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THE STRUCTURE OF R&D ACTIVITY OF THE JAPANESE ECONOMY

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I. Introduction

The Japanese economy is said to have entered the new technological stage around in the middle of the 1970's after having caught up with the level of technology of other advanced industrialized countries. It is pointed out especially in the recent aspect of the foreign trade of the Japanese economy which shows the great excess of exports over imports of industrial products, evoking much political dispute between Japan and other trade partners.

On the other hand, the research and development (R&D) activity in Japanese industries has been taken to concetrate their efforts upon application, development, or improvement of existing technological ideas, and to have a comparatively less interest in basic research activity.

The purpose of this paper is to make clear the structure of R&D activity of the Japanese industry by constructing and estimating a simple econometric model, concentrating our attention to R&D behavioral equations.

Principal characteristics of the model are as follow: (1) The technological level of the Japanese economy is considered as an endogenous variable in the macro-economic model. It is represented as an accumulation of domestically developed techniques and of those introduced from foreign countries. Only the techniques which are actually used in industries are taken into account; (2) The R&D expenditure of the industry is specified in two behavioral equations, namely, an equation of basic R&D expenditure and that of applied R&D expenditure. These expenditures, along with government expenses for R&D, become financial sources which give birth to new techniques; (3) The amount of expenditure for industrial R&D is basically financed from business earnings and therefore influenced by the demand side of the national economy; (4) We must admit that Japan had ever owed new technological idears to the United States or other industrialised countries and the past statistics on introduction of foreign technology tells the fact. These days, however, it is observed that the number of techniques introduced from foreign countries has been decreasing with the recent curtailment of technological gap between Japan and those countries. Under the past and present state of things, a behavioral equation for the introduction of foreign technology is specified in the model and it is shown that the behavior of Japanese industries for it has substantially changed according to gradual reduction of technological gap and to rapid enhancement of Japan's technological level itself.

II. Model

Our econometric model of the Japanese economy is composed of two parts, namely, the demand side and the supply side. The latter is constructed centering around a macro-economic production function which shifts over time in accordance with technological progress. The level of technology (T) at a certain year is measured as a composite of a stoch of domestically developed techniques (P) and that of techniques introduced from foreign countries (S), the former being adjusted for obsolescence of technological knowledge with the use of utilization ratio of patents retained by the industry.

A stock of techniques (P) is represented by an accumulation of those applied for patents and R&D efforts made by the industry for many years give birth to the new techniques applied for patents at a current year (PN). The R&D efforts at a certain year are measured by the amount of expenditures for basic R&D (EB) and applied R&D (EA).

These R&D efforts of industries will raise the technological level (T) of the Japanese economy as a whole and, on one hand, the heightened technological level will expand the production capacity of the national economy (PGNP). Besides, increase of the rate of technological progress ($\Delta T/T$) is considered to push down the general price level (P_c) as well. On the other hand, the production capacity expanded by the rise of technological level is apt to be in excess of the aggregate demand (GDE) and the gap between demand and supply (GAP) thus produced may have an unfavorable effect on th economy by depressing investment activity although commodity exports will be promoted.

