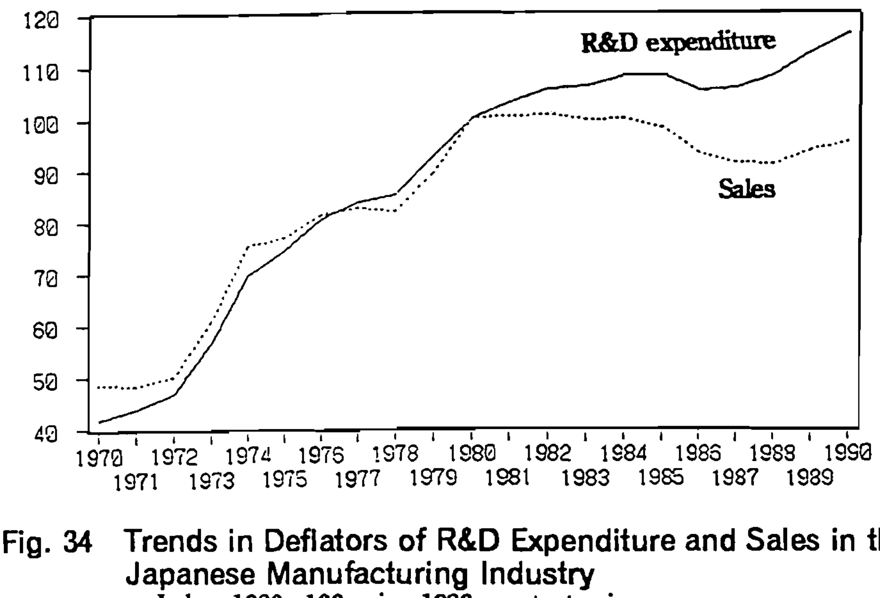

Fig. 34 Trends in Deflators of R&D Expenditure and Sales in the Japanese Manufacturing Industry
– Index: 1980=100 using 1980 constant prices

Fig. 35 compares trends in R&D intensity measured by both current prices (nominal) and constant prices (real) in Japan's manufacturing industry total and major sectors over the period 1976-1990. Looking at Fig. 35 we can note that R&D intensity in real terms stagnated or decreased during the "bubble economy," while R&D intensity in nominal terms increased, thereby demonstrating the above illusion. In addition to the above structural factors, we should not overlook the cyclical factors typically observed in the current stagnation of electrical machinery and transport industries resulting from demand stagnation derived from stagnation of innovative products.

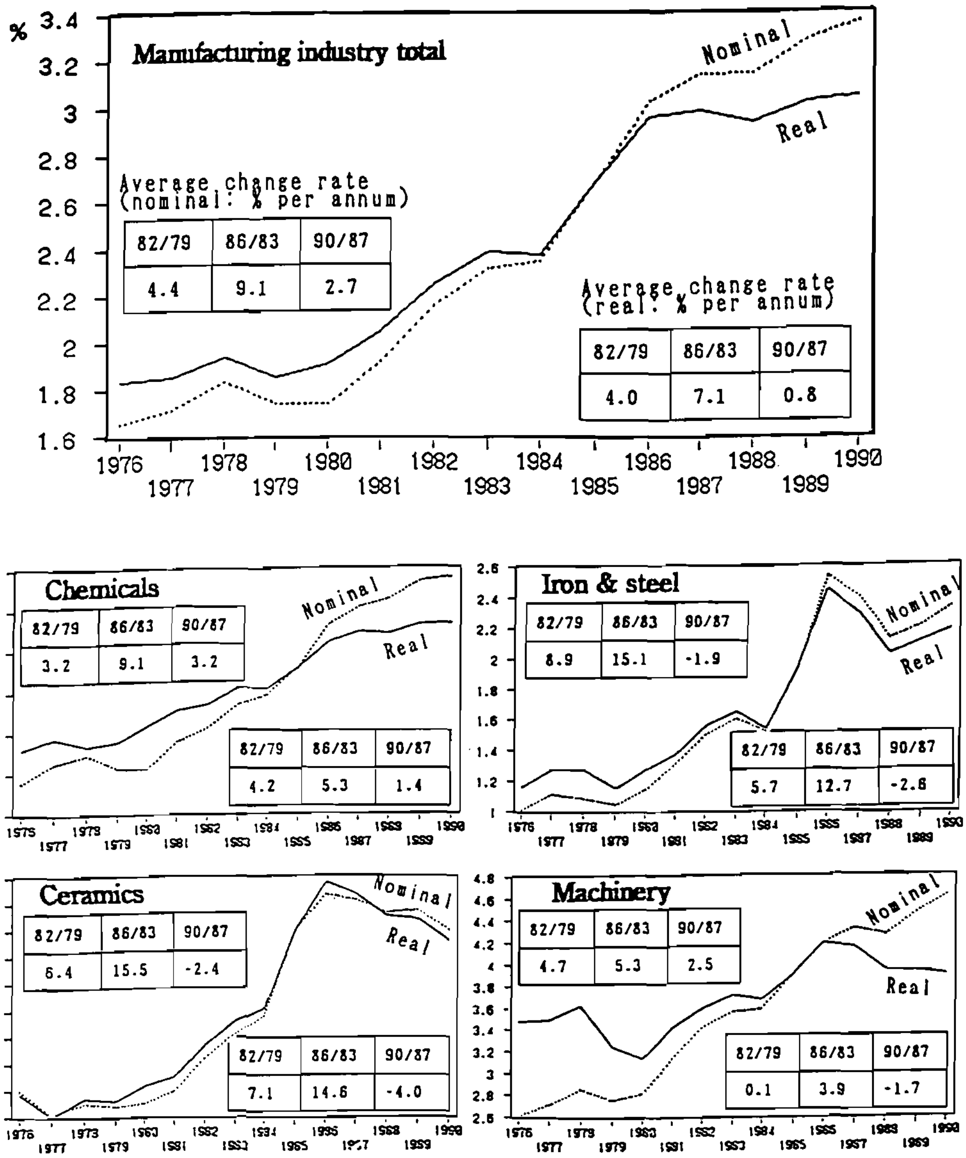

Fig. 35 Trends in R&D Intensity in the Major Sectors of the Japanese Manufacturing Industry (1976–1990)
– Current prices and 1985 constant prices

Sources: Report on the Survey of Research and Development (Management and Coordination Agency), White Paper on Japanese Science and Technology (Science and Technology Agency), and Economic Statistics Annual (The Bank of Japan)

4. Perspective of New Technology Policy and its Implication

The remarkable growth of the Japanese economy has been largely attributed to a virtuous cycle between technological development and economic growth supported by technology's complement to capital and the substitution of constrained production factors such as labor, energy and environmental capacity. This cycle has been developing consistently in both quantitative and qualitative respects. An ecosystem, which is respected as a prime example of such a cycle, demonstrates that consistent efforts to improve quality are indispensable [27] for the system's maintenance. Similarly, in order to maintain Japan's cycle, it is necessary to consistently initiate creative technological innovation so as to induce broad new scientific inventions and discoveries.

There are indications that full-scale efforts to promote research on basic technology seriously began as Japan's industrial technology approached the technological frontier [23]. Nevertheless, it is feared that these efforts are declining due to a stagnation in R&D investment following the "bubble economy" and its bursting [48], which has raised fears regarding R&D efforts to relax energy and environmental constraints [31]. Japan successfully overcame both energy and environmental constraints in the 1960s, 1970s and the first half of the 1980s. Despite this success, Japan's economy once again faces prospective constraints following the fall of international oil prices and the succeeding "bubble economy." Stagnation of R&D investment has accelerated this fear, resulting in a stagnation of sustainable growth [48].

Industry recognizes the need for fundamental research as well as the acceleration of energy and environmental R&D in order to prevent stagnation, which could lead to a dramatic improvement in productivity increases, thereby maintaining international competitiveness as well as overcoming increasing energy and environmental constraints. Even so, a stagnating trend in R&D investment could result in a shift from basic research to applied and development research, in addition to a decrease in energy and environmental R&D.

Recognizing this trend and realizing its role in an international context, MITI has made extensive efforts to encourage, stimulate and induce vitality from academia, national research laboratories and industries by fulling utilizing its restructured National R&D Programs.

The basic principle for this challenge can be summarized as follows: First of all, we should remember "recognition of commitments from the future-the day after tomorrow for tomorrow." We should keep in mind the example of an ecosystem, which demonstrates that once the above cycle begins to deconstruct, remediation of the system becomes impossible. Similarly, as an ecosystem requires consistent efforts to improve quality for its own maintenance, so does the interaction between technology and economic development. Secondly, in order to maintain a virtuous cycle which encourages a consistent challenge, the following three points are therefore essential:

(i) Encouragement for ambitious targets,
(ii) A comprehensive approach among sectors, and
(iii) Harmony between competition and cooperation.

In order to realize such a principle, based on long-term prospects, a comprehensive systems analysis approach will become more significant in terms of identifying the basic future direction of prospective technologies, prospective creative and fundamental research subjects, in addition to priorities in energy and environmental R&D subjects which instill confidence and develop general consensus.

This work provides one possible prototype for the above mentioned approach. Moreover, further complementary work with comparative analyses among countries concerned with different historical development paths is expected to provide valuable insight into the above target.

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Appendices

Appendix I : System of MITI's Industrial Technology Policy

Appendix II: Basic Data

Appendix I System of MITI's Industrial Technology Policy

This appendix, focusing on the National R&D Program, demonstrates MITI's industrial technology policy system.

