# Analysis of the effect of R&D investments on economic growth

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## 1. Introduction

The studies on the relationship between technological change and economic growth have started by the introduction of aggregate production function (Cobb & Douglas, 1928) which specifies the relationship between output and factors of production. The factors of production considered usually are capital and labour, and sometimes including technology. Since then, Abramovitz (1956), Kendrick (1956) and Slow (1957) included technological knowledge in the production function assuming that knowledge is growing with time, and that technical change is exogenous.

More recently, studies by researchers such as Griliches (1980), Mansfield (1980), Nadiri (1980) and Scherer (1982) derived estimates of total factor productivity

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growth using a Cobb-Douglas approach, and then regressed these estimates against various measures of innovation inputs, normally R&D expenditures, which are expressed either in an aggregated form or broken down into components such as basic and applied, private and government.

However, because of the limitation of mathematical methods, researchers concentrated on the relationship between one or two measures and productivity or economic growth. This may cause over- or under- estimate of the relationship due to unadequate modelling of all the factors involved. One of the reasons that the previous studies could not analyse simultaneously the relationship between various input measures and economic growth, is that there was no appropriate method to estimate these relationships. This paper analyses the effects of various R&D investments on the economic growth at national level, empirically based on the new growth theory. To this end, the relationships between various R&D investments and economic growth as well as the effect of social factors are analysed. Based on the results of the analysis, a simulation model is developed, which shows the relationship between R&D investments and economic growth rate, and verified by analysing the correlation between the actual economic growth rate and the estimated economic growth rate, using the data between 1981 and 1995 of the selected eight countries.

## 2. Analysis model proposed

In order to investigate the effects of R&D investments on the economic growth, an analytical model is proposed, as shown in Figure 1, that shows the process by which various R&D investments affect economic growth (Link, 1996, and Langlois and Robertson, 1996).

This model is based on the fundamental concept that; 1) some government R&D investments and policies stimulate business R&D investment, 2) government and business R&D investments affect economic growth after being influenced by social factors. Social factors are defined, in this paper, as those factors which influence the relationship between R&D input and economic output.

### *R&D inputs classified*

Figure 1 shows how various R&D inputs at time t affect economic growth. This model is divided into three stages as input, process and output. In the input stage, the inputs are classified into government level inputs and business level inputs at time t, and already existing R&D stock at time t.