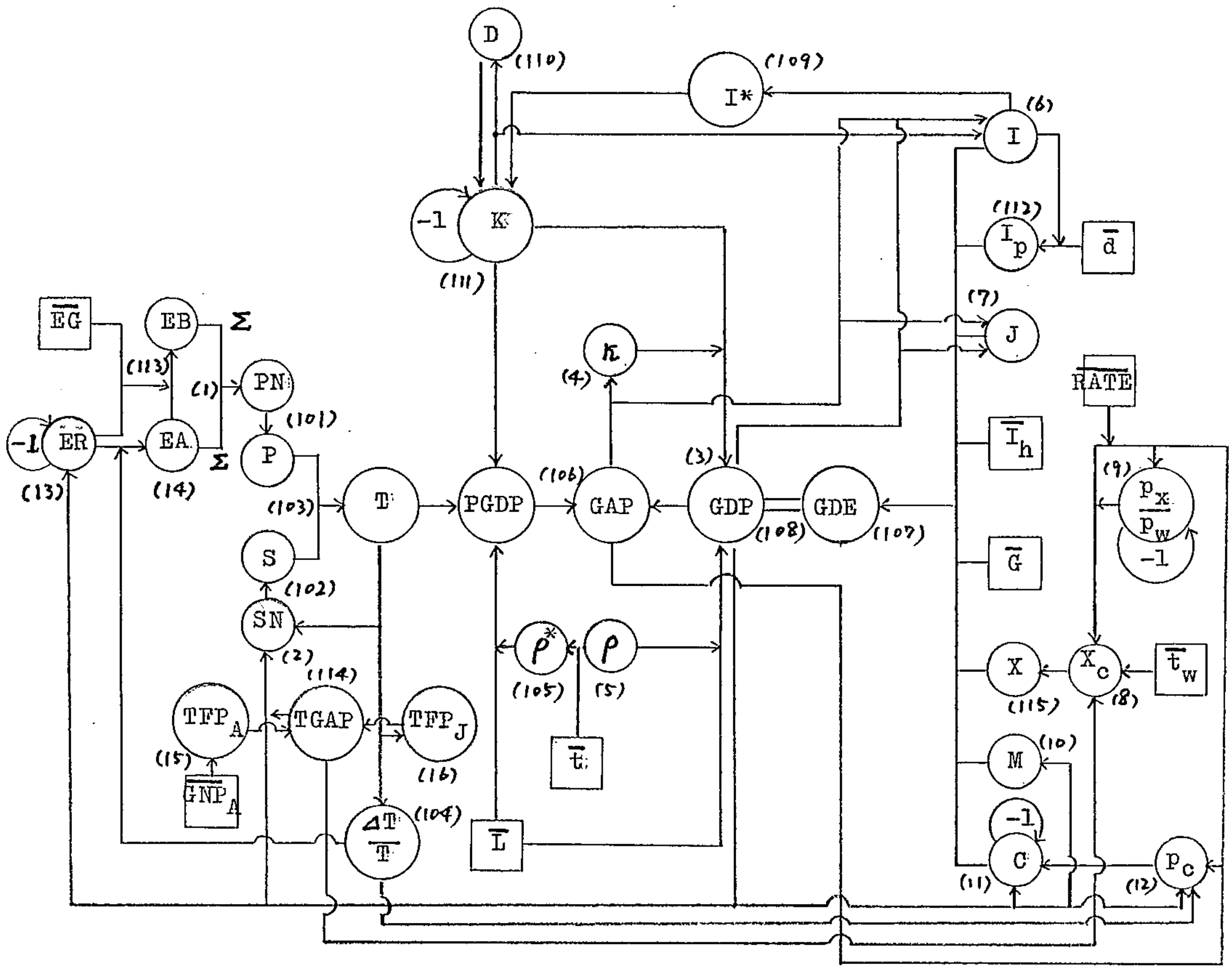
Figure 1 shows the over-all picture of causation and interraction among economic variables, where circled characters stand for endogenous variables and those in a quadangle represent exogenous and policy variables. One or two digits numbers in parentheses show structural equations which explain the variables with those parenthesized numbers and three digits numbers mean identical or statistical equations.

The model is composed of thirty one equations, sixteen of which are behavioral ones , the rest being identities. Those estimated expressions are found in Appendix A. Some important equations are explained in the next place.

(a) R D output equation [equation (1)]

The R&D output (patents applied for) at a certain year is a product of accumulated efforts made for many years (Mansfield [1965], Schmookler [1966], Minasian [1969] et al.) and expenditures for R D at a certain year will contribute only to a portion of the current output. In other words, expenditures for one year will contribute to R&D output successively during several years along with ex-

Figure 1. Overall Picture of Causation among Variables



penditures for the other years in accordance with some lag structure. As the progress ratio of a certain R&D program in one year is supporsed to randomly distribute until accomplishment, the distribution of contribution of expenditures for a year can be considered to be subject to Poisson distribution. That is, the probability of taking θ years until accomplishment of a program is represented as

$$(2.1) \qquad p_{\theta} = \frac{\lambda^{\theta}}{\theta!} \cdot e^{-\lambda} \qquad (\theta = 0,1,2,\ldots\ldots)$$

and a portion of contribution of expenditures of θ years before, $EB_{t-\theta}$, to the present R&D output, PN_t, can be expressed as

$$(2.2) \qquad p_{\theta} \cdot EB_{t-\theta}$$

assuming that the portion is proportionate to the probability of taking θ years until accomplishment.

Refferring to the results of sampling studies made by the Japan Society for the Promotion of Machine Industry [1981] (see also Sahal [1981] and Taylor and Silberston [1973]), we use Poisson distribution of $\lambda = 5$ (years) for basic R&D and that of $\lambda = 3$ (years) for applied R&D. Then, the number of patents applied for at year t (PN_t) can be expressed as a following equation:

$$(2.3) \qquad PN_t = \alpha \left(\sum_{\theta=0}^{n} p_{\theta} \cdot EB_{t-\theta} \right)^{\beta} \left(\sum_{\theta=0}^{n} q_{\theta} \cdot EA_{t-\theta} \right)^{\gamma} e^{u_t}$$

where $EB_{t-\theta}$ and $EA_{t-\theta}$ are amounts of expenditures made θ years before for basic R&D and applied R&D, respectively, p_{θ} and q_{θ} are lag parameters derived from the Poisson distributions for these two types of R&D, and u_t is a disturbance term.