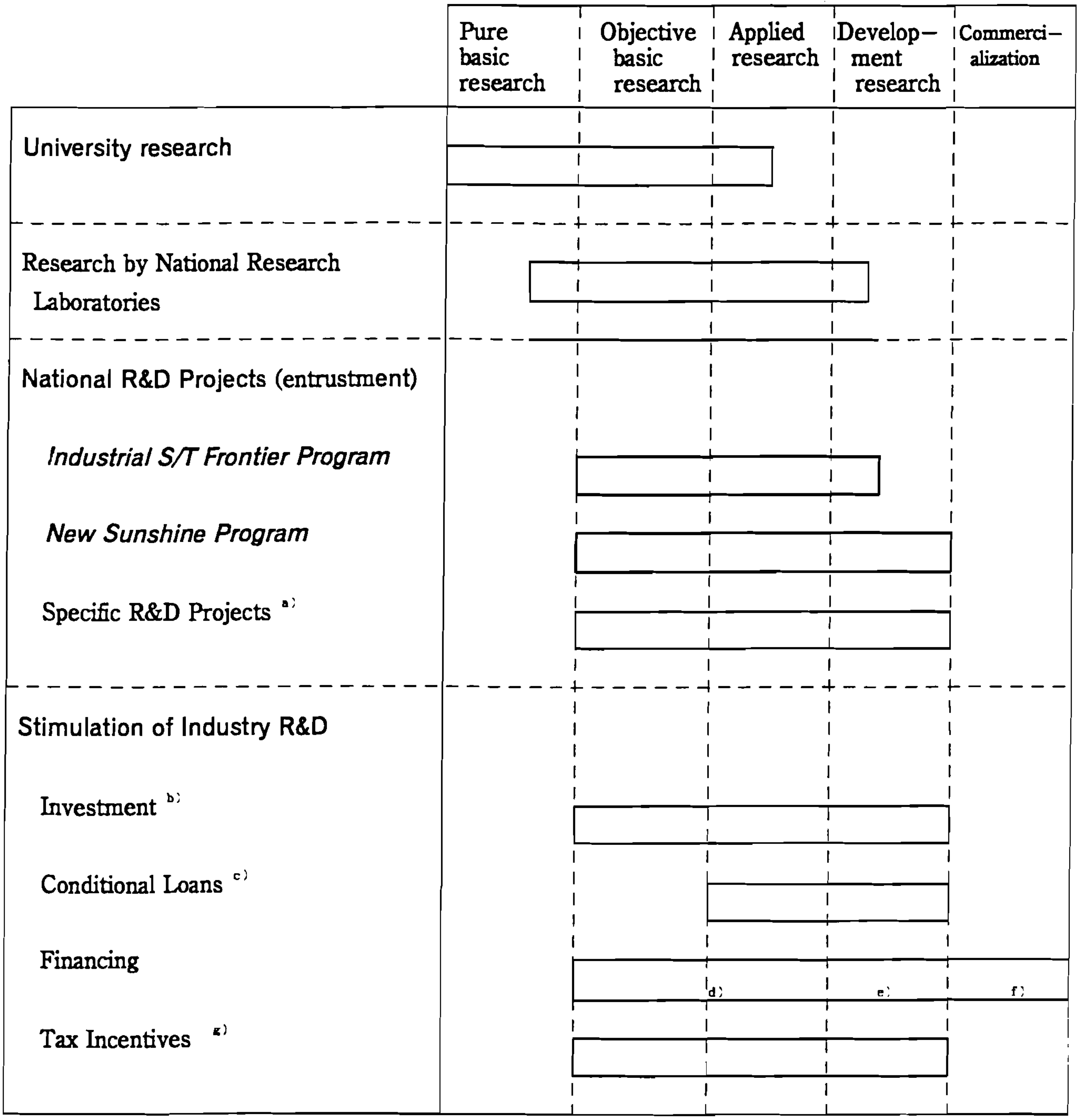


Fig. A1 Scheme of the Role of R&D Policy Measures by R&D Stage

a) R&D on advanced computers, aerospace, energy, etc., and stages covered by various policies differ depending on objective fields.

b) Capital investment for R&D projects initiated by private firms on basic or applied research provided by the Japan Key Technology Center (JKTC).

c) Coverages of stages differ depending on policy objectives.

d) Financing for construct. of research facilities provided by the Jpn Develop. Bank (JDB) while financ. by JKTC covers applied research to develop. res.

e) Financing for develppment for commercialization provided by JDB.

f) Financing for commercialization of new technology provided by JDB.

g) Tax credit for increasing R&D expenditure.

SUBJECTS – Completed/On–going Projects: ISTFP

1966 68 1970 72 74 76 78 1980 82 84 86 88 1990 92 (as of the end of FY 1992)

New Materials

- Advanced Alloys (81–88)
- Advanced Composite (81–88)
- Synthetic Membranes (81–90)
- Synthetic Metals (81–90)
- High–Perform. Plastics (81–90)
- High–Perform. Ceramics (81–92)
- Photo–Reactive Materials (85–92)
- Superconducting Materials/Devices (88–97)
- High–perform. Materials for Severe Envir. (89–96)
- Non–linear Photonics Materials (89–98)
- Advanced Chemical Processing Techno. (90–96)
- Silicon–based Polymers (91–2000)

Biotechnology Chemistry

- New Method of Olefine Prod. (67–72)
- Olefine Prod. from Heavy Oil (75–81)
- C1 Chemical Technology (80–86)
- Bioreactor (81–88)
- Large–Scale Cell Cultivation (81–89)
- Utiliz. of Recombinant DNA (81–90)
- New Water Treat. (85–90)
- Marine Biotechnology (88–96)
- Molecular Assemblies of Protein (89–98)
- Complex Carbohydrates (91–2000)

Electronics/ Information/ Communication

- S–High Perform. Computer (66–71)
- Pattern Inf. Processing (71–80)
- Optical Measurement & Control (79–85)
- Fertiled ICs for Extr. Cond. (81–85)
- High–Speed Computing for S/T (81–89)
- Superlattice Devices (81–90)
- Three–Dimensional ICs (81–90)
- Interoperable Database (85–91)
- Bio–Electronics Devices (86–95)
- New Models for Software Architecture (90–97)
- Quantum Functional Devices (91–2000)
- Ultimate Manipulation of Atoms/Molecules (92–2001)

Machinery/ Aerospace

- Jet Engines for Aircraft (71–81)
- Direct Steelmaking Process (73–80)
- Flexible Manufact. System (77–84)
- Automated Sewing System (82–90)
- Advanced Robotics (83–90)
- OS for ERS (84–88) *OS: Observation System; ERS: Earth Resources Satellite
- Adv. Mater.–Proc./Machin. (86–93)
- Super–hyper Sonic Transp. Propulsion (89–98)
- Micromachine Technology (91–2000)

Human, Life & Society

- Sea Water Desalination (69–77)
- Electric Car (71–77)
- Compreh. Automobile Control (73–79)
- Underground Space Develop. (89–95)
- Human Sensory Measurement (90–98)

Natural Resources

- Desulfurization (66–71)
- RC US Oil Drill. (70–75)
- Subsea Oil Prod. (78–84) *RC: Remote Controlled; US: Undersea
- Resources Recovery Tech. (73–82)
- Manganese Nodule Mining System (81–96)

Medical & Welfare

- Medical Apparatus (76– Completed 16 projects On–going 4 projects)
- Welfare Apparatus (76– Completed 15 projects On–going 7 projects)

Fig. A2 R&D Projects Undertaken in the Industrial Science & Technology Frontier Program Field

SUBJECTS — Completed/On-going Projects: NSS

1974 76 78 1980 82 84 86 88 1990 92 (as of the end of FY 1992)

New Energy

Solar
- Photovoltaic Power Generation (74–96)
- Solar Thermal (74–96)

Geothermal
- Exploration Tech./ Resources Survey (74–97)
- Advanced Geothermal Power Plant (74–2002)

Coal Convertion
- Coal Liquefaction (74–98)
- Coal Gasification (74–94)

Hydrogen
- Prod./Transp./Stor./Util.(74–2000)

Wind, Ocean, Biomass
- Wind P/G, OTEC, Biomass Conversion (81–95)

P/G: Power Generation; OTEC: Ocean Thermal Energy Conversion

Energy Conservation

Fuel Cell
- Phosphoric Acid FC (81–90) FC: Fuel Cell
- Molten Carbonate (81–97)
- SOFC/PEFC SOFC: Solid Oxide FC; PEFC: Polymer Electrolyte FC (81–97)

Energy Accumulation
- Waste Heat Utilization (76–83)
- Super Heat Pump (84–92)

High–Efficient Generation
- Advanced Gas Turbine (78–87)
- Ceramic Gas Turbine (88–96)
- EPA: Electric Power Apparatuses Superconductivity Tech. for EPA (88–98)

High–Efficient Engine
- Stirling Engine for Wide Use (78–87)

Energy Storage
- Advanced Battery EPSS (80–91) EPSS: Electric Power Storage System
- Dispersed–Type Battery Power Storage (92–2001)

Environmental Protection

Envir. Friendly Prod. Process
- High–Perform. Bioreactor (90–99)
- Biolog. Prod. of Hydrogen (91–98)
- Metallic Materials Recycl. (91–98)

Low Envir. Load Substances
- Advanced Refrigerant (90–94)
- Biodegradable Plastics (90–97)

CO_2 Fixation & Utilization
- CO_2 Circul. Mecha. (90–94)
- Biological CO_2 Fixat. (90–99)
- Chemical CO_2 Fixat. (90–99)
- HIgh–Temper. CO_2 Separ./Recovery (92–2000)

Fig. A3 R&D Projects Undertaken in the New Sunshine Program Field

SUBJECTS – Priority (ISTFP)

New Materials	[A] Polymeric matrials with a highly specific structure, Structure–controlled molecular/polymeric materials, Autonomous reaction materials, Organic magnetic materials, Cluster materials, Environment friendly materials, Computer chemistry, Integrated inorganic materials, Human–sized glasses with arrayed microstructure [B] High– performance carbon materials]
Biotechnology	[A] Evolution engineering, RNA engineering, Self–organized materials, Biochemical conversion technology, [B] Symbiosis engineering, Preservation application of tropical functions
Elect./Inf./Communic.	[A] Bio–electronics interface, Femtosecond technology, Information–field based technology, Cold–beam assisted processes, Advanced adaptive problem solver, Integrated CAD environment, [B] Counterhazard electronics, Quantum metric standards, Selflearning information–server, Multi–modalinformation environment system, Super networking technology
Machinery/Aerospace	[A] Artificial molecular machine, Advanced tribology, Highly–reliable manufacturing system, Selflearning machine, Precise fabrication and measurement using energy beam, Microgravity utilization, Environment friendly all composite airplane, Super/hyper–sonic transportation, High performance VTOL [B] Symbiotic machine, Eco–factory, Global environment monitoring system
Human, Life & Society	[A] Cross–sensory transformation and integration technology [B] Home robotics, New comprehensive automobile control technology, Optimal community information offering technology, Support system for skill learning through lifetime, Asseessment technology of influence of product life–cycle on environment and resources, Three–dimensional city system
Natural Resources	[A] Ultra–deep drilling/exploration/monitoring system, Bio–enhanced oil recovery and bio–improved technology [B] Urban mine development technology system, Offshore marginal oil production system
Medical & Welfare	[A] Advanced medical diagnosis and treatment technology, Physical function substitution technology [B] Advanced health care technology, Social activity support technology, Daily life activity support technology

