THE IMPACT OF TECHNOLOGICAL CHANGE ON ECONOMIC GROWTH IN THE MANUFACTURING SECTOR OF KOREA

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Thesis submitted to the Faculty of
the Virginia Politechnic Institute and State University
in partial fulfillment of the requirements for the degree of

MASTER OF ARTS

in

Economics

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May, 1994

Blacksburg, Virginia

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(ABSTRACT)

The relationships between technological change and economic growth, and research and development and economic growth in the manufacturuing sector of Korea were investigated. This study was based on an analysis of capital and labor input, research and development(R&D) stock, productivity and output data for the period of 1971-1989.

The effects of technological change and other factor inputs on economic growth were examined using ordinary least squares regression and generalized least squares in the Cobb-Douglas production function. As expected, the results indicated that there is a significant relationship between technological change and output growth. A strong relationship was also found between Research and Development(R&D) and output growth. And the results indicate that R&D stock accumulated domestically has a positive correlation with the stock of imported technology.

The rate of return to R&D investment was estimated 64 percent and was reduced to 20 percent with consideration of the time lag between R&D investment and the application and commercializtion of the R&D innovation. The rate of return to imported technology stock was found larger than that of R&D stock accumulated domestically.

A description of the theoretical framework, the methodology applied, and the detailed results is included.

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CHAPTER ONE

INTRODUCTION

There is an emerging order of competition in the world economy today. Increasing attention is being given both by industry and government to new sources and policies to stimulate technological change. Important decisions are being made all over the world regarding strategies and policies for technology-based economic growth. As innovation is the launching point for technology-based competition, research and development is increasingly the key element in competitive strategies.

From a purely economic point of view, technological advancement contributes to economic growth through the commercialization and use of inventions providing economic benefits from the sale of new products and services, and lower costs of production technology can be solely process or product technique related- hence it lowers prices of existing products or services. While the importance of technology is recognized well, it is difficult to measure the contribution of technology or to quantify effectively its impact on economic growth because technological progress is determined by diverse factors, and the underlying process that characterizes technological progress is complex. Many attempts, however, have been made to explain the growth in the measured productivity of traditional factors of production by incorporating research resources in the production function and social accounting frameworks. There are many empirical studies that concluded that technological change and industrial research and development(R&D) investments contributed significantly to productivity growth.

In contrast, less attention in Korea has been paid to the contribution of technological change to economic growth, few efforts have been made empirically to measure the effects of technological change because it has been argued that behind the high economic growth in Korea was the rich endowment of human resources(well-educated and movtivated manpower) rather than technological progress.

The aim of this paper is to assess whether or not there exists a significant relationship between technological change and economic growth in the manufacturing sector of Korea. I estimate the rate of technological change by decomposing output growth into its various sources. First, I construct the aggregate production function and then examine technological change and other input factors in the given production function and their contributions to economic growth. I also measure the rate of research and development (R&D) in the form of a stock of technological knowledge and the rate of return to R&D. I undertake this investigation utilizing not only domestic R&D investment data but also royalty payment data for imported technologies by industry as the two major R&D inputs, reflecting the fact that the importation of technology has played an important role in Korea's high rate of technological change hence the resulting rapid economic growth.

I will test the hypothesis that R&D expenditure increased output, as measured by stock of technological knowledge. I will then test the hypothesis that imported technology has a strong relationship with R&D expenditures. I will also compare the impact of technological change and other input factors in the Korea's production function with those in some other countries.

CHAPTER TWO

SOME ASPECTS OF THE RELATION BETWEEN TECHNICAL CHANGE AND ECONOMIC PERFORMANCE

The Impact of Technical Change

It is useful to detail briefly some of the changes that an economy is likely to experience as new technology is introduced. Basically the prime outcome of technological advance is considered to be improvements in economic welfare. However, there are numerous areas where technology would have an impact. Just to list some of them, one may consider that technology will have some impact on :

productivity,

employment,

investment,

trading performance,

income distribution,

the quality of goods,

economic growth,

inflation,

the environment,

security and defence,

and the industrial structure of an economy.[1]

1 Stoneman, P., The Economic Analysis of Technology Policy : Clarendon Press, Oxford, 1987, 14-34.

This paper will be restricted to just two aspects of performance : output and productivity.