A role of basic R&D in technological progress has greatly changed in Japan for past twenty years. Before around the so-called oil crisis, Japanese industries had admittedly devoted themselves to rapid advancement of technology by concentrating their efforts upon applied R&D and had comparatively made light of basic R&D. In these ten years, however, they have made a greater effort to develop new technology by themselves, as the technological gap is reduced between Japan and other industrialized countries, especially the United States. From such a point of view, the equation may be revised so as to accomodate the structural change in basic R&D activity which has occurred during this period of observation. That is,

$$(2.4) \quad \ln(PN_t) = \ln\alpha + (\beta_0 + \beta_1 \cdot D_{74}) \ln\left(\sum_{\theta=0}^{n} p_{\theta} \cdot EB_{t-\theta}\right) + \ln\left(\sum_{\theta=0}^{n} q_{\theta} \cdot EA_{t-\theta}\right) + u_t$$

where D_{74} is a dummy variable explaining the structural change, taking zero's before 1974 and one's from 1974 and downward.

(b) R&D expenditures [equations (15), (16) and (113)]

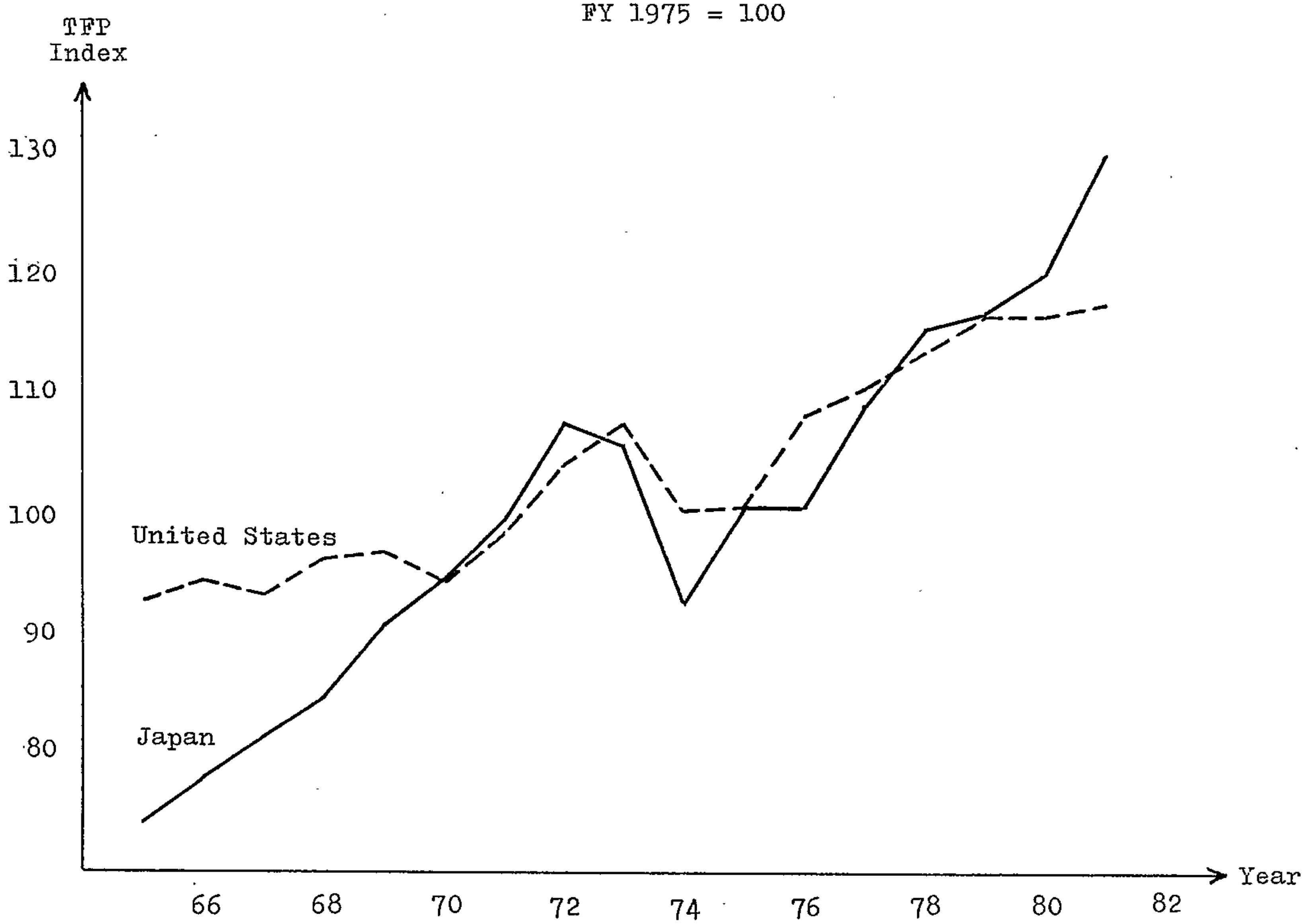
R&D costs of industries are financed by themselves and by the government. The amount financed by the government is politically determined and hence is taken as a policy variable (EG). Although it is not easy to suppose any definite model for basic R&D because of its nature of a social good, the amount of expenditure for applied R&D by private enterprises is thought to basically depend on total fund available for them and to tend to grow at an increasing rate as technological level goes up. That is,