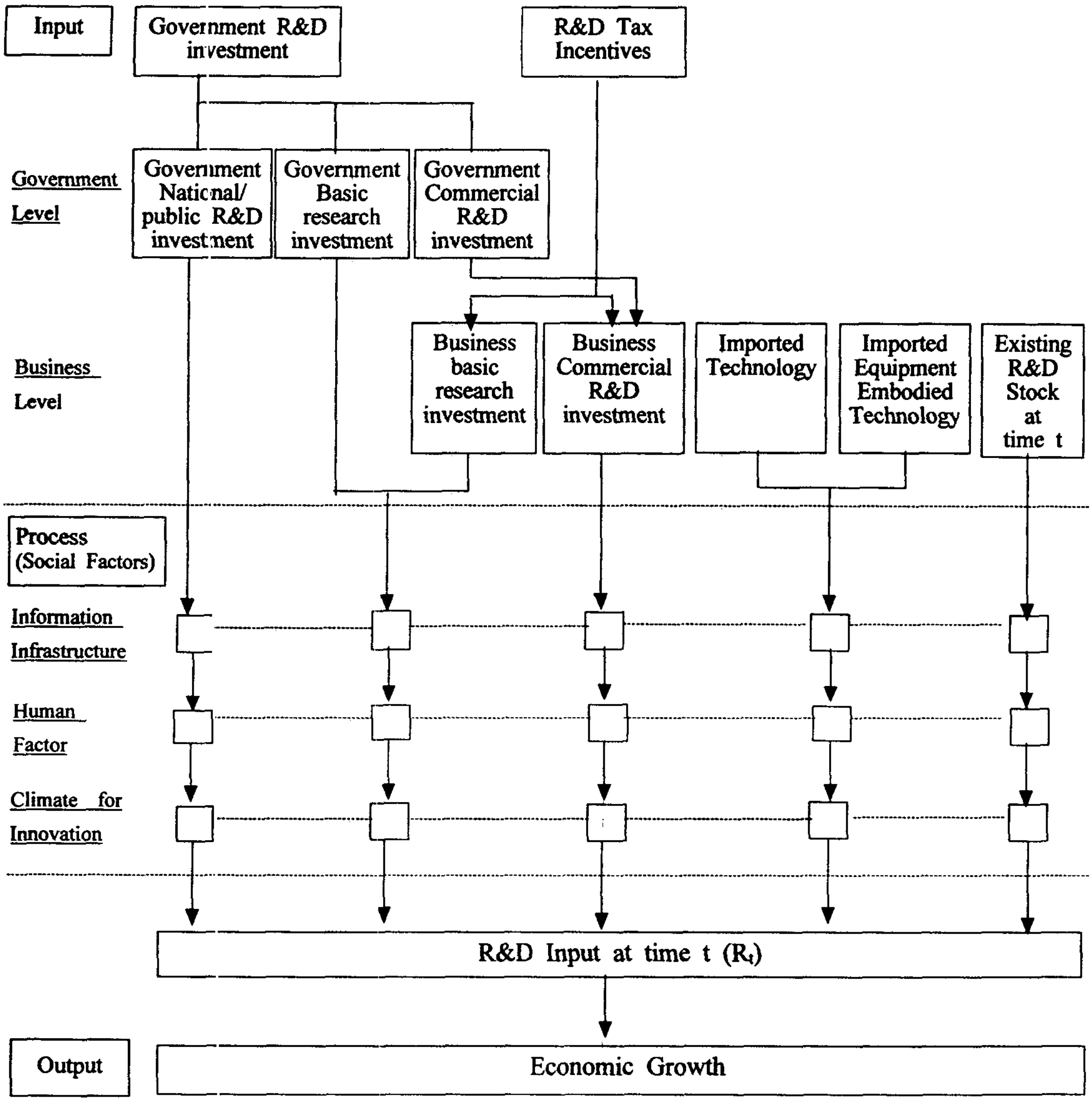
Inputs at government level are defined as ; 1) government R&D investment which is divided into national/ public R&D investment, basic research investment and commercial R&D investment; 2) R&D tax incentives. National/ public R&D means, in this paper, the research in the field of national security, public health improvement, transportation systems, environment, etc., which differs greatly from R&D for product development within private companies. The results of government national/ public can be used to strengthen national defence and to enhance public welfare by raising national security ability and public living standards. Basic research investment is the investment on basic research which is not for solving an immediate problem or for inventing a particular product. Commercial R&D is somewhere in between basic research and product commercialisation. Some type of commercial R&D may be extremely risky or have an especially large gap between private and social returns. This type of government support to industry makes the private companies more active in R&D investment by reducing the burden of the potential consequences of failure.

On the other hand, inputs at business level are defined as; 1) business basic research investment, 2) business commercial R&D investment which is being influenced by government funding in commercial R&D investment and R&D tax incentives, 3) imported technology, 4) imported capital goods with embodied technology.

To estimate the effects (rates of return) of government and business R&D inputs on economic growth efficiently, the various inputs of government and business sector are classified into following four inputs.

- government national/ public R&D investment (GRN),
- basic research investment (both from government and business sector) (BASIC)

〈Figure 1〉 Analytical Model




- business commercial R&D investment (BRC), and
- total imported technology (imported technology + imported equipment embodied technology) (ImpoT)

As shown in Figure 1, BRC consists of government and business sector R&D expenditure on commercial R&D. When estimating the rates of return of government commercial R&D investment (GRC) and business commercial R&D investment, the rate of return of business commercial R&D investment must be estimated to avoid double counting of the effect of government commercial R&D investment. The relationship between GRC and BRC can then be investigated.

Both imported technology (ImT) and imported equipment embodied technology (ImET) are considered together as a single input, as they have similar forms of technology transfer. ImT is expressed in terms of financial expenditure and can be easily obtained from published data, but ImET cannot be directly obtained from existing data. It must be calculated from the import data of a country. The key point in estimating ImET is to find out the magnitude of the R&D intensity of the imported capital goods. As far as the R&D intensities and the price of imported capital goods are known, the amount of R&D contained in the imported capital goods can be estimated. However, to find out the R&D intensities of every imported capital good is effectively impossible because it needs enormous quantities of data on R&D investment and turnover on products and producing companies abroad. Therefore, it is proposed to estimated ImET with the data on national R&D intensities of exporting countries and the amounts of imports of capital goods from those countries. ImET of a country is calculated as follow;

$$ImET = \sum_{k=1}^{n} \Sigma \; RI_k \, .Im_k \qquad (1)$$

where $RI_k$ is the R&D intensity of exporting country k (=R&D expenditure/GDP)
$Im_k$ is the amount of imported capital goods from country k
n is the number of countries to be considered (28 OECD countries are considered as major capital goods exporting countries)

### *Social factors considered*

Social factors considered in this paper are; 1) Human factors (HF), comprise the ratio of R&D personnel to population and the quality of labour force, 2) Information infrastructure (II), comprises R&D environment, and 3) Climate for innovation (CI), comprises incentives to researchers. Social factors are affected by government policies and endeavour, and the level of economic conditions of a country. Thus, these factors can be considered as arising from government policies.