Extensive Pre–project study → Leading Research

A: Basic & Creative R&D B: Mission Oriented R&D

Fig. A4 Scheme of Identification of Priority Projects to be Challenged by ISTFP

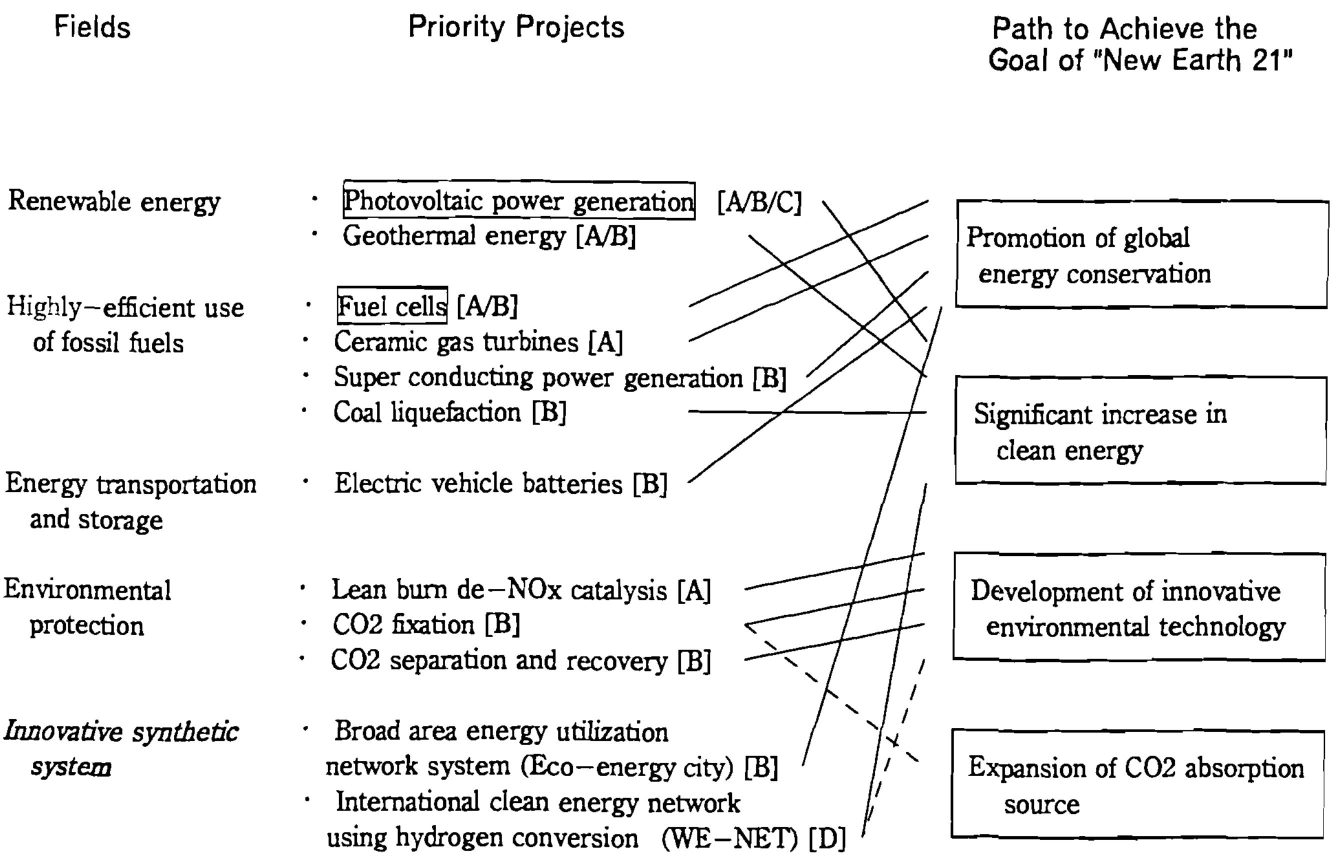


Fig. A5 Scheme of Identification of Priority Projects to be Challenged by NSS

a) A: Subjects which Japan and other advanced nations (AN) should challenge over the short/medium term.
B: Subjects which Japan and other AN should challenge for technological breakthroughs over the medium/long term.
C: Subjects which are expected to contribute to easing energy and environmental constraints in developing nations over the short/medium term.
D: Subjects for worldwide challenge over the medium/long term.

b) $\boxed{\ldots}$ indicates projects to accelerate construction of a virtually spin cycle: decrease in cost by technological improvement → increase in demand → further decrease in cost through massproduction.

Table A1 Steps for Undertaking New R&D projects in the Industrial Science & Technology Frontier Program (ISTFP)

A. Leading Research Theme

1. $\boxed{\text{Comprehensive survey}}$ on trends in leading–edge R&D activities in respective fields.
2. $\boxed{\text{Questionnaire}}$ to nat. research instit. and related bureaus on new candidate subjects.
3. Inter–bureau meeting on sectoral R&D.
4. Advice from external experts.
5. *Planning sub–committee* of *Industrial Technology Council (ITC).*
6. Sectoral screening by the Office of Industrial Science & Technology (OIST).
7. Assessment by academic fields.
8. Elaborative meetings among related bureaus.
9. Judging committee on draft screening on new subjects.
10. *Planning sub–committee* of *ITC.*
11. Draft of budget request for next fiscal year to be adjusted in MITI.
12. *Industrial Science & Technology Development Committee (ISTDC)* of *ITC.*
13. Budget request for next fiscal year to be submitted to Ministry of Finance.
14. Government draft budget.
15. Formulation of leading research implementation system.
16. <u>Start of leading research</u>.
17. <u>Completion of leading research</u>.

B. R&D Projects

18. $\boxed{\text{Assessment}}$ of feasibility of prospecting projects by OIST.
19. Elaborative meetings among related bureaus.
20. Judging committee on draft screening on new projects.
21. *Planning sub–committee* of *ITC.*
22. Draft of budget request for next fiscal year to be adjusted in MITI.
23. *ISTDC* of *ITC.*
24. Budget request for next fiscal year to be submitted to Ministry of Finance.
25. Government draft budget. ⟶ FUNDING
26. *Projects development sub–committee and ISTDC* of *ITC.*
27. MITI's R&D project basic plan. ⟶ BASIC PLAN
28. Public announcement for project proposals.
29. Examination of proposals and consignment contract. ⟶ ORGANIZATION (28–29)
30. <u>Start of R&D</u>.
31. *Evaluation sub–committee* and *ISTDC* of *ITC.*
32. Phased evaluation.
33. <u>Completion of R&D</u>.
34. *Evaluation sub–committee* and *ISTDC* of *ITC.* ⟶ EVALUATION (32–35)
35. Final evaluation.
36. Following up of completed projects. ⟶ TRANSFER

Table A2 Criteria for Undertaking New R&D Projects in the Industrial Science & Technology Frontier Program (ISTFP)

A. Leading Research Theme

1. Suitability to Objective of ISTFP

(i) Suitability to Policy Objective

a) Basic Nature

- Challenge pre–competitive stage R&D that involves high risks and requires a long lead time before commercialization can take place
- Requires an integration of abilities of industry, academic bodies and government research institutes under a national initiative

b) Objective Field

- Basic and creative R&D which will contribute to further development of the economy and society by building a new technology paradigm with a new concept, philosophy and approach and/or by making technological break–throughs; or
- Mission–oriented R&D to attain the social goals of meeting the public demand and realizing a higher quality life, securing natural resources, and constructing the basis for promotion of science and technology

(ii) Far–reaching Impacts to Industry

R&D which is expected to provide far–reaching impacts to broad industries, not to specific industries

2. Suitability to Objectives of Leading Research

(i) Worthiness to Pre–project Study

- Due to technological uncertainty
- Due to extensiveness of the concept
- Due to complicated international implications
- Due to broad social impacts

(ii) Maturity of Technology Optimum to Undertake Pre–project Study

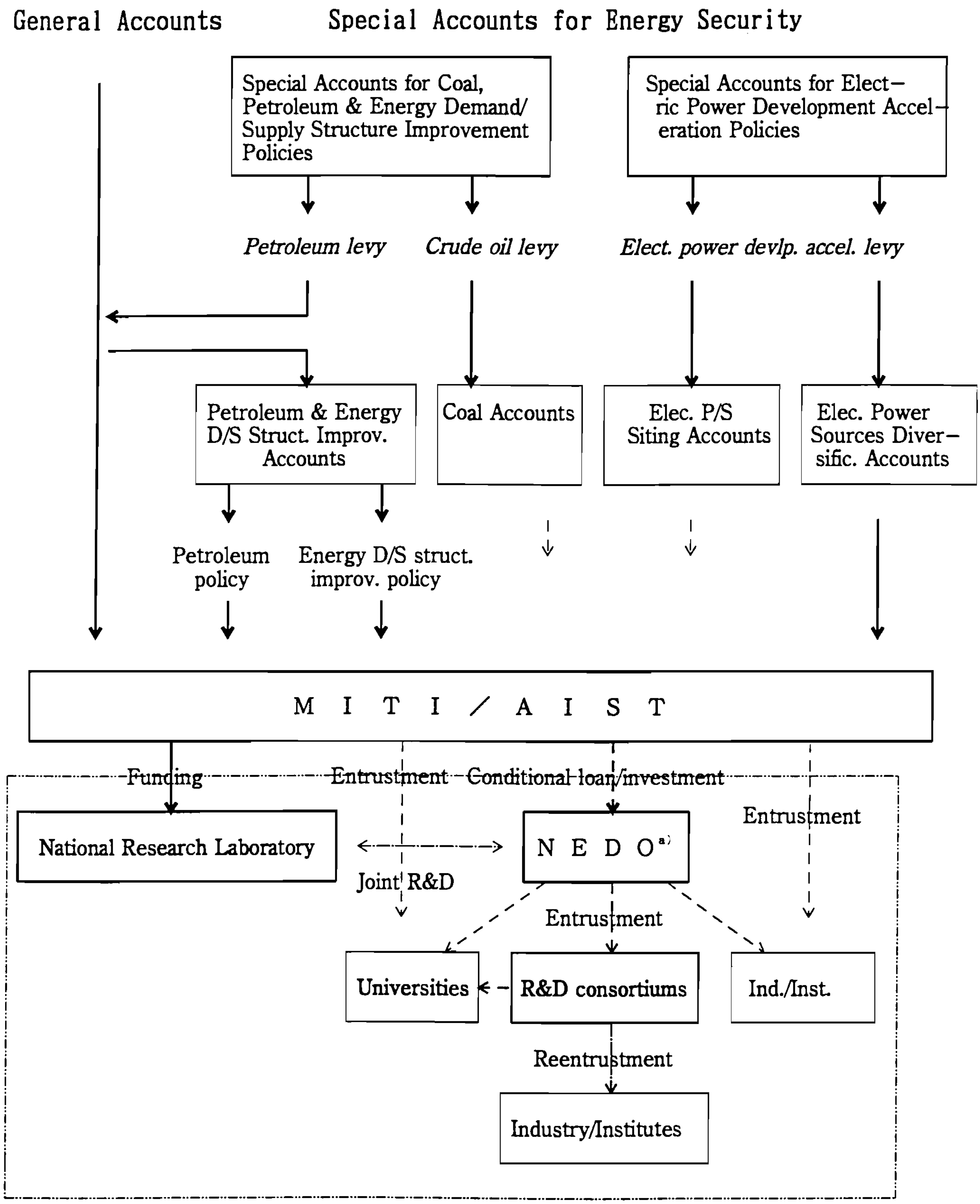
3. Suitability to

(i) Japan's Initiative in a Global Context

(ii) A Reliable Research Organization

B. R&D Projects

Projects which satisfy conditions listed in 1. above and which are also able to respond to the requirements listed in 3. above.



a NEDO: New Energy & Industrial Technology Development Organization (MITI's affiliate)

Fig. A6 Scheme of the Funding Mechanism for National R&D Program

BASIC PLAN

Basic Mission as a National R&D Program Project

1. Nature of R&D Program Projects
   - Pre/non–competitive stage
   - High–risk and/or long lead–time
2. Organization of Research Teams
   - Tie–ups among ind., gov. lab. and univ.
   - Maximize the vitality of participants
3. Management of Implementation
   - Periodic review and adjustment
   - Annual report published
4. Transfer of R&D Results
   - Co–owner project results
   - Utilization of project results
5. Comprehensive Approach
   - Systematic integration with other policy tools for supplement/smooth shift to practical application/broad diffusion

Basic Principle

1. Challenging Ambitious Targets
2. System Approach in a Global Context
3. Compreh. Approach among Intersectors
4. Harmony between Competition and Coop.
5. Maximize Potential Role of Gov. Lab.
6. Initiative Led by Leading R&D Sites
7. Parallel R&D Efforts and Develop. of Practical Application

Basic Plan

1. Objective and the Goals of the Project
2. Period of R&D and Total Amount of Fund
3. Targets of R&D
4. Time Horizon and Stage Plan of R&D
5. Principle of Evaluation
6. Principle of a System for R&D Challenge

Basic Principle of R&D Implementation

1. R&D Centers/Facilities expected to be Utilized
2. Ideal Picture of Tie–Up
3. Principle of Way Conduct R&D
4. Principle of R&D Management

Nat. Res. Lab. AIST/MITI NEDO

Survey on Forefront R&D → Nat. Res. Lab.