$$(2.5) \quad EA_t = \alpha (EG_t + ER_t)^{\beta_0 + \beta_1 (\Delta T/T)} \cdot e^{u_t}.$$

(c) Introduction of foreign technology [equation (2)]

The post-war Japanese economy has grown owing to foreign technology, but nowadays the number of techniques introduced fron other countries is diminishing. The behavior of introducing foreign technology might depend upon technological gap between Japan and other industrialized countries as well as the current level of Japanese technology. We estimate the technological gap (TGAP) as difference of total factor productivities between Japan and the United States using the data appearing in Kendrick and Grossman [1980] for the United States economy. Figure 2 shows the estimated result of the gap between these two countries. The technological gap (TGAP) and the current level of technology (T) will explain the behavior of the Japanese economy about introduction of foreign technology, along with the current level of activity of the national economy, as follows:

Figure 2. Technological Gap between Japan and the United States
(Comparison of total factor productivities)
FY 1975 = 100



$$SN_t = \alpha + \beta\left(\frac{GDP_t + GDP_{t-1}}{2}\right) - \gamma T_t + \delta TGAP_t + u_t. \tag{2.6}$$

III. Results

Sixteen structural equations were estimated under the observed data from 1965 to 1981 using ordinary least squares method. Original data of R&D expenditures for basic and applied R&D were gathered starting off with those for 1959 and were used for working up the value of actual R&D efforts made by the Japanese economy to get to the current R&D output (PN_t) under the lag structure of Poisson distributions as explained in the preceding section.

We herein descibe the main results of estimation of individual equations and those of a final test of the entire model.

(i) Main structural equations

(a) Current R&D output (PN_t)

The behavior of industrial R&D activities was estimated under the assumption that it has suffered a substantial change with respect to the structure of R&D spectrum during this observation period. Before the so-called oil crisis of 1973 to 74, Japanese industries had been seen to attach importance to acquiring technology which produces an immediate effect to actual production. After that, however, they have been giving regard to basic R&D, as technological gap lessens between them and those in other technologically advanced countries.

The estimated equation explains that situation as follows:

$$(3.1)\quad \ln PN_t = \underset{(1.23)}{1.9545} + (\underset{(0.16)}{0.0759} + \underset{(6.30)}{1.5778}\, D_{74}) \ln(\sum_{\theta=0}^{n} p_\theta\, EB_{t-\theta})_{-1} + \underset{(1.85)}{0.6036} \ln(\sum_{\theta=0}^{n} q_\theta\, EA_{t-\theta})_{-1} - \underset{(-6.27)}{21.0167}\, D_{74}$$

$$R^2 = 0.993;\ D.W. = 1.395.$$

D_{74} is a dummy variable introduced so as to express the assumed structural change over the observation period and the summations of expenditures are conducted by going back to 1959. Parenthesized figures under estimated parameters in the equation mean t-statistics for the corresponding parameters, and R^2 and D.W. stand for coefficient of determination and Durbin-Watson ratio, respectively. (The same notations are used through this paper.)

After 1974, contribution of efforts for basic R&D to R&D output has changed to be significant and the equation has shifted downward as a whole, which tells that devising new techniques has gradually become difficult with heightening level of technology of Japanese industries.

(b) Expenditure for applied R&D (EA_t)

The amount of expenditure for applied R&D can be explained by the following equation according to the relation considered in the preceding section:

$$\text{(3.2)} \quad \ln EA_t = \underset{(-24.36)}{-\,3.1739} + (\underset{(154.74)}{1.1912} + \underset{(3.04)}{0.0374}\,\frac{\Delta T}{T})\ \ln(ER_t + EG_t)$$

$$R^2 = 0.9996;\ D.W. = 1.604.$$

Elasticity of expenditure for applied R&D with respect to total R&D fund is estimated as 1.1912 in a technologically stable state, that is, $T/T = 0$, and it grows at a marginal rate of 3.74 % as a rate of technological rate goes up.