HF, II and CI may be defined as follows;

HF = 1,000 RDP + SE
II = Telephone Line Density
CI = Research funds per researcher / GDP per head

where RDP is ratio of R&D personnel to population, SE is ratio of completed upper secondary education in population.

### *R&D Tax incentives*

The B-index Methodology (Warda, 1996) is used to compare the relative importance of R&D tax support across countries. However, in this paper, the inverse of the B-index is used as an index to show the level of government R&D tax incentives (TI) to business expenditure in R&D.

## 3. Analysis of the effect of R&D investments and social factors on economic growth

To analyse empirically the effects of R&D investments and social factors on economic growth, using the analytical model as shown in Figure 1, mathematical analyses on the following items are carried out. 1) Analysis of the relationship between various R&D investments and economic growth. 2) Analysis of the effects of social factors on the relationship between R&D investments and economic growth. 3) Analysis of the relationship between GRC and BRC, in order to investigate the effect of GRC on economic growth

To investigate the above mentioned analyses, Ordinary Least Square (OLS) method is pursued at the macroeconomic level, and the concept of total factor productivity (TFP) is used to quantify economic growth rate arising from all sources. In this paper, TFP is based on the concept that economic growth can be achieved by technological input as well as capital and labour inputs, and is generally defined as the ratio of output relative to inputs (capital and labour).

### *Basic mathematical model*

To derive the relationship between TFP growth and R&D, the extended form of Cobb-Douglas function is used.

$$Y_t = Ae^{\lambda t} R_t^{\gamma} K_t^{\alpha} L_t^{\beta} \tag{2}$$

where Y is output, A is coefficient, R is the R&D stock input, K is the capital input, L is the labour input, and $\gamma$, $\alpha$, $\beta$ are the output elasticities with respect to the inputs, R, K and L. The term $e^{\lambda t}$ is included to take account of effects on gross output, Y, which are not directly due to R, K and L.

The direct estimate of $\gamma$ in equation (2) needs R&D stock data that is impossible to calculate because its rate of depreciation and obsolescence are not known. It is proposed to adopt the following indirect approach to avoid difficulties in constructing consistent R&D stock data.

### *Estimate of TFP growth rate*

Using equation (2), TFP can be expressed as follows;

$$TFP = \frac{Y_1}{K_t^{\alpha}\ L_t^{\beta}} = A\,e^{\lambda t}\ R_t^{\gamma} \tag{3}$$

Taking the natural logarithm of the first two parts of equation (3), and then differentiating with respect to time, we obtain;

$$\frac{\dot{TFP}}{TFP} = \frac{\dot{Y}}{Y} - \alpha\frac{\dot{K}}{K} - \beta\frac{\dot{L}}{L} \tag{4}$$

where dot ( · ) denotes differentiation with respect to time.

*Estimate of the relationship between TFP growth rate and R&D investments*

Taking the natural logarithm and differentiating the first and third parts of equation (3) with respect to time, and applying the definition of the output elasticity of R&D stock, $\gamma$, we obtain;

$$\frac{\dot{TFP}}{TFP} = \lambda + \left(\frac{\partial Y}{\partial R}\right)\frac{\dot{R}}{Y} \equiv \lambda + \rho\frac{r_{total}}{Y} \qquad (5)$$

where $\rho$ is the rate of increase of real growth output to the increase of R&D stock or simply the rate of return on R&D expenditure, and $r_{total}$ is total annual R&D expenditure of a country.

The change of R&D stock between year t and year t-1 is not measured in currently available data. To make equation (5) calculable, the increase of R&D stock is replaced with the R&D investment of the year t ($r_{total}$) which is the only currently available data, assuming that the depreciation of R&D stock in the year t is negligibly small.