Intl. Forum/Workshop → NEDO

AIST/MITI ↕ Subcommittee for Project Development

Subcommittee for Project Development ↕ Industrial Technology Council Advisory Committee

Fig. A7 Scheme of Drafting Basic Plans for National R&D Program Projects

MITI R&D Project Basic Plan
and
Basic Principle of R&D Implementation

↓

NEDO R&D Project Basic Plan

↓

Public Announcement --- in "Tsusansho Koho" (a daily gov. gazzette published by MITI), "Nature", and "Science"

2 weeks ↓

Explanatory Meeting

2 months ↓

Proposal Deadline

↓

NEDO Examination

↓

Entrustment Contract

↓

Start of R&D

Qualification of Applicants

The applicant must
(i) have previous R&D experience in the ind. tech. field covered by or related to the project;

(ii) have the organizational structure, human resources and research facilities required to carry out the R&D project and to achieve the project's targets;

(iii) be in sound financial conddition and possess the ability to manage its finances and facilities as necessary to smoothly carry out the project.

Criteria for Selecting R&D Project Participants

(i) Satisfaction with the above qualifications
(ii) Quality of the proposal
- The goal of the R&D work
- The methodology and contents of the R&D work
- The economic aspects of the R&D work

Fig. A8 Scheme of Organizing R&D Tie-ups for National R&D Program Projects

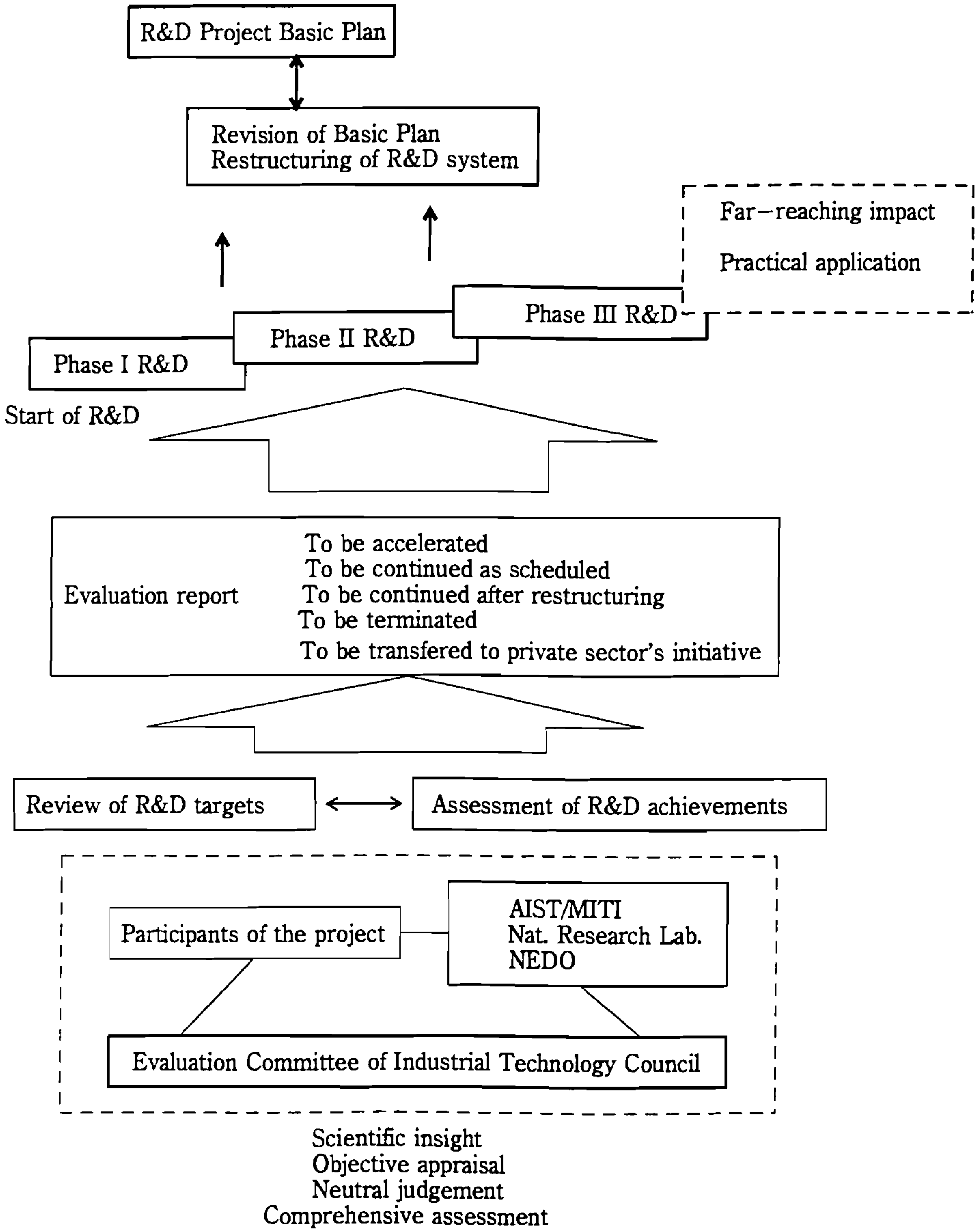


Fig. A9 Evaluation Mechanism of National R&D Program Projects

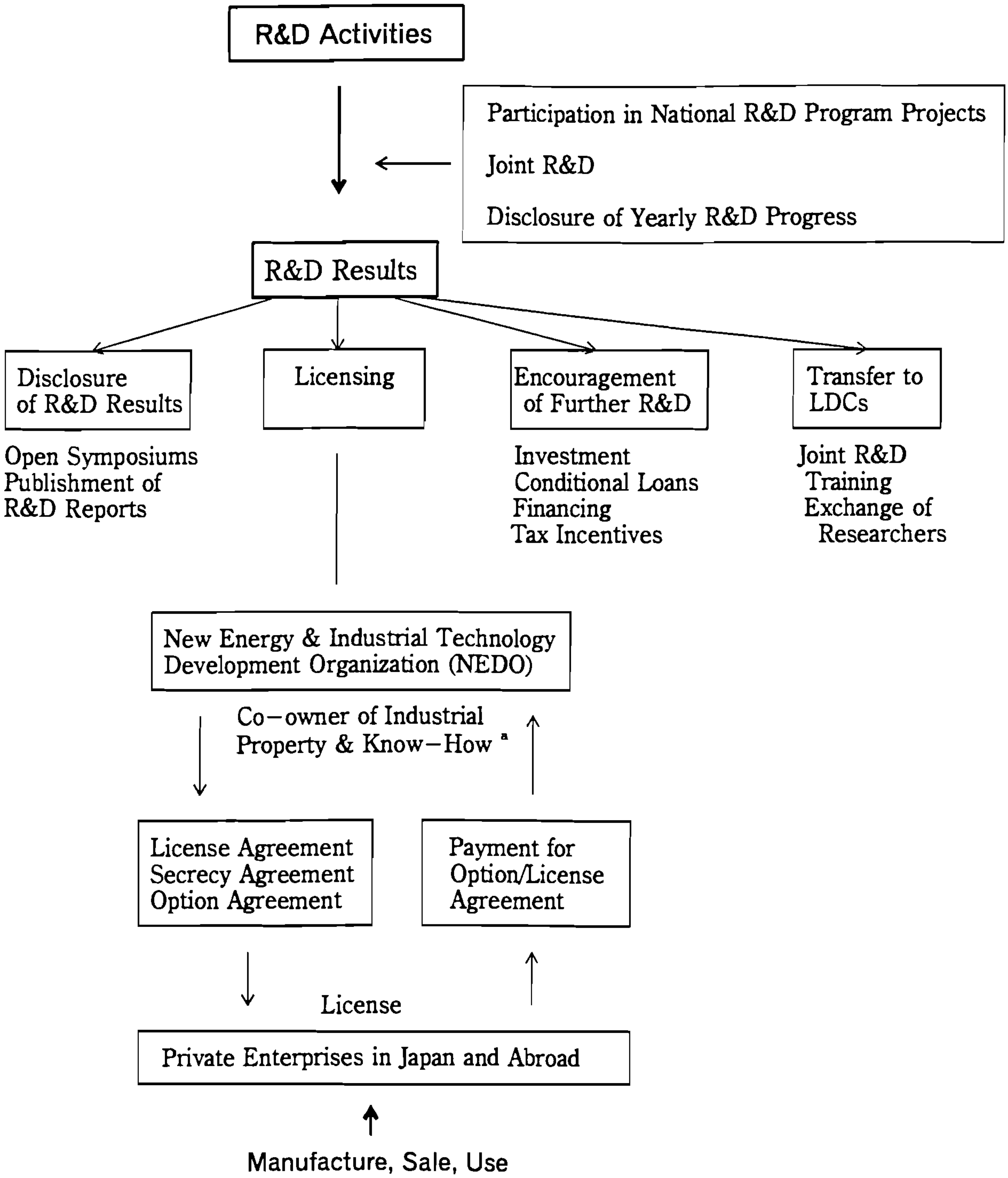


Fig. A10 Technology Transfer System for R&D Results Developed through National R&D Programs

a System of co-owner on energy R&D is under consideration.

Appendix II Basic Data

GENERAL

YEAR	GCN	IMIN	GDPN	GC85	IMI85	GDP85
1955	8505.10	6124.20	2380.90	21487.80	15456.00	6031.80
1956	11043.20	8087.30	2955.90	25513.20	18441.10	7072.10
1957	13165.00	9682.40	3482.60	29302.60	21436.50	7866.10
1958	12230.00	8726.40	3503.60	29139.40	21010.00	8129.40
1959	15081.10	10809.70	4271.40	34840.50	25734.50	9106.00
1960	19187.10	13651.70	5535.40	43299.30	32555.20	10744.10
1961	23407.00	16509.80	6897.20	51637.50	38598.20	13039.30
1962	24924.70	17398.60	7526.10	55856.70	41731.30	14125.40
1963	28255.70	19470.60	8785.10	62870.60	46051.30	16819.30
1964	32800.90	22386.60	10414.30	72024.90	52412.40	19612.50
1965	34636.70	23551.10	11085.60	76023.30	55463.10	20560.20
1966	39934.60	27341.30	12593.30	86348.10	63121.60	23226.50
1967	48436.30	33052.30	15384.00	101854.80	74592.60	27262.20
1968	56235.50	37820.20	18415.30	116774.40	85553.20	31221.20
1969	67284.10	45308.90	21975.20	137069.40	100890.90	36178.50
1970	80378.50	53976.30	26402.20	157363.50	115498.00	41865.50
1971	84233.20	55803.00	28430.20	165236.80	121316.80	43920.00
1972	93010.30	61092.40	31917.90	179074.10	130915.30	48158.80
1973	118288.10	78720.00	39568.10	198873.20	144088.10	54785.10
1974	146532.60	101395.40	45137.20	191359.60	138251.00	53108.60
1975	144486.60	99685.70	44800.90	183563.60	131250.30	52313.30
1976	165550.70	114450.20	51100.50	199021.60	141837.70	57183.90
1977	177399.30	121987.00	55412.30	208123.00	148734.70	59388.30
1978	185646.80	125101.40	60545.40	218516.50	157383.70	61132.80
1979	207584.80	142769.40	64815.40	232337.50	165581.30	66756.20
1980	242496.30	172264.00	70232.30	241707.30	170225.40	71481.90
1981	250840.50	175902.00	74938.50	247310.90	172518.40	74792.50
1982	254090.60	175623.10	78467.50	248840.90	170710.80	78130.10
1983	259644.30	177896.50	81747.80	257130.50	175609.80	81520.70
1984	279496.10	190251.10	89245.00	276504.70	188078.90	88425.80
1985	287810.30	193137.70	94672.60	287810.30	193137.70	94672.60
1986	275271.20	179008.90	96262.30	292387.80	200275.20	92112.60
1987	274714.60	175418.00	99296.60	300949.90	202089.70	98860.20
1988	296560.00	189910.50	106649.50	327460.30	219461.00	107999.40
1989	322245.70	207790.50	114455.20	348517.00	231897.60	116619.40
1990	348072.00	224628.80	123443.20	370691.10	245198.70	125492.40
1991	366078.00	234742.00	131336.00	389791.80	256371.00	133420.80
1992	351620.40	222050.30	129570.10	379651.00	248659.40	130991.60