On the other hand, no explicable relation could be obtained for the behavior of basic R&D and therefore in this model actual expenditure for it is tentatively treated as the rest of total R&D fund after deduction of expenditure for applied R&D.

(c) Introduction of foreign technology (SN_t)

It is natural that industries should rely largely upon foreign technology at their lower level of technology and that the degree of dependence should lessen as the difference of the levels diminishes. But it will still be true that growth of national economy itself asks for introduction of foreign technology because private enterprises seek profitable business opportunity more actively under such circumstances.

The relation is estimated as follows:

$$(3.3) \quad SN_t = -\underset{(-1.27)}{463.12} + \underset{(6.56)}{0.03769} \left(\frac{GDP_t + GDP_{t-1}}{2}\right) - \underset{(-4.42)}{0.03513}\, T_t + \underset{(1.08)}{6.00664}\, TGAP_t$$

$$R^2 = 0.876; \; D.W. = 1.628$$

where GDP_t stands for gross domestic production in year t. Technological standard attained in year t, T_t, is measured under definition,

$$(3.4) \quad T_t = 0.05933\, P_t + S_t.$$

In this equation, P_t and S_t are the numbers of techniques produced domestically (PN) and introduced from foreign countries (SN), respectively, accumulated over the observation period. That is,

$$(3.5) \quad P_t = \sum_{\theta=0}^{14} PN_{t-\theta}$$

$$(3.6) \quad S_t = \sum_{\theta=0}^{14} SN_{t-\theta}$$

The coefficient 0.05933 of the accumulated number of techniques, P_t, means average utilization ratio of patents in industries which is obtained from the Survey Report of Smaller Enterprises Agency [see Appendix B].

(d) Potential capacity of production ($PGDP_t$)

The potential GDP of the Japanese economy is estimated on the basis of a macro-production function obtained as

$$(3.7) \quad \ln\left(\frac{GDP_t}{\rho_t \bar{L}_t}\right) = \underset{(-0.94)}{-0.31437} + \underset{(7.86)}{0.49156} \ln\left(\frac{\kappa_t K_t}{\rho_t \bar{L}_t}\right) + \underset{(3.91)}{0.19211} \ln T_t$$

$$R^2 = 0.992; \text{ D.W.} = 1.652.$$

This function is of ordinary Cobb-Douglas type and the estimation was carried out under the condition that elasticities of production with respect to capital (0.49156) and to labor (0.50844) sum up to one. Elasticity of GDP with respect to technological level is estimated as 0.19211.

The potential capacity of production can be calculated by putting a utilization ratio of capital at one and a working time index at the possible maximum working time index ρ^* which is obtained by connecting indeces in peak load years. The potential capacity estimates (PGDP) thus obtained give data for differences between supply and demand of the national economy (GDP) together with the data of actual GDP.

(ii) Final test of the entire model

The estimated results of the model appear all together in Appendix A. The values of current endogenous variables were calculated simultaneously for each year from 1966 to 1981 using the values of endogenous variables for the initial year 1965 only and those of exogenous variables for each year. The summary of the results is presented in

Table 1, showing average percentage errors of calculated values against actual observed values.

Reviewing the whole results, it appears that the structure of R&D activity of Japanese industries is desribed in a fairly satisfactory way in this model because the values of endogenous variables concerning the number of patents (PN, N, SN, and S) and those of expenditures for R&D (ER, EB, and EA) could be estimated to the degrees of accuracy of less than five and ten percent of errors, respectively, except the number of techniques introduced from foreign countries. In particular, the accuracy of the estimated number of patents applied for (PN) leads to desirable estimation of technological level (T) (its absolute percentage error is only 1.15 %), which brings an acceptable estimation of macro-production function of the Japanese economy.

Table 1. Average Percentage Errors between Calculated and Observed Values in Final Test

Main Current Endogenous Variables	Average Percentage Errors
PN: Number of patents applied for	4.25
N: Number of stock of patents	1.02
SN: Number of techniques introduced from foreign countries	10.22
S: Number of stoch of foreign techniques in Japan	1.67
T: Technological level	1.15
TGAP: Gaps in technology	34.67
T/T: Rate of technological progress	7.42
K: Gross capital stock	2.22
I: Gross fixed investment	13.07
IP: Gross fixed investment for preventing of polution	11.62
J: Change in inventries	30.72
X: Export	6.12
M: Import	3.82
C: Consumption	1.50
p_c: Consumer price index	10.60
p_x/p_w: Ratio of export price index to world trade price index	3.60
PGDP: Potential GDP	1.27
GDP: Actual GDP	3.02
GAP: Gaps between supply and demand	43.25
ER: Expenditure for R&D	8.77