Since the model should represent the impact of various kinds of R&D investments, an extended model must be developed. To develop the extended model based on the identified four inputs, let

$$r_{total} = GRN + BRC + BASIC + ImpoT \qquad (6)$$

When equation (6) is applied to equation (2), economic output can be expressed as follows under the assumption that each R&D input factor has a different stock and a different elasticity.

$$\frac{\dot{TFP}}{TFP} = \lambda + \rho_{GRN}\frac{GRN}{Y} + \rho_{BASIC}\frac{BASIC}{Y} + \rho_{BRC}\frac{BRC}{Y} + \rho_{ImdpT}\frac{ImpoT}{Y} \qquad (7)$$

where $\rho_{GRN}$, $\rho_{BASIC}$, $\rho_{BRC}$, $\rho_{ImpoT}$ are rates of return of GRN, BASIC, BRC and ImpoT.

Equation (7) is the theoretical model in which the TFP growth rate is expressed as a function of various R&D intensities.

### *Estimate of effect of social factors*

In equation (5), the change of R&D stock at time t is assumed to be the same as the R&D investment at time t. However, R&D investment transforms into R&D stock after being influenced by the social factors of the society.

Thus, when each social factor is assumed to affect exponentially the relationship between R and $r_{total}$, and influences the other social factors, the change of R at time t of equation (5) is expressed as follows;

$$\dot{R} = B.(HF)^{kHF} \cdot (II)^{kII} \cdot (CI)^{kCI} \cdot r_{total} \tag{8}$$

where $k_{HF}$, $k_{II}$ and $k_{CI}$ are coefficients of HF, II and CI.

B is a time constant, which is included to take account of effects on the changes of R&D stock, which are not directly due to HF, II and CI.

When equation (8) is applied to equation (5), TFP growth rate can be expressed as follow;

$$\frac{\dot{TFP}}{TFP} = \lambda + \left(\frac{\partial Y}{\partial R}\right) \cdot B \cdot (HF)^{kHF} \cdot (II) \cdot (CI)^{kCI} \frac{\cdot\, r_{total}}{Y} = \lambda + \rho \frac{r_{total}}{Y} \tag{9}$$

Thus $\rho$ can be expressed as follow;

$$\rho = \left(\frac{\partial Y}{\partial R}\right) \cdot B \cdot (HF)^{kHF} \cdot (II)^{kII} \cdot (CI)^{kCI} = \rho_0 \cdot B \cdot (HF)^{kHF} \cdot (II)^{kII} \cdot (CI)^{kCI} \tag{10}$$

where $\rho_0 = \partial Y / \partial R$.

In order to estimate the values of $k_{HF}$, $k_{II}$ and $k_{CI}$, equation (10) can be decomposed into the R&D inputs, and the rates of return of R&D inputs considered here are expressed as follows;

$$\rho_{GRN} = \rho_{GRN0} \cdot B_{GRN} \cdot (HF)^{kHF} \cdot (II)^{kII} \cdot (CI)^{kCI} \quad (11)$$

$$\rho_{BASIC} = \rho_{BASIC0} \cdot B_{BASIC} \cdot (HF)^{kHF} \cdot (II)^{kII} \cdot (CI)^{kCI} \quad (12)$$

$$\rho_{BRC} = \rho_{BRC0} \cdot B_{BRC} \cdot (HF)^{kHF} \cdot (II)^{kII} \cdot (CI)^{kCI} \quad (13)$$

$$\rho_{ImpoT} = \rho_{ImpoT0} \cdot B_{ImpoT} \cdot (HF)^{kHF} \cdot (II)^{kII} \cdot (CI)^{kCI} \quad (14)$$

where $\rho_{GRN0}$, $\rho_{BASIC0}$, $\rho_{BRC0}$ and $\rho_{ImpoT0}$ are the real values of rates of return of GRN, BASIC, BRC and ImpoT, and $B_{GRN}$, $B_{BASIC}$, $B_{BRC}$ and $B_{ImpoT}$ are time constants.

Since the values of social factors are estimated at the national level in this paper, the effect of these social factors are assumed to be the same, regardless of R&D sectors and funding levels. Here, the coefficients, $k_{HF}$, $k_{II}$ and $k_{CI}$, show how much R&D related social factors affect economic growth of a country, and indicate the efficiency of social factors.

### *Relationship between GRC and BRC*

The relationship between BRC at time t, and GRC at time t, GDP at time t-1 and tax incentive is expressed as the following function, assuming that there exists a linear relationship between $BRC_t$, $GRC_t$ and $GDP_{t-1}$.

$$BRC_t = a_0 + a_1 GRC_t + a_2 GDP_{t-1} \quad (15)$$

$$a_2 = b_0 + b_1 TI \quad (16)$$

where $a_0$, $b_0$, are constants, $a_1$, $a_2$ and $b_1$ are coefficients of $GRC_t$, $GDP_{t-1}$ and TI.