GCN (gross cost), IMIN (intermediate input), GDPN (gross domestic production) all current prices. GC85 (gross cost), IMI85 (intermediate input). GDP85 (GDP) all 1985 constant prices.

unit: billion yen

Source: Annual Report on National Accounts (Economic Planning Agency)

YEAR	V	SN	S	IIP85P	IIP85V
1955	6031.80	4325.00	9106.62	8.212	7.800
1956	7072.10	5615.00	11326.44	10.144	9.600
1957	7866.10	6695.00	13129.15	11.413	10.800
1958	8129.40	6220.00	13044.72	11.413	10.800
1959	9106.00	7670.00	15927.68	14.251	13.500
1960	10744.10	9756.90	20025.32	17.512	16.600
1961	13039.30	11869.00	24266.02	20.712	19.600
1962	14125.40	13452.20	28100.74	21.739	20.600
1963	16819.30	15731.50	32287.75	25.241	23.900
1964	19612.50	18579.90	38282.56	28.381	26.900
1965	20560.20	18917.40	38977.95	29.347	27.800
1966	23226.50	23035.40	46466.44	34.299	32.500
1967	27262.20	27627.60	55307.52	40.519	38.400
1968	31221.20	34000.40	67808.34	46.678	44.200
1969	36178.50	40574.40	78404.27	54.468	51.600
1970	41865.50	49216.40	92565.36	60.386	57.200
1971	43920.00	50676.20	96166.50	61.775	58.300
1972	48158.80	58867.90	108214.56	66.666	64.300
1973	54785.10	72128.10	108913.43	76.570	72.300
1974	53108.60	87878.80	110056.74	73.792	65.300
1975	52313.30	95247.80	118026.88	66.606	62.400
1976	57183.90	105073.10	123953.42	73.369	69.100
1977	59388.30	112732.20	132250.76	75.664	71.300
1978	61132.80	114798.20	136492.35	79.770	76.300
1979	66756.20	142567.40	153455.95	85.386	82.400
1980	71481.90	166780.60	162028.58	87.983	84.100
1981	74792.50	175967.20	169860.58	87.258	85.800
1982	78130.10	174637.30	167810.57	86.775	85.300
1983	81520.70	184025.70	179442.03	88.768	90.100
1984	88425.80	203731.60	197745.00	96.859	97.700
1985	94672.60	205759.60	205759.60	100.000	100.000
1986	92112.60	189259.40	203921.70	99.300	99.900
1987	98860.20	194443.10	213644.86	102.400	105.800
1988	107999.40	214397.70	236306.95	111.600	115.200
1989	116619.40	234161.30	249504.53	118.300	120.400
1990	125492.40	257397.10	271796.94	123.800	127.200
1991	133420.80	264709.60	281486.97	126.000	126.500
1992	130991.60	254600.00	275165.85	118.700	118.500

V (value added = GDP85), SN (sales, cuurent prices), S (sales, 1985 constant prices), IIP85P (index of industrial production, 1985=100, production weight), IIP85V (value added weight)
unit: billion yen

Sources: Annual Report on National Accounts (Economic Planning Agency)
Report on the Survey of Research & Development (Management and Coordination Agency)
Anual Report on Indices on Mining and Manufacturing (MITI)

YEAR	GCN	GLCN	GCCN	GMCN	GECN
1955	8505.10	1122.401	1258.499	5772.80	351.400
1956	11043.20	1343.404	1612.495	7657.60	429.700
1957	13165.00	1527.124	1955.475	9139.90	542.500
1958	12230.00	1693.850	1809.749	8210.10	516.300
1959	15081.10	1913.986	2357.413	10234.10	575.600
1960	19187.10	2291.548	3243.851	12966.70	685.000
1961	23407.00	2794.235	4102.964	15735.80	774.000
1962	24924.70	3294.741	4231.358	16566.40	832.200
1963	28255.70	3821.378	4963.721	18554.10	916.500
1964	32800.90	4419.105	5995.194	21398.80	987.800
1965	34636.70	4961.803	6123.796	22479.70	1071.400
1966	39934.60	5622.545	6970.754	26192.10	1149.200
1967	48436.30	6748.689	8635.311	31786.70	1265.600
1968	56235.50	8028.233	10387.067	36403.70	1416.500
1969	67284.10	9446.769	12528.431	43722.60	1586.300
1970	80378.50	11176.089	15226.111	52157.80	1818.500
1971	84233.20	12783.657	15646.543	53769.90	2033.100
1972	93010.30	14741.952	17175.948	58906.80	2185.600
1973	118288.10	18552.833	21015.267	75901.50	2818.500
1974	146532.60	23272.700	21864.500	96427.10	4968.300
1975	144486.60	24934.528	19866.372	93850.50	5835.200
1976	165550.70	27475.421	23625.079	107538.50	6911.700
1977	177399.30	30080.048	25332.252	114574.80	7412.200
1978	185646.80	31687.747	28857.653	118258.30	6843.100
1979	207584.80	33841.228	30974.172	135436.30	7333.100
1980	242496.30	36671.873	33560.427	160944.40	11319.600
1981	250840.50	39578.276	35360.224	164392.20	11509.800
1982	254090.60	41228.235	37239.265	164435.60	11187.500
1983	259644.30	43285.074	38462.726	167379.60	10516.000
1984	279496.10	46362.917	42882.083	179845.00	10406.100
1985	287810.30	48909.091	45763.509	182729.80	10407.900
1986	275271.20	50702.344	45559.956	170489.10	8519.800
1987	274714.60	51457.496	47839.104	168363.50	7054.500
1988	296560.00	54094.767	52554.733	182955.30	6955.200
1989	322245.70	57909.907	56545.293	200778.70	7011.800
1990	348072.00	62788.975	60654.225	217008.10	7620.700
1991	366078.00	67305.882	64030.118	226708.00	8034.000
1992	351620.40	69445.663	60124.437	214452.30	7598.000

GCN (gross cost), GLCN (gross labor cost), GCCN (gross capital cost), GMCN (gross materials cost), GECN (gross energy cost) all current prices.
unit: billion yen

Sources: Annual Report on National Accounts (Economic Planning Agency)
Quartery report on Unincorporated Enterprises (Management and Coordination Agency)
Industrial Statistics (MITI)

YEAR	CE	CEUIE
1955	1026.000	96.400
1956	1244.500	98.904
1957	1416.900	110.224
1958	1566.200	127.650
1959	1776.900	137.086
1960	2139.700	151.848
1961	2600.200	194.035
1962	3078.500	216.241
1963	3560.200	261.178
1964	4092.000	327.105
1965	4616.200	345.603
1966	5259.800	362.745
1967	6255.100	493.589
1968	7412.000	616.233
1969	8871.900	574.869
1970	10644.500	531.589
1971	12279.100	504.557
1972	14102.000	639.952
1973	17768.000	784.835
1974	22326.400	946.300
1975	24082.600	851.927
1976	26551.000	924.420
1977	29116.100	963.948
1978	30680.100	1007.647
1979	32786.200	1055.028
1980	35561.400	1110.473
1981	38398.200	1180.075
1982	40203.600	1024.635
1983	42284.300	1000.774
1984	45360.900	1002.016
1985	47925.300	983.790
1986	49728.400	973.944
1987	50452.600	1004.896
1988	52997.800	1096.967
1989	56918.500	991.407
1990	61793.500	995.475
1991	66311.900	993.982
1992	68514.200	931.462

CE (income of paid employees), CEUIE (income of unincorporated enterprises) all current prices.
unit: billion yen

Sources: Annual Report on National Accounts (Economic Planning Agency)
Quartely Report on Unincorporated Enterprise (Management and Coordination Agency)

YEAR	EP	PEM	MH
1955	746.500	596.900	198.700
1956	807.400	665.700	205.200
1957	875.600	727.700	204.300
1958	931.000	769.400	201.300
1959	952.200	784.800	204.900
1960	1014.300	848.900	207.200
1961	1081.400	909.000	203.300
1962	1139.300	961.800	198.000
1963	1188.300	1000.500	196.400
1964	1226.100	1027.500	195.500
1965	1251.700	1052.100	191.800
1966	1287.200	1078.100	193.000
1967	1379.600	1142.500	193.900
1968	1411.500	1162.100	193.000
1969	1452.800	1195.100	190.000
1970	1452.900	1230.200	187.400
1971	1459.300	1247.000	184.300
1972	1460.300	1250.900	183.300
1973	1521.600	1298.900	182.000
1974	1507.000	1304.000	173.200
1975	1422.800	1239.300	167.800
1976	1415.600	1229.700	173.900
1977	1401.400	1218.600	174.500
1978	1381.600	1196.900	175.600
1979	1379.100	1189.400	177.900
1980	1405.700	1213.400	178.200
1981	1420.400	1231.500	177.400
1982	1413.100	1231.700	177.000
1983	1436.000	1254.300	178.000
1984	1465.400	1290.100	180.500
1985	1478.000	1316.900	179.700
1986	1470.100	1310.300	178.200
1987	1451.900	1292.100	179.100
1988	1481.700	1320.100	181.100
1989	1511.800	1348.900	179.300
1990	1534.800	1379.100	176.600
1991	1583.400	1431.700	173.200
1992	1604.400	1457.900	168.100

EP (employed persons), PEM (paid employees): 10 thousand persons,
MH (monthly working hours): hour

Sources: Annual Report on National Accounts (Economic Planning Agency)
Year Book of Labor Statistics (Ministry of Labor)

YEAR	CS	CSA	OR
1955	10724.00	10524.00	105.000
1956	11222.00	10973.00	108.500
1957	12252.00	11737.00	103.900
1958	13345.00	12798.50	95.900
1959	14511.00	13928.00	110.800
1960	16893.00	15702.00	115.500
1961	19642.00	18267.50	116.700
1962	23309.00	21475.50	109.400
1963	27043.00	25176.00	109.900
1964	30875.10	28959.05	117.300
1965	34510.40	32692.75	112.100
1966	37679.10	36094.75	112.800
1967	42480.80	40079.95	113.300
1968	49365.20	45923.00	112.800
1969	57569.50	53467.35	113.400
1970	67650.80	62610.15	110.600
1971	77247.90	72449.35	104.300
1972	86331.00	81789.45	105.000
1973	94259.10	90295.05	109.000
1974	102181.70	98220.40	99.800
1975	109353.40	105767.55	85.100
1976	115523.40	112438.40	92.100
1977	121876.90	118700.15	91.400
1978	126811.10	124344.00	94.800
1979	132920.20	129865.65	100.500
1980	139936.10	136428.15	100.600
1981	148328.80	144132.45	95.900
1982	156228.80	152278.80	93.100
1983	164114.30	160171.55	94.300
1984	173643.20	168878.75	99.800
1985	186398.70	180020.95	100.000
1986	197673.50	192036.10	95.400
1987	207363.30	202518.40	95.500
1988	218371.00	212867.15	101.100
1989	234381.30	226376.15	103.300
1990	251456.70	242919.00	105.700
1991	272491.60	261974.15	104.100
1992	290935.60	281713.60	96.000