Studies on the Contribution of Technical Change to Economic Growth

First-generation Studies

Modern work on the contribution of technical change to economic performance was initiated by three almost contemporaneous studies of the US economy by Solow (1957), Abramovitz (1956), and Fabricant (1954), of which that by Solow has probably been the most influential. Looking at the non-farm American economy over the period 1909-1949 , he postulated that the output(Q) of the economy was related to its inputs of labor(L), capital(K), and time(t) according to a Cobb-Douglas production function with constant returns to scale like (1).

$$Q_t = Ae^{\lambda t}K_t^{\alpha}L_t^{\beta} \tag{1}$$

where λ is the rate of disembodied technical change, α and β are the elasticities of each input and A is a constant specifying the initial output level. Assuming capital and labor are paid their marginal products, α can be measured by capital's share in national income. With this estimate of α one can calculate the importance of time in the determination of output by accounting for what is due to increases in K and L and attributing the residual to time. From (1), using the dot convention for a derivative with respect to time, one may derive (2).

$$\lambda = \frac{\dot{Q}}{Q} - \alpha\frac{\dot{K}}{K} - (1-\alpha)\frac{\dot{L}}{L} \tag{2}$$

By the use of readily available data on Q, K, and L, one may estimate λ, the residual (also known as the rate of growth of total productivity). Solow's estimates using (2) imply that λ = 1.5 percent per annum, that is in the absence of changes in K and L, the output of the non-farm American economy could have grown at about 1.5 percent per annum. Based on this finding he concluded that about 90 percent of the observed increase in output per man was attributable to residual or time factor and only about 10 percent to increases in capital per man.[2]

Matthews (1964) presented information on the importance of the residual for the United Kingdom using a similar approach. He attributed to the residual the following percentages as contributions to the growth of real GDP; 1856-99, 45 percent; 1899-1913, -18 percent; 1924-37, 25 percent; 1948-62, 46 percent.

Denison (1962) suspected the equating of the residual with technical change. The residual could contain a number of important influences on productivity growth. He attempted to break down the residual into its constituent parts. By doing so, he was left with a result that, in the US, 'advances in knowledge' (his term for technical change) were responsible for about 40 percent of total increase in national income per head, but 40 percent is still a significant contribution.

Jorgenson (1987) and Maddison (1987) have substantially reduced the size of the residual by incorporating estimated changes in the quality of factor inputs.

Second-generation Studies

These studies move one stage further from the residual analysis by regarding technical change as a separate input into the production process. It is still

2 Solow,R.,"Technical Change and the Aggregate Production Function", the Review of Economics and Statistics, Aug.1957, Vol.39, No.3, 312-320.

allowed that some changes will take place as time advances, but what is concentrated on is R&D as a productive input. It is argued that R&D spending adds to a stock of knowledge *C*, and this stock of knowledge is an input into the production process, as are *K* and *L*. Knowledge is allowed to depreciate over time and thus *C* is calculated as a weighted sum of past R&D expenditures. It is then generally hypothesized that the production relationship can be written as (3) :

$$Q_t = Ae^{\lambda t} C_t^{\gamma} K_t^{\alpha} L_t^{\beta} \tag{3}$$

The unit of analysis is the firm, the industry, or the whole economy.

Early studies by Griliches (1980) or Mansfield (1968) on firm- or micro-level data of return on R&D expenditure are in the range of 30-45 percent. Starting basically from this work, a number of further studies have proceeded to refine the analysis, the approach, and the data, seeking further estimates of these rates of return. Griliches and Mairesse (1984) and Cuneo and Mairesse (1984) estimated an equation such as (3), and suggested that γ in the US and France is in the 0.08-0.15 range. Soete, Turner, and Patel (1983) estimate for different countries on time-series data for the 1960s and 1970s the following elasticities of output with respect to R&D; UK, 7-14 percent; US, 14 percent; Japan, 16 percent; France, 10 percent.[3)]

The results above enable one to draw a few preliminary conclusions. First, there is a considerable amount of evidence from different economies and different time periods to support the view that technological change is an important factor in the generation of econoic growth. Secondly, on the more restricted issue of

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3 Soete, L., Turner, R. and Patel, P., "R&D, International Technological Diffusion and Productivity Growth", mimeo, SPRU, University of Sussex, Aug., 1983.

the return to R&D, one can observe statistically significant positive relationships between R&D expenditures and economic growth at various different levels of aggregation.

Outline of Korea's Performance in Technical Change

Korea is not rich in natural resources. But Korea has experienced rapid economic growth and technology development since the early 1960s. The rapid growth of the Korean economy is known world-wide, and recognized as a successful model for other developing countries. Often referred to as export-led, the development strategy with strong government intervention transformed the economic base from agriculture to industry. It is the result of six consecutive five-year Economic Development Plans starting from 1962. In 1962, its economy was a typical underdeveloped one, as symbolized by a few economic indicators: $87 per capita GNP and $2.3 billion total GNP. In 1991 ending the sixth five