## 4. Econometric analysis

The rates of return of various R&D investments of the selected countries during 1981 to 1995 are estimated using OLS method, and the coefficients of human factors, information infrastructure and climate for innovation are estimated based on the methodology developed here, and summarised in Table 1.

The countries selected for econometric analysis are U.S.A., U.K., France, Germany, Japan, Italy, the Netherlands and Spain. R&D and economic data, used to analyse empirically the effect of R&D investment on economic growth, are based on the data set from the Basic Science and Technology Statistics (OECD, 1995 and 1997a) and the National Accounts (OECD, 1998b) published by the OECD. The other data, which are additionally needed for the analysis, are collected from OECD's education and labour data books (1997b and 1998a), or each government's official data books (OST, 1997). The Software used for econometric analysis is the Excel software (version 5.0) of Microsoft Corporation.

### *Consideration of rate of return*

As shown in Table 1, the rates of return of BRC of Italy, the Netherlands and Spain are greater than 1. However, the contribution to economic growth(TFP growth rate in Table 1) of Italy and Spain arising from BRC is not so high compared with other countries. The average rate of return of BRC for the surveyed countries is estimated as 70.9 %.

U.K. and Spain have greater values of TFP growth rate by GRN than other countries, while France has a lesser value compared with its input. Most countries have invested between 0.2% to 0.3% of their GDP in GRN, and achieved between 0.05% to 0.1% of TFP growth rate due to their GRN. The average rate of return of GRN for the surveyed countries is estimated as 33 %.

The Netherlands and Germany have negative rates of return of BASIC, even though they have invested a greater amount of R&D funding in basic research than

〈Table 1〉 Estimated results of selected countries

| | U.S.A. | U.K. | France | Germany | Japan | Italy | Netherlands | Spain |
|---|---|---|---|---|---|---|---|---|
| Rate of return of BRC | 0.495<br>(2.43) | 0.611<br>(1.27) | 0.965<br>(2.98) | 0.599<br>(1.84) | 0.656<br>(3.14) | 1.253<br>(1.31) | 1.486<br>(1.89) | 1.235<br>(0.3) |
| BRCr | 0.0145 | 0.0139 | 0.0131 | 0.0174 | 0.0174 | 0.0062 | 0.0095 | 0.0034 |
| TFP growth rate by BRC | 0.0091 | 0.0085 | 0.0126 | 0.0104 | 0.0114 | 0.0077 | 0.0142 | 0.0042 |
| Rate of return of GRN | 0.073<br>(0.053) | 0.824<br>(0.55) | 0.077<br>(0.099) | 0.204<br>(0.066) | 0.156<br>(0.11) | 0.351<br>(0.12) | 0.347<br>(0.13) | 2.108<br>(0.22) |
| GRNr | 0.0025 | 0.0032 | 0.0044 | 0.0021 | 0.0022 | 0.0017 | 0.0026 | 0.0012 |
| TFP growth rate by GRN | 0.0002 | 0.0026 | 0.0003 | 0.0004 | 0.0003 | 0.0006 | 0.0009 | 0.0026 |
| Rate of return of BASIC | 0.832<br>(0.23) | −1.684<br>(−0.39) | 0.024<br>(0.007) | −0.295<br>(−0.115) | −0.268<br>(−0.096) | −7.268<br>(−0.94) | −2.804<br>(−1.09) | 8.589<br>(0.47) |
| BASICr | 0.0013 | 0.0011 | 0.0015 | 0.0023 | 0.0015 | 0.0009 | 0.0028 | 0.0005 |
| TFP growth rate by BASIC | 0.0011 | −0.002 | 0.00003 | −0.0007 | −0.0004 | −0.0066 | −0.0079 | 0.0045 |
| Rate of return of ImpoT | −0.602<br>(−0.09) | −1.147<br>(−0.47) | −0.118<br>(−0.086) | −0.939<br>(−0.43) | 0.127<br>(0.05) | 0.903<br>(0.34) | 0.679<br>(0.58) | 0.848<br>(0.45) |
| ImpoTr | 0.0012 | 0.0039 | 0.0031 | 0.0051 | 0.0011 | 0.0024 | 0.0162 | 0.0068 |
| TFP growth rate by ImpoT | −0.0007 | −0.0045 | −0.0004 | −0.0048 | 0.0001 | 0.0022 | 0.011 | 0.004 |
| $k_{HF}$ | −0.042<br>(−0.02) | −0.12<br>(−0.43) | −0.63<br>(−0.07) | −0.29<br>(−0.35) | −0.77<br>(−0.10) | 0.05<br>(0.11) | 0.01<br>(0.003) | 0.22<br>(0.23) |
| $k_{II}$ | −0.45<br>(−0.08) | −0.003<br>(−0.01) | −0.14<br>(−0.07) | −0.15<br>(−0.21) | −0.34<br>(−0.05) | 0.12<br>(0.51) | −0.24<br>(−0.09) | 0.17<br>(0.31) |
| $k_{CI}$ | −0.20<br>(−0.05) | −0.09<br>(−0.49) | −0.57<br>(−0.27) | −0.2<br>(−0.52) | 0.01<br>(0.004) | 0.12<br>(0.78) | −0.02<br>(−0.03) | 0.28<br>(0.81) |