CS (capital stock), CSA (CSAt = (CSt+CSt−1)/2): billion yen (1985 constant prices)
OR (operating rate): index, 1985=100

Sources: Statisrics of Enterprisers' Capital Stock (Economic Planning Agency)
Anual Report on Indices on Mining and Manufacturing (MITI)

YEAR	M	E
1955	13937.00	17500.00
1956	16701.62	20040.00
1957	19482.02	22517.00
1958	19112.11	21865.00
1959	23483.08	25938.00
1960	29774.12	32040.00
1961	35305.91	37929.50
1962	38197.32	40714.00
1963	42064.48	45931.00
1964	47768.51	53501.00
1965	50371.67	58657.00
1966	57338.98	66620.00
1967	67865.68	77499.00
1968	77919.66	87944.00
1969	91813.79	104575.00
1970	105018.99	120726.00
1971	110270.72	127259.00
1972	119563.95	130776.00
1973	131049.70	150212.00
1974	125385.85	148216.00
1975	119690.54	133177.00
1976	129817.90	138477.00
1977	136888.32	136479.00
1978	145636.62	135335.00
1979	153457.25	139678.00
1980	158602.01	133910.00
1981	161558.25	126269.00
1982	160334.38	119544.00
1983	165756.18	113521.00
1984	177588.51	120857.00
1985	182729.77	119907.00
1986	190293.37	114998.00
1987	191954.41	116766.00
1988	208699.10	123985.00
1989	220748.14	128450.00
1990	233764.36	131732.00
1991	244774.26	133603.00
1992	237239.99	131560.00

M (materials): billion yen (1985 constant prices)
E (final energy consumption): 1010 Kcal

Sources: Industrial Statistics (MITI)
Comprehensive Energy Statistics (Agency of Natural Resources & Energy of MITI)

YEAR	L	K	M	E	T
1955	1756103. 2	10895. 49	13902. 15	17412. 50	623. 700
1956	1961103. 0	11739. 02	16659. 87	19939. 80	735. 700
1957	2117212. 3	12030. 11	19433. 32	22404. 41	843. 800
1958	2217438. 7	12108. 06	19054. 78	21711. 94	968. 300
1959	2306852. 7	15223. 88	23412. 63	25756. 43	1139. 600
1960	2486143. 8	17890. 97	29684. 80	31815. 72	1351. 800
1961	2607316. 7	21030. 37	35200. 00	37626. 06	1566. 900
1962	2674763. 8	23177. 02	38063. 63	40388. 28	1796. 300
1963	2764177. 8	27281. 06	41917. 26	45563. 55	2110. 800
1964	2836735. 9	33493. 40	47601. 32	53072. 99	2515. 000
1965	2840864. 9	36118. 12	50193. 41	58177. 02	2966. 000
1966	2940856. 8	40169. 04	57122. 63	66058. 78	3445. 800
1967	3168403. 5	44860. 41	67606. 12	76793. 95	3965. 100
1968	3223177. 2	51218. 82	77536. 02	87024. 75	4471. 000
1969	3263136. 0	59971. 97	91337. 19	103433. 23	4978. 800
1970	3214659. 6	68506. 45	104429. 13	119286. 41	5620. 000
1971	3168338. 2	74722. 97	109626. 18	125696. 97	6507. 600
1972	3155546. 2	84873. 02	118824. 67	129048. 99	7630. 500
1973	3263114. 4	97242. 77	130307. 85	148312. 84	9014. 200
1974	3074369. 3	96813. 88	124760. 46	146426. 47	10517. 600
1975	2804340. 7	88893. 37	119071. 34	131455. 60	11994. 500
1976	2892722. 2	102311. 50	129133. 34	136734. 34	13501. 100
1977	2873386. 8	107233. 36	136121. 59	134698. 06	14852. 900
1978	2849988. 0	116541. 91	144753. 92	133507. 12	16013. 500
1979	2881339. 6	129041. 65	152478. 90	137024. 67	17065. 800
1980	2938375. 5	135673. 84	157630. 40	132011. 70	18094. 200
1981	2953071. 4	136565. 87	160394. 37	124263. 22	19161. 500
1982	2926872. 0	139942. 15	159002. 89	117557. 16	20326. 200
1983	2990186. 4	148925. 21	164211. 22	111347. 19	21624. 500
1984	3088716. 0	166010. 07	175789. 86	118461. 69	23129. 600
1985	3098962. 4	177178. 95	180603. 08	117241. 42	24864. 300
1986	3050641. 5	180111. 00	187805. 40	112255. 19	26807. 400
1987	3024569. 2	189877. 78	189198. 75	113790. 88	29009. 100
1988	3114847. 6	211041. 85	205516. 91	120743. 65	31578. 800
1989	3143057. 3	229154. 68	217236. 89	124927. 34	34467. 400
1990	3138747. 1	251451. 84	229807. 44	127977. 85	37412. 000
1991	3177873. 6	266886. 01	240638. 22	129751. 40	40512. 500
1992	3122798. 2	264473. 38	233206. 91	127744. 76	43910. 500

L (labor: 10 thousand person−hour/month), K (capital: billion yen (1985 constant perices)),

M (materials: billion yen (1985 constant perices)), E (final energy consumption: 1010 Kcal)
T (technology knowledge stock: billion yen (1985 constant perices))

Respective services of input for R&D are deducted from L. K. M and E.
Source: calculation using above data.

YEAR	PL	PK*100	PM	PE*100
1955	0.063	11.388	41.420	2.008
1956	0.067	13.543	45.849	2.144
1957	0.071	16.035	46.914	2.409
1958	0.075	14.744	42.957	2.361
1959	0.081	15.275	43.580	2.219
1960	0.090	17.886	43.550	2.137
1961	0.105	19.246	44.569	2.040
1962	0.121	18.010	43.370	2.044
1963	0.136	17.940	44.108	1.995
1964	0.153	17.649	44.796	1.846
1965	0.172	16.709	43.290	1.826
1966	0.188	17.120	44.310	1.725
1967	0.210	19.016	45.430	1.633
1968	0.245	20.051	45.320	1.610
1969	0.285	20.663	46.190	1.516
1970	0.342	21.988	46.540	1.506
1971	0.396	20.706	47.300	1.597
1972	0.458	20.000	47.790	1.671
1973	0.558	21.352	57.918	1.876
1974	0.743	22.305	76.904	3.352
1975	0.870	22.071	78.410	4.381
1976	0.930	22.813	82.837	4.991
1977	1.025	23.349	83.699	5.431
1978	1.088	24.480	81.200	5.056
1979	1.149	23.732	88.256	5.250
1980	1.219	24.452	101.476	8.453
1981	1.308	25.582	101.754	9.115
1982	1.373	26.267	102.557	9.358
1983	1.411	25.464	100.979	9.264
1984	1.460	25.443	101.270	8.610
1985	1.534	25.421	100.000	8.679
1986	1.612	24.868	89.592	7.408
1987	1.649	24.735	87.710	6.041
1988	1.679	24.420	87.664	5.609
1989	1.780	24.180	90.953	5.458
1990	1.930	23.622	92.831	5.785
1991	2.045	23.478	92.619	6.013
1992	2.145	22.231	90.394	5.775

Pl (price of labor: 1000 yen/person-hour), Pk (price of capital: yen/yen)), Pm (prices of materials: 1985=100), Pe (prices of energy: yen/10 Kcal)

Source: calculation using above data.

YEAR	PL85	PK85	PM85	PE85
1955	4.109	44.800	41.420	23.133
1956	4.403	53.277	45.849	24.702
1957	4.635	63.078	46.914	27.756
1958	4.908	58.002	42.957	27.204
1959	5.327	60.091	43.580	25.566
1960	5.921	70.360	43.550	24.630
1961	6.901	75.709	44.569	23.509
1962	7.931	70.847	43.370	23.548
1963	8.891	70.571	44.108	22.988
1964	10.011	69.426	44.796	21.270
1965	11.223	65.730	43.290	21.043
1966	12.290	67.348	44.310	19.873
1967	13.700	74.803	45.430	18.813
1968	16.003	78.878	45.320	18.556
1969	18.584	81.282	46.190	17.475
1970	22.290	86.495	46.540	17.353
1971	25.811	81.452	47.300	18.405
1972	29.907	78.675	47.790	19.254
1973	36.380	83.993	57.918	21.616
1974	48.419	87.742	76.904	38.618
1975	56.715	86.824	78.410	50.478
1976	60.609	89.743	82.837	57.502
1977	66.796	91.850	83.699	62.569
1978	70.927	96.301	81.200	58.253
1979	74.904	93.356	88.256	60.483
1980	79.499	96.189	101.476	97.386
1981	85.295	100.632	101.754	105.014
1982	89.512	103.327	102.557	107.816
1983	91.959	100.172	100.979	106.731
1984	95.185	100.086	101.270	99.196
1985	100.000	100.000	100.000	99.999
1986	105.100	97.826	89.592	85.353
1987	107.460	97.301	87.710	69.603
1988	109.473	96.062	87.664	64.628
1989	116.014	95.119	90.953	62.889
1990	125.798	92.924	92.831	66.647
1991	133.274	92.358	92.619	69.278
1992	139.829	87.453	90.394	66.535

Pl85, Pk85, Pm85 (= Pm), Pe85 are indices of respective prices (1985=100)

Source: calculation using above data.

YEAR	LDEF	KDEF	MDEF	EDEF
1955	5.522	57.105	40.400	21.200
1956	6.002	60.115	46.000	22.500
1957	6.242	62.880	47.000	24.400
1958	6.482	64.397	43.800	23.000
1959	6.962	68.217	45.000	22.400
1960	7.563	72.718	44.200	22.000
1961	8.403	73.398	43.700	21.100
1962	9.123	75.861	40.300	20.400
1963	10.084	72.438	40.000	20.300
1964	11.164	72.302	40.300	20.100
1965	12.124	74.220	39.700	20.400
1966	13.565	73.643	41.000	20.200
1967	15.366	75.895	42.000	20.300
1968	17.647	79.055	41.800	20.400
1969	20.528	80.042	42.800	20.000
1970	24.129	81.916	44.700	20.300
1971	27.490	85.338	43.400	21.800
1972	31.692	87.238	43.800	21.800
1973	39.255	93.301	56.900	22.900
1974	49.459	93.500	74.100	37.700
1975	55.222	93.000	74.700	45.900
1976	61.944	94.000	81.100	50.100
1977	67.346	94.000	83.200	53.500
1978	71.308	97.000	81.400	50.300
1979	76.470	95.000	88.300	55.000
1980	82.112	100.000	104.600	91.700
1981	86.674	105.000	103.200	102.100
1982	90.636	107.276	102.700	107.700
1983	93.397	105.026	101.700	104.500
1984	96.998	104.000	101.900	100.100
1985	100.000	100.000	100.000	100.000
1986	101.440	100.000	93.100	85.600
1987	103.121	100.343	90.500	74.700
1988	107.803	96.148	91.300	69.900
1989	114.045	91.990	94.300	69.600
1990	120.048	88.959	94.500	73.500
1991	124.129	85.824	95.000	73.500
1992	125.570	83.515	92.800	71.300