EB: Expenditure for basic R&D	3.32
EA: Expenditure for applied R&D	7.57

IV. Concluding Remarks

In this paper, we have presented an econometric model of the basic structure of R&D activities of Japanese industries and of the Japanese economy influenced by the technological progress. By this statistical estimation, it was made clear that the behavior of Japanese industries concerning R&D has undergone a substantial change over these twenty years. That is, in the past, Japanese industries had attached so much importance to applied R&D in order to acquire techniques of immediate use, but they have been making greater effort to obtain new technological knowledge by themselves since the middle of the 1970's. It means that Japan's backwardness in industrial technology compared with the United States and other advanced industrialized countries has rapidly disappeared and that she has found found herself in the situation where she is obliged to develop new technology by her own efforts. Also, it has been shown by the estimated structural equations that Japanese industries have been faced with more difficulties of producing new techniques than ever.

In the aspect of the Japanese economy as a whole, the technological progress in Japanese industries has a favorable effect on it by lowering commodity price level on one hand, but it produces adverse effects on investment of equipment through a gap between supply and demand enlarged by heightened potential capacity or productivity on the other. Furthermore, augmented supply capacity relative to the national demand will necessarily tend towards greater amount of exports, which may produce serious international polical problems.

One of the important questions which remains unsolved in this paper is the behavior of Japanese industries in regard to basic R&D. As for basic R&D activities in industries, although some estimating efforts were made in this study, we could not obtain satisfactory results, because we have not yet been sufficiently prepared both in theory and in statistical materials. It remains to be a major task of the auther's subsequent researches.

Appendix A

System of Structural Equations

Note: Samples used for estimation	1965 to 1981
Method of estimation	Ordinary least squares
Figures in parentheses	t-statistics
R^2	Coefficient of determination
D.W.	Durbin-Watson ratio

(I) Behavioral and technical equations

(1) Current number of patents applied for

$$\ln PN = \underset{(1.23)}{1.9545} + (\underset{(0.16)}{0.0759} + \underset{(6.30)}{1.5778}\, D_{74}) \ln(\sum_{\theta} p_{\theta}\, EB_{t-\theta})_{-1}$$

$$+ \underset{(1.85)}{0.6036} \ln(\sum_{\theta} q_{\theta}\, EA_{t-\theta})_{-1} - \underset{(-6.27)}{21.0167}\, D_{74}$$

$$R^2 = 0.993;\ D.W. = 1.395$$

(2) Current number of techniques introduced from foreign countries

$$SN = \underset{(-1.27)}{-463.12} + \underset{(6.56)}{0.03769} \left(\frac{GDP + GDP_{-1}}{2}\right) - \underset{(-4.42)}{0.03513}\, T$$

$$+ \underset{(1.08)}{6.00664}\, TGAP$$

$$R^2 = 0.876;\ D.W. = 1.628$$

(3) Production function of national economy (to estimate PGDP)

$$\ln\left(\frac{GDP}{\rho \bar{L}}\right) = \underset{(-0.94)}{-0.31437} + \underset{(7.86)}{0.49156} \ln\left(\frac{\chi K}{\rho \bar{L}}\right) + \underset{(3.91)}{0.19211} \ln T$$

$$R^2 = 0.992;\ D.W. = 1.652$$

(4) Utilization ratio of gross capital stock

$$\chi = \underset{(61.58)}{0.9963} - \underset{(-7.76)}{1.6632}\ GAP$$

$$R^2 = 0.802;\ D.W. = 1.856$$

(5) Working time index

$$\ln \rho = \underset{(-3.43)}{-0.0161} - \underset{(-9.05)}{0.00496}\ (\bar{t} - 1966)$$

$$R^2 = 0.845;\ D.W. = 0.627$$

(6) Gross fixed investment excluding investment for prevention of pollution

$$I = \underset{(-0.38)}{-1639.5} + \underset{(2.10)}{0.21962} \left(\frac{GDP + GDP_{-1}}{2} \right) - \underset{(-0.21)}{0.01395}\ K_{-1}$$

$$- \underset{(-3.25)}{60686.6}\ GAP$$

$$R^2 = 0.970;\ D.W. = 1.312$$

(7) Change in inventries

$$J = \underset{(1.72)}{1483.8} - \underset{(-2.11)}{12861.0}\ GAP + \underset{(2.03)}{0.01345}\ GDP - \underset{(-1.81)}{1306.5}\ D_{74}$$