1) BRCr, GRNr, BASICr and ImpoTr represent the ratio of each R&D input to GDP and TFP growth rate by each R&D input is calculated according equation (9).

2) The t-values of the estimate are shown in parentheses

other countries. However, Spain has a high rate of return of BASIC compared to the input, possibly because of over-estimated TFP growth rate, or because of relatively low input of BASIC. Among the countries, only U.S.A., France and Spain have positive rates of return from their basic research investments.

The Netherlands, Spain, Italy and Japan have achieved positive TFP growth rate in proportion to the amount of ImpoTr. The ImpoT represents the technological demand of the business sector. Thus countries, which have large ImpoT demand, invest relatively small amounts of funds on BRC. Accordingly, the countries which have achieved considerable amount of TFP growth rate by ImpoT, like the Netherlands, Spain and Italy, have a greater ratio of ImpoT with respect to BRC than other countries.

### *Coefficients of social factors*

When the coefficient of a social factor has a positive value, the change of R&D stock increases due to the increase of the value of the social factor (refer to equation 8). On the other hand, when the coefficient of a social factor has a negative value, the change of R&D stock decreases due to the increase of the value of the social factor.

As shown in Table 1, the U.S.A., U.K., France, Germany and Japan have negative coefficient of HF. The values of HF of these countries are greater than the other countries which have positive coefficient of HF. The magnitude of the negativeness or the positiveness of the coefficient depends on the relationship between the increase or decrease rate of HF and TFP growth rate. Thus, it can be explained that the value of HF of the countries, which have negative coefficient of HF, are reached its mature stage. In the case of the Netherlands, the value of coefficient of HF is near zero (0.01). Thus it can be said that this country is well keeping the moderate level of HF compared with their economic growth.

Countries which have large negative value of $k_{II}$ (such as U.S.A.) can be considered to have invested much in the information infrastructure compared with their economic growth for the concerned period. It appears that these countries have invested to meet the steeply-increasing, anticipated, future demand on information infrastructure or as a leisure facility.

On the other hand, in the case of the countries which have a negative relationship, but the value of $k_{II}$ is almost zero (such as U.K.), it is believed that appropriate levels of investment on II was attained during the examined period. However, in the case of the countries which have a positive values like Italy and Spain, these countries need continuous increase of II in order to maintain their economic growth.

As shown in Table 1, U.S.A., U.K., France, Germany and the Netherlands have negative values of $k_{CI}$, while Japan, Italy and Spain have positive value. The value of CI of the surveyed countries is generally decreased. The countries, which have positive coefficient of CI, show less decrease rate than the other countries. In the case of U.S.A., the coefficient of CI is estimated to have a negative value, even though the changes of CI is not so high. It means that this country is sensitive for the changes of CI. On the other hand, the coefficient of CI of Spain is estimated to have a positive value, even though the changes of CI is rather high. Thus, it can be explained that Spain is not sensitive to the changes of CI.

### *Relationship between BRCt, GRCt and $GDP_{t-1}$*

The relationship between $BRC_t$, $GRC_t$ and $GDP_{t-1}$ are estimated, and the results are shown in Table 2.