LDEF: wage index, KDEF (whole sale price of capital goods), MDEF (whole sale price of materials), EDEF (whole sale price of fuel and electlicity)

Sources: Wage index of Manufacturing Industry (Ministry of Labor)
Economic Statistics Annual (The Bank of Japan)

YEAR	RN	RLN	RKN#	RMN	RON
1955	47.500	14.725	21.116	9.500	8.075
1956	59.000	18.880	25.794	11.800	10.030
1957	69.500	22.935	29.514	13.900	11.815
1958	70.000	23.800	28.949	14.000	11.900
1959	85.800	29.700	35.297	17.200	14.200
1960	112.100	36.300	48.997	22.400	14.900
1961	143.000	48.000	61.798	28.000	17.900
1962	161.400	60.000	62.672	32.800	24.600
1963	188.100	75.200	67.888	38.300	29.100
1964	223.400	89.200	82.399	44.400	34.000
1965	226.900	99.700	72.679	46.800	34.900
1966	268.800	120.200	82.291	57.800	42.600
1967	350.500	148.500	121.225	70.700	52.000
1968	464.600	193.000	157.027	101.700	76.700
1969	578.000	235.900	209.010	118.100	107.300
1970	760.900	307.200	278.963	155.800	137.000
1971	810.700	353.600	270.375	165.200	145.400
1972	953.200	445.100	296.261	187.200	169.000
1973	1193.500	553.800	397.218	211.200	226.200
1974	1459.400	750.900	398.269	255.800	265.700
1975	1536.500	821.000	386.942	260.300	278.400
1976	1727.400	918.500	423.369	306.200	322.700
1977	1923.100	1004.700	478.812	351.200	361.800
1978	2098.700	1077.200	536.404	400.000	386.100
1979	2447.100	1208.100	676.309	467.600	472.100
1980	2895.600	1367.700	834.018	545.200	579.600
1981	3374.200	1528.600	995.092	680.200	664.100
1982	3755.500	1653.400	1159.211	761.000	781.200
1983	4257.200	1890.400	1321.818	855.300	907.100
1984	4776.500	2050.800	1534.079	996.000	1049.100
1985	5543.600	2285.600	1880.783	1156.700	1237.900
1986	5739.600	2400.500	1942.691	1201.000	1291.000
1987	6101.200	2552.600	2105.857	1270.400	1395.300
1988	6754.600	2778.200	2359.143	1443.000	1614.600
1989	7706.200	3072.500	2798.651	1650.600	1847.300
1990	8660.300	3386.600	3180.930	1884.200	2137.400
1991	9195.400	3587.000	3461.916	1924.500	2284.600
1992	8971.100	3725.900	3245.862	1786.100	2369.500

RN (R&D exenditure), RLN (R&D expenditure for labor cost), RKN# (R&D expenditure for tangible fixed assets), RMN (R&D expenditure for materials), RON (other R&D expenses) all current prices.
unit: billion yen

Source: Report on the Survey of Research & Development (Management and Coordination Agency)

YEAR	REN	RKN	RDDEF
1955	2.158	21.116	25.100
1956	2.525	25.794	29.000
1957	3.150	29.514	30.800
1958	3.250	28.949	27.500
1959	3.602	35.297	28.800
1960	4.402	48.997	29.800
1961	5.201	61.798	30.800
1962	5.927	62.672	30.000
1963	6.711	67.888	30.200
1964	7.400	82.399	30.500
1965	7.720	72.679	30.600
1966	8.508	82.291	31.800
1967	10.074	121.225	33.000
1968	12.872	157.027	34.300
1969	14.989	209.010	36.400
1970	18.936	278.963	38.700
1971	21.524	270.375	40.400
1972	24.638	296.261	43.300
1973	31.281	397.218	52.100
1974	54.430	398.269	64.600
1975	68.257	386.942	68.900
1976	79.330	423.369	74.300
1977	88.387	478.812	77.400
1978	85.095	536.404	78.700
1979	95.090	676.309	85.400
1980	148.681	834.018	92.400
1981	170.307	995.092	95.200
1982	181.888	1159.211	97.500
1983	189.681	1321.818	98.000
1984	195.620	1534.079	100.000
1985	220.516	1880.783	100.000
1986	195.408	1942.691	97.300
1987	172.342	2105.857	97.800
1988	174.256	2359.143	99.900
1989	184.448	2798.651	104.100
1990	208.569	3180.930	107.300
1991	221.983	3461.916	107.900
1992	213.237	3245.862	107.600

REN (R&D expenditure for energy), RKN (R&D expenditure for capital) al current prices and RDDEF (R&D deflator: 1985=100)

Source: Report on the Promotion of Research Industry (Institute of Economic Research)

YEAR	RLNS*100	RKNS*100	RMNS*100	RENS*100	Total
1955	31.000	44.455	20.000	4.544	100.000
1956	32.000	43.719	20.000	4.280	100.000
1957	33.000	42.467	20.000	4.532	100.000
1958	34.000	41.356	20.000	4.643	100.000
1959	34.615	41.139	20.046	4.198	100.000
1960	32.381	43.708	19.982	3.927	100.000
1961	33.566	43.215	19.580	3.637	100.000
1962	37.174	38.830	20.322	3.672	100.000
1963	39.978	36.091	20.361	3.567	100.000
1964	39.928	36.884	19.874	3.312	100.000
1965	43.940	32.031	20.625	3.402	100.000
1966	44.717	30.614	21.502	3.165	100.000
1967	42.368	34.586	20.171	2.874	100.000
1968	41.541	33.798	21.889	2.770	100.000
1969	40.813	36.160	20.432	2.593	100.000
1970	40.373	36.662	20.475	2.488	99.999
1971	43.616	33.350	20.377	2.655	100.000
1972	46.695	31.080	19.639	2.584	100.000
1973	46.401	33.281	17.695	2.621	100.000
1974	51.452	27.289	17.527	3.729	100.000
1975	53.433	25.183	16.941	4.442	100.000
1976	53.172	24.509	17.726	4.592	100.000
1977	52.243	24.897	18.262	4.596	100.000
1978	51.327	25.558	19.059	4.054	100.000
1979	49.368	27.637	19.108	3.885	99.999
1980	47.233	28.802	18.828	5.134	99.999
1981	45.302	29.491	20.158	5.047	99.999
1982	44.026	30.867	20.263	4.843	100.000
1983	44.404	31.049	20.090	4.455	100.000
1984	42.935	32.117	20.852	4.095	100.000
1985	41.229	33.927	20.865	3.977	100.000
1986	41.823	33.847	20.924	3.404	99.999
1987	41.837	34.515	20.822	2.824	100.000
1988	41.130	34.926	21.363	2.579	100.000
1989	39.870	36.316	21.419	2.393	100.000
1990	39.104	36.730	21.756	2.408	100.000
1991	39.008	37.648	20.928	2.414	100.000
1992	41.532	36.181	19.909	2.376	100.000

RLNS, RKNS, RMNS and RENS are shares of respective component of R&D expenditure.

Source: calculation using above data.

YEAR	TIN	TINN	TICN	TI
1955	7.700	1.200	6.500	37.448
1956	9.300	1.400	7.900	45.016
1957	10.600	1.500	9.100	50.873
1958	10.900	1.400	9.500	52.184
1959	13.900	1.700	12.200	66.135
1960	19.300	2.300	17.000	91.040
1961	25.000	2.900	22.100	113.876
1962	28.600	3.200	25.400	130.590
1963	33.400	3.700	29.700	149.070
1964	40.200	4.400	35.800	163.878
1965	41.500	4.400	37.100	158.737
1966	49.200	5.000	44.200	176.450
1967	64.100	6.500	57.600	220.393
1968	85.000	8.500	76.500	274.781
1969	107.500	10.800	96.700	333.758
1970	141.500	14.200	127.300	422.450
1971	132.100	15.100	117.000	378.484
1972	168.300	13.000	155.300	456.671
1973	167.500	16.700	150.800	421.717
1974	154.500	12.500	142.000	370.834
1975	164.900	11.900	153.000	370.620
1976	173.800	17.000	156.800	323.839
1977	184.100	13.900	170.200	281.426
1978	188.200	36.400	151.800	266.570
1979	235.000	22.700	212.300	312.314
1980	233.200	25.800	207.400	295.880
1981	255.600	23.100	232.500	319.690
1982	278.100	42.500	235.600	319.467
1983	272.900	42.200	230.700	292.736
1984	276.900	30.700	246.200	289.313
1985	288.700	31.800	256.900	295.287
1986	258.400	33.500	224.900	263.919
1987	281.000	55.800	225.200	282.255
1988	309.400	53.100	256.300	309.453
1989	326.900	47.000	279.900	332.815
1990	368.200	71.000	297.200	370.055
1991	393.100	53.100	340.000	389.552
1992	410.700	93.100	317.600	391.615

TIN (technology import), TINN (technology import: new contract), TICN (technology import: continuous contract) all current prices.
TI (technology import): 1985 constant prices.

Source: Report on the Survey of Research & Development (Management and Coordination Agency)

YEAR	GTCN	GTC	RP
1955	55.200	264.721	10.000
1956	68.300	325.969	11.000
1957	80.100	371.149	12.000
1958	80.900	377.766	13.000
1959	99.700	457.916	14.000
1960	131.400	582.706	14.400
1961	168.000	707.237	12.600
1962	190.000	758.606	13.500
1963	221.500	833.070	15.500
1964	263.600	942.275	16.900
1965	268.400	900.240	17.400
1966	318.000	1021.733	17.400
1967	414.600	1282.515	17.900
1968	549.600	1629.300	19.800
1969	685.500	1921.670	21.600
1970	902.400	2388.600	23.400
1971	942.800	2385.167	26.700
1972	1121.500	2658.057	25.700
1973	1361.000	2712.504	27.500
1974	1613.900	2629.968	27.800
1975	1701.400	2600.663	30.100
1976	1901.200	2648.739	29.400
1977	2107.200	2766.051	29.200
1978	2286.900	2933.279	29.100
1979	2682.100	3177.771	29.400
1980	3128.800	3429.647	31.600
1981	3629.800	3864.018	33.200
1982	4033.600	4171.262	35.100
1983	4530.100	4636.818	36.100
1984	5053.400	5065.813	39.400
1985	5832.300	5838.887	40.900
1986	5998.000	6162.788	43.500
1987	6382.200	6520.701	44.600
1988	7064.000	7070.814	48.400
1989	8033.100	7735.505	51.000
1990	9028.500	8441.164	53.700
1991	9588.500	8911.702	54.400
1992	9381.800	8729.069	56.300

GTCN (gross technology cost: current prices), GTC (gross technology cost: 1985 constant prices), RP (number of researchers: 10 thousand)

Sources: calculation using above data.
Report on the Survey of Research & Development (Management and Coordination Agency)