$$R^2 = 0.750;\ D.W. = 2.38$$

(8) Commodity exports

$$\ln \left(\frac{X_c}{RATE} \right) = \underset{(-5.07)}{-4.4218} + \underset{(10.14)}{1.8574} \ln \bar{t}_w - \underset{(-2.21)}{0.48314} \ln \left(\frac{p_x}{\bar{p}_w} \right)$$

$$- \underset{(-1.15)}{0.29721} \ln TGAP$$

$$R^2 = 0.987;\ D.W. = 1.864$$

(9) Export price index relative to that of world trade

$$\frac{p_x}{\bar{p}_w} = \underset{(0.41)}{0.0503} - \underset{(-1.16)}{0.56458}\, GAP + \underset{(10.52)}{0.95483} \left(\frac{p_x}{\bar{p}_w} \right)_{-1}$$

$R^2 = 0.958$; D.W. = 1.322

(10) Imports of goods and services

$$\ln M = \underset{(-13.83)}{-5.8356} + \underset{(36.70)}{1.3146} \ln GNP + \underset{(4.23)}{0.11432}\, \bar{Z}$$

$R^2 = 0.990$; D.W. = 1.434

(11) Personal consumption expenditure

$$C = \underset{(2.36)}{6377.01} + \underset{(1.35)}{0.17168} \left(\frac{GDP + GDP_{-1}}{2} \right) - \underset{(-0.94)}{57.706}\, p_c$$

$$+ \underset{(2.56)}{0.69969}\, C_{-1}$$

$R^2 = 0.995$; D.W. = 1.482

(12) Consumer price index

$$p_c = \underset{(2.21)}{51.736} - \underset{(-3.28)}{550.83} \left(\frac{\Delta T}{T} \right) + \underset{(5.87)}{0.000427}\, GDE$$

$R^2 = 0.948$; D.W. = 0.626

(13) Total R D expenditures financed by private enterprises

$$ER = \underset{(0.42)}{43665.5} + \underset{(1.66)}{5.5192} \left(\frac{GDP + GDP_{-1}}{2} \right) + \underset{(2.53)}{0.60523}\, ER_{-1}$$

$R^2 = 0.970$; D.W. = 0.816

(14) Applied R&D expenditure of the Japanese economy

$$\ln EA = \underset{(-24.36)}{-3.1739} + (\underset{(154.74)}{1.1912} + \underset{(3.06)}{0.0374} \left(\frac{\Delta T}{T} \right)) \ln(\overline{EG} + ER)$$

$R^2 = 0.9996$; D.W. = 1.604

(15) Total factor productivity of the United States

$$TFP_A = \underset{(23.68)}{56.94} + \underset{(17.27)}{0.03554}\ \overline{GNP}_A$$

$$R^2 = 0.961;\ D.W. = 1.450$$

(16) Total factor productivity of Japan

$$\ln TFP_J = \underset{(-5.11)}{-2.8108} + \underset{(12.99)}{0.6361} \ln T$$

$$R^2 = 0.918;\ D.W. = 0.644$$

(II) Identities

(101) Stock of new techniques developed in Japan

$$P = \sum_{\theta=0}^{14} PN_{-\theta}$$

(102) Stock of techniques introduced from foreign countries

$$S = \sum_{\theta=0}^{14} SN_{-\theta}$$

(103) Level of technology

$$T = 0.05933\ P + S$$

(104) Rate of technological progress

$$\frac{\Delta T}{T} = \frac{T - T_{-1}}{T_{-1}}$$

(105) Maximum trend of working time index

$$\rho^* = \exp(-0.004957\ (\bar{t} - 1966))$$

(106) Gaps between capacity output and actual demand

$$GAP = \frac{PGDP - GDP}{PGDP}$$

(107) Gross domestic expenditure

$$GDE = C + I + I_p + J + I_h + G + X - M$$

(108) Equilibrium between gross domestic product and expenditure

$$GDP = GDE$$

(109) Gross fixed investment adjusted for discrepancy between data sources (see Appendix B)

$$I^* = 0.94851\ I$$

(110) Capital consumption allowances

$$D = 0.05072\ K_{-1}$$

(111) Gross capital stock

$$K = K_{-1} + I^* - D$$

(112) Gross investment for prevention of pollution

$$I_p = \left(\frac{\bar{d}}{1 - \bar{d}} \right) \cdot I$$

(113) Basic R D expenditure of the Japanese economy

$$EB = \frac{1}{p_b} (\bar{p}_e\ (ER + \overline{EG}) - \bar{p}_a\ EA)$$

(114) Gaps in technological levels between the United States and Japan

$$TGAP = TFP_A - TFP_J$$

(115) Exports of goods and services

$$X = 1.1351\ X_c$$

Appendix B

List of Variables and Sources of Statistical Data

(I) Endogenous variables

PN: Number of patents applied for, in actual number, taken from Official Report of Patent Agency, Patent Agency (Government of Japan).