〈Table 2〉 The relationship between BRC, GRC and GDP.

| BRCt | Coefficient of GRCt | Coefficient of GDPt-1 | Coefficient of GDPt-1 including TI |
|---|---|---|---|
| U.S.A. | 1.1074<br>(5.837) | 0.0198<br>(12.384) | -0.0006 + 0.0197 TI<br>(-0.887) (13.962) |
| U.K. | 1.1418<br>(2.213) | 0.0201<br>(6.175) | 0.0201 TI |
| France | 0.5732<br>(2.53) | 0.0239<br>(25.063) | -0.0013 + 0.0254 TI<br>(-2.575) (24.45) |
| Germany | 3.5085<br>(0.873) | 0.0156<br>(1.746) | 0.00001 + 0.0163 TI<br>(0.062) (35.34) |
| Japan | 20.9<br>(1.83) | 0.0217<br>(6.75) | 0.00036 + 0.0209 TI<br>(4.877) (131.95) |
| Italy | 1.824<br>(5.815) | 0.0081<br>(6.487) | 0.00008 + 0.0083 TI<br>(2.5) (114.54) |
| Netherlands | 1.9094<br>(6.019) | 0.0091<br>(7.387) | 0.0082 TI |
| Spain | 3.2518<br>(6.678) | 0.0051<br>(6.289) | -0.0021 + 0.0061 TI |

The figures in parentheses refer to the t-values

The meaning of the coefficient of GRC is explained as follows; When a government investment in GRC is 1, BRC increases by the amount of the coefficient. However, since BRC consists of GRC and commercial R&D investment by business sector, the real increase rate of business sector commercial R&D investment by GRC become; the coefficient of GRC - 1.

Accordingly, in the case of U.K., when the government invests £1.00 of its R&D fund to the business sector, the business sector increases its R&D investment by as much as £0.14. Japan has an extraordinarily large ratio of BRC to GRC compared with other countries. This can happen when the government relies on policy support to the business sector rather than direct R&D. The value of coefficient of France is less than 1. It is probable that some part of the business sector's R&D is relying on government R&D investment. This situation usually happens when the government is leading some part of R&D investment and/or participating actively in business sectors R&D.

The relationship between BRC and GDP shows how much the business sector reinvests of their output in R&D. Technologically advanced countries, such as U.S.A., U.K., France, Germany and Japan, have invested more than 1.5% of their ratio of BRC with respect to GDP, while Italy, the Netherlands, and Spain have invested less than 1% of their ratio.

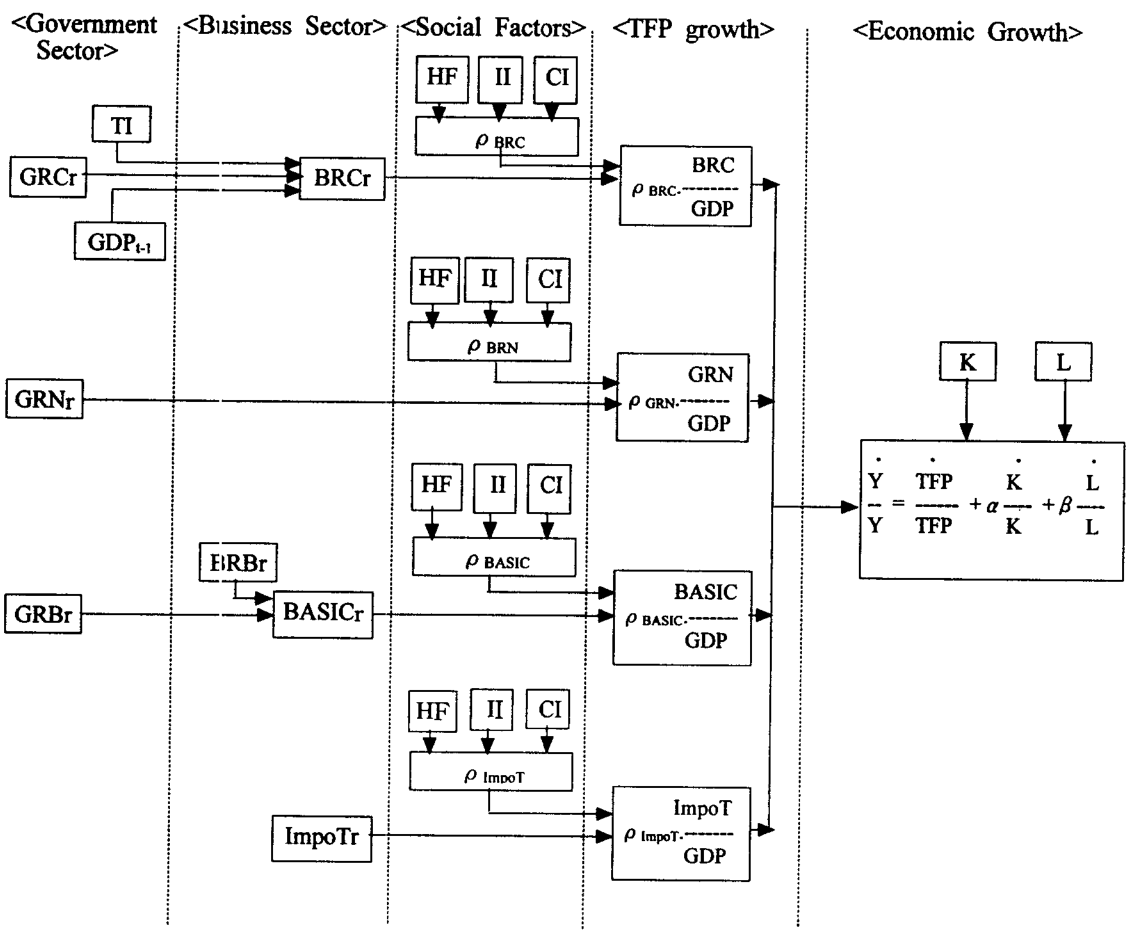
The estimate of the relationship between BRC and GDP including tax incentives is also shown in Table 2. The country which has the highest slope, in accordance with the changes of TI, is France. This means that the amount of their business sector's R&D investment is most greatly influenced by the government TI measure among the countries examined.