YEAR	AGR	EP	CONS	RET	SERV
1955	1679. 50	746. 50	217. 30	497. 90	379. 10
1956	1643. 00	807. 40	223. 90	523. 40	400. 40
1957	1618. 10	875. 60	254. 00	553. 80	416. 70
1958	1561. 40	931. 00	266. 20	578. 40	407. 40
1959	1504. 80	952. 20	295. 40	602. 70	440. 20
1960	1493. 90	1014. 30	315. 60	624. 70	433. 80
1961	1453. 00	1081. 40	341. 10	629. 40	425. 70
1962	1410. 90	1139. 30	367. 30	642. 90	422. 80
1963	1333. 70	1188. 30	369. 90	685. 10	435. 30
1964	1279. 70	1226. 10	393. 30	708. 90	446. 50
1965	1233. 60	1251. 70	414. 90	740. 00	483. 20
1966	1203. 20	1287. 20	423. 30	779. 90	523. 00
1967	1179. 60	1379. 60	421. 80	795. 50	541. 20
1968	1151. 80	1411. 50	414. 40	832. 00	581. 10
1969	1124. 60	1452. 80	416. 50	859. 10	596. 40
1970	1073. 60	1452. 90	442. 90	872. 80	691. 30
1971	995. 80	1459. 30	469. 30	891. 70	722. 50
1972	947. 80	1460. 30	489. 10	906. 10	752. 60
1973	903. 30	1521. 60	520. 90	931. 70	766. 40
1974	880. 90	1507. 00	514. 00	941. 50	758. 40
1975	861. 80	1422. 80	528. 70	965. 00	788. 90
1976	844. 30	1415. 60	541. 70	985. 00	803. 50
1977	836. 60	1401. 40	547. 90	1011. 40	845. 30
1978	826. 30	1381. 60	567. 90	1018. 50	866. 50
1979	797. 60	1379. 10	582. 20	1030. 30	930. 80
1980	756. 60	1405. 70	591. 00	1043. 00	943. 60
1981	732. 90	1420. 40	583. 70	1060. 90	969. 40
1982	718. 90	1413. 10	577. 70	1078. 20	1009. 60
1983	695. 40	1436. 00	573. 20	1093. 90	1072. 50
1984	668. 90	1465. 40	552. 40	1098. 30	1106. 40
1985	659. 80	1478. 00	549. 20	1098. 80	1140. 00
1986	643. 30	1470. 10	550. 00	1115. 30	1176. 30
1987	633. 40	1451. 90	546. 30	1133. 90	1234. 20
1988	622. 30	1481. 70	572. 90	1151. 00	1262. 90
1989	613. 40	1511. 80	590. 60	1160. 30	1315. 20
1990	605. 70	1534. 80	601. 50	1170. 40	1386. 50
1991	587. 00	1583. 40	619. 00	1183. 30	1449. 00
1992	573. 60	1604. 40	633. 70	1181. 00	1491. 50

AGR (agriculture), EP (manufacturing), CONS (construction), RET (retails and whole sales), SERV (service industry)
unit: 10 thousand

Sources: Annual Report on National Accounts (Economic Planning Agency)

YEAR	OTHER	TOTAL
1955	547.00	4067.30
1956	569.70	4167.80
1957	590.80	4309.00
1958	614.50	4358.90
1959	630.40	4425.70
1960	656.00	4538.30
1961	691.00	4621.60
1962	730.80	4714.00
1963	762.00	4774.30
1964	806.00	4860.50
1965	836.10	4959.50
1966	864.00	5080.60
1967	887.00	5204.70
1968	891.00	5281.80
1969	907.00	5356.40
1970	909.90	5443.40
1971	943.20	5481.80
1972	954.40	5510.30
1973	990.90	5634.80
1974	1009.30	5611.10
1975	1030.10	5597.30
1976	1053.00	5643.10
1977	1068.20	5710.80
1978	1105.70	5766.50
1979	1105.80	5825.80
1980	1125.80	5865.70
1981	1143.50	5910.80
1982	1161.60	5959.10
1983	1178.30	6049.30
1984	1178.50	6069.90
1985	1178.20	6104.00
1986	1201.10	6156.10
1987	1208.80	6208.50
1988	1221.10	6311.90
1989	1244.40	6435.70
1990	1272.80	6571.70
1991	1284.80	6706.50
1992	1299.10	6783.30

YEAR	FOOD	TXTILE	PAPER	CHEMICAL	OILCOL
1955	2279.40	594.70	86.50	99.20	170.80
1956	2411.50	721.30	135.80	108.40	222.00
1957	2487.30	822.70	155.80	109.70	273.80
1958	2538.10	838.70	176.80	150.50	366.00
1959	2741.60	853.20	224.10	204.50	439.10
1960	2741.00	907.80	310.10	243.60	525.60
1961	3171.10	1028.00	400.10	303.90	675.30
1962	3399.10	1116.70	431.50	321.00	842.70
1963	3825.10	1207.50	518.70	406.30	1020.10
1964	3988.70	1365.90	596.00	508.10	1247.60
1965	4149.90	1463.10	653.10	604.20	1331.10
1966	4562.10	1615.00	738.70	719.60	1651.40
1967	5241.40	1612.40	821.80	936.40	1990.50
1968	5567.70	1730.30	995.40	1165.30	2244.40
1969	5946.10	1815.60	1120.90	1497.80	2483.30
1970	6481.30	2258.20	1265.10	1720.80	2586.90
1971	6758.80	2267.60	1393.80	2147.60	2494.90
1972	6804.50	2251.70	1613.60	2543.10	2885.80
1973	8825.20	2396.40	1747.80	2648.40	2943.50
1974	8832.50	2872.80	1565.90	2721.30	2242.10
1975	8908.30	2768.80	1590.50	2608.80	3437.80
1976	8931.20	2518.80	1849.30	2999.30	3843.80
1977	9949.50	2444.10	1732.10	3438.50	3766.20
1978	8701.40	2228.20	1782.50	4142.00	4284.60
1979	10409.70	2407.40	1970.40	4353.80	2679.10
1980	10290.80	2745.30	1905.80	4237.00	2966.80
1981	10630.10	2748.10	2212.00	4816.50	3549.80
1982	11100.00	2689.40	2259.40	5403.10	3956.90
1983	11524.90	2753.50	2356.70	5906.90	3329.60
1984	11011.20	2611.80	2395.00	6656.30	3591.10
1985	11133.90	2545.10	2390.10	7031.60	3924.90
1986	10797.10	2408.30	2345.20	8076.60	39.80
1987	10468.50	2443.20	2499.70	8720.20	2163.30
1988	10838.50	2368.90	2718.40	9581.60	837.30
1989	10994.80	1981.00	3106.50	10878.10	1208.60
1990	11601.90	2172.50	3233.10	11359.70	1029.90
1991	11593.70	2074.20	3187.50	11662.30	765.40
1992	11243.40	2293.00	3100.60	12779.50	1252.50

FOOD (food), TXTILE (textile), PAPER (paper and pulp), CHEMICAL (chemicals), OILCOL (oil and coal), CEMENT (ceramics), IRON (iron and steel), METAL (metal), GMACHIN (general machinery), EMACHIN (electric machinery), TMACHIN (transport equipment), FMACHIN (fine machinery), OTHER (other manufacturing and V (total = value added)

unit: billion yen

Sources: Annual Report on National Accounts (Economic Planning Agency)

YEAR	CEMENT	IRON	METAL	GMACHIN	EMACHIN
1955	219.10	483.70	161.60	182.30	31.50
1956	295.70	451.50	247.60	302.10	31.60
1957	323.40	589.80	248.90	373.50	42.90
1958	355.80	434.90	240.90	344.60	61.90
1959	416.50	588.20	310.90	437.40	93.50
1960	509.40	834.30	403.50	649.70	137.40
1961	647.80	1193.90	484.90	877.70	219.70
1962	676.40	939.30	604.90	1022.80	278.40
1963	825.40	1024.60	842.00	1085.40	302.00
1964	1022.60	1561.30	1046.80	1323.20	368.30
1965	1095.40	1520.90	1157.10	1348.80	362.20
1966	1180.20	1671.10	1373.20	1474.40	416.60
1967	1352.80	2038.50	1546.90	1920.70	610.00
1968	1630.90	2406.50	1721.90	2336.90	790.30
1969	1912.20	3281.00	2149.30	2918.50	1054.00
1970	2281.90	4272.50	2690.90	3697.50	1340.60
1971	2482.00	4634.80	2791.60	3862.40	1470.80
1972	2838.60	5396.60	3177.40	3851.60	1955.00
1973	3301.40	6325.90	3947.80	4219.80	2521.70
1974	3126.00	5709.30	3186.40	4302.10	2567.30
1975	2610.10	5633.20	2597.80	4092.30	2275.80
1976	2668.90	6128.00	2602.10	4593.00	2996.30
1977	2638.50	5715.60	2827.40	5062.60	3399.70
1978	2696.40	6386.50	3115.80	5306.50	3821.00
1979	2800.90	7955.30	3376.10	6180.00	4666.20
1980	2688.60	8266.50	3380.70	7620.20	6063.90
1981	2839.70	6894.40	3628.90	8608.90	6947.00
1982	2814.10	6728.90	3910.70	9148.80	8004.20
1983	3002.40	5989.50	4046.50	9348.90	9832.60
1984	3087.40	7602.30	4105.90	10412.30	12567.80
1985	3447.30	7865.20	4638.30	11852.40	13966.60
1986	3319.50	6990.10	4964.50	11482.80	15440.40
1987	3545.20	7693.70	5041.10	11378.90	16929.50
1988	3902.80	8495.60	5458.60	13340.70	20680.10
1989	4080.40	9012.10	5596.90	14685.70	23752.00
1990	4203.60	9270.20	6267.50	16073.00	26884.30
1991	4128.00	9160.20	6664.60	17447.90	31654.70
1992	4045.30	8398.10	7006.20	16014.80	30440.10

YEAR	TMACHIN	FMACHIN	OTHER	V
1955	226.90	27.40	1468.70	6031.80
1956	371.80	33.10	1739.70	7072.10
1957	411.60	38.30	1988.40	7866.10
1958	397.50	42.60	2181.10	8129.40
1959	480.40	49.90	2266.70	9106.00
1960	700.10	65.00	2716.60	10744.10
1961	813.60	89.00	3134.30	13039.30
1962	996.20	93.50	3402.90	14125.40
1963	1261.00	120.00	4381.20	16819.30
1964	1645.40	154.60	4784.00	19612.50
1965	1852.60	164.00	4857.80	20560.20
1966	2097.00	194.20	5533.00	23226.50
1967	2631.50	230.00	6329.30	27262.20
1968	3261.50	267.70	7102.40	31221.20
1969	3679.40	320.10	8000.30	36178.50
1970	4528.00	356.30	8385.50	41865.50
1971	4538.70	382.20	8694.80	43920.00
1972	4724.60	417.30	9699.00	48158.80
1973	5596.10	602.60	9708.50	54785.10
1974	6307.00	711.30	8964.80	53108.60
1975	6124.00	519.10	9146.80	52313.30
1976	7089.40	594.20	10369.60	57183.90
1977	7218.70	761.80	10433.60	59388.30
1978	6960.10	858.90	10848.90	61132.80
1979	7435.60	1011.10	11510.60	66756.20
1980	8524.70	1275.30	11516.30	71481.90
1981	8697.30	1397.30	11822.30	74792.50
1982	8242.50	1397.40	12474.70	78130.10
1983	8758.10	1564.60	13106.30	81520.70
1984	9283.00	1636.80	13474.70	88425.80
1985	10009.00	1859.80	14008.40	94672.60
1986	10167.30	1739.50	14341.30	92112.60
1987	11270.40	1543.40	15163.10	98860.20
1988	11932.80	1752.20	16092.00	107999.40
1989	12812.20	1980.70	16530.50	116619.40
1990	13792.10	2036.10	17568.50	125492.40
1991	14580.60	2191.00	18310.80	133420.80
1992	14454.20	1926.40	18037.50	130991.60