P: Stock of patents, in real number, calculated from equation (101).

SN: Number of techniques introduced from foreign countries, in actual number, taken from Annual Report of Introduction of Foreign Technology, Science and Technics Agency (Government of Japan).

S: Stock of techniques introduced from foreign countries, in actual number, calculated from equation (102).

ER: R&D expenditure financed by private enterprises, in 1975 million yen, taken from Report on the Survey of Research and Development, Science and Technics Agency.

EA: Applied R&D expenditure, in 1975 million yen, ditto.

EB: Basic R&D expenditure, in 1975 million yen, ditto.

T: Level of technology, in actual number, estimated from equation (103).

T/T: Rate of technological progress, in ratio, calculated from equation (104).

TFP_A: Total factor productivity index of the United States, 100 at 1975, calculated using data provided in Kendrick and Grossman [1980].

TFP_J: Total factor productivity index of Japan, 100 at 1975, estimated by the author.

TGAP: Gaps in technology between the United States and Japan, in differences of indeces, calculated by equation (114).

GDP: Gross domestic production, in 1975 thousand million yen, taken from Annual Report on National Accounts, Economic Planning Agency (Government of Japan).

PGDP: Ptential capacity output of GDP, in 1975 thousand million yen, estimated with the use of equation (3).

GAP: Ratio of difference between capacity output and actual demanf, calculated by equation (106).

K: Gross capital stock excluding equipment for prevention of pollution, in 1975 thousand million yen, calculated by equation (111).

$\varkappa$: Index of utilization ratio of capital equipmrnt, 1.00 at 1966, taken from Statistics of Ministry of International Trade and Industry, Ministry of International Trade and Industry.

ρ : Working time index, 1.00 at 1966, taken from Survey of Labor Force, Prime Minister's Office.

ρ^*: Maximum trend of working time index, estimated by connecting peak values of working time indeces 's.

I: Gross fixed investment excluding investment for prevention of pollution, in 1975 thousand yen, taken from Annual Report on National Accounts, Economic Planning Agency and from mimeographed material provided by Japan Development Bank.

I*: Gross fixed investment, in 1975 thousand million yen, taken from mimeographed material, Capital Stock of Private Enterprises, provided by Economic Planning Agency.

D: Capital consumption allowances for K, in 1975 thousand million yen, ditto.

I_p: Gross investment for prevention of pollution, in 1975 thousand million yen, taken from mimeographed material provided by Japan Development Bank.

GDE: Gross domestic expenditure, in 1975 thousand million yen, taken from Annual Report on National Accounts, Economic Planning Agency.

C: Personal consumption expenditures, ditto.

J: Change in inventries, in 1975 thousand million yen, ditto.

X: Exports of goods and services, ditto.

M: Imports of goods and services, ditto.

p_c: Consumer price index, in 100 at 1975, taken from Annual Report on Consumer Price Indeces, Bank of Japan.

p_x: Export price index, 1.00 at 1975, taken from Economic Statistics of Japan, Bank of Japan.

(II) Exogenous variables

L: Employment, in ten thousand persons, taken from Survey of Labor Force, Prime Minister's Office.

I_h: Residential construction, in 1975 thousand million yen, taken from Annual Report on National Accounts, Economic Planning Agency.

G: Government consumption expenditure, ditto.

X_c: Commodity exports, ditto.

EG: R D expenditure financed by the government, in 1975 million yen, taken from Report on the Survey of Research and Development, Science and Technics Agency.

GNP_A: Gross national product of the United States, in 1972 thousand million dollars, taken from Statistical Abstract of the United States, U. S. Department of Commerce.

d: Ratio of investment for prevention of pollution to gross investment including I_p, taken from mimeographed material provided by Japan Development Bank.

RATE: Exchange rate, in yen per dollar, taken from Economic Statistics of Japan, Bank of Japan.

t_w: Index of world trade, 100 at 1973, taken from Monthly Bulletin of Statistics, Unuted Nations.

p_w: Export price index of manufactured goods of eleven leading industrial countries, 100 at 1975, ditto.

p_e: Price index of total R&D expenditure, 100 at 1975, taken from White Paper of Science and Techniques, Science and Technics Agency.

p_b: Price index of basic R&D expenditure, ditto.

p_a: Price index of applied R&D expenditure, ditto.

t: Year.

D_{74}: Dummy variable explaining the effect of structural change during observation period; 0 for 1965 to 1973 and 1 for 1974 to 1981.

Z: Dummy variable explainig the effect of "oil crisis"; 1 for 1973 and 74, and 0 for others,

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