### *Simulation model development*

Based on the estimated results, a simulation model is developed and is shown in Figure 2. This simulation model can apply to all countries, when appropriate coefficients, estimated using the data of each country, are put into the equations of the model.

The simulation model validated by investigating the correlation between the

〈Figure 2〉 Simulation model




actual economic growth rates and the estimated economic growth rates. The correlation between these two values (actual value and estimated value) summarised in Table 3.

〈Table 3〉 Correlations between estimated and real GDP growth rates

| Country | U.S.A. | U.K. | France | Germany | Japan | Italy | Netherlands | Spain | Average |
|---|---|---|---|---|---|---|---|---|---|
| Correlation coefficient | 0.938 | 0.861 | 0.863 | 0.975 | 0.962 | 0.832 | 0.737 | 0.888 | 0.882 |

The average correlation between estimated and real GDP growth rate of the countries considered is about 0.882. This average value of correlation is an acceptable value demonstrating the accuracy of the simulation model. Thus, the developed simulation model may be used to analyse the relationship between R&D inputs and economic growth rate.

## 5. Conclusions

The purpose of this work is to investigate the effects of various R&D investments on the economic growth. To this end, the following key points have been identified; 1) Relationship of R&D inputs classified into government sector R&D inputs and private sector R&D inputs. 2) Estimates of rates of return of various R&D investments. 3) Analysis of the effect of government R&D input on private sector R&D. 4) Analysis of the effect of the social factors which affect the relationship between R&D inputs and economic growth.

Based on the above analysis, this paper found that; the average rate of return of BRC for the surveyed countries is estimated as 70.9%, and that of GRN is estimated as 33%. The three countries, U.S.A., France and Spain have achieved positive rates of return from their basic research investments. On the other hand, Japan, Italy, the Netherlands and Spain have achieved positive rates of return from their imported technology, while U.S.A., U.K., France and Germany could not achieve economic growth from ImpoT.

From the analysis of the effect of social factors on the relationship between R&D investments and economic growth, I found that; the coefficients of social factors of the most technologically advanced countries, such as U.S.A., U.K., France, Germany, have negative values indicating that the increases of social factor during the surveyed period were sufficient and not advisable to maintain the present increase rate. In the case of Japan, the coefficients of HF and II have negative values, while the Netherlands have negative values of II and CI. However, in the case of Italy and Spain, the coefficients of all social factors were estimated to have positive values, meaning the values of social factors are advisable to increase for further economic development.

From the results above, a simulation model was developed, and verified by investigating the correlation between the actual and the estimated economic growth rate. The average correlation was estimated about 88.2% which is an acceptable value demonstraing the accuracy of the model.

However, the time-lag effect, which is naturally believed to exist between the R&D input and the economic growth, could not be analysed in a mathematical form, because of the lack of the data for this relationship. In order to take account of this effect, when estimating the relationship between them, the time-lag effect in this relationship was included implicitly by using the data of last fifteen years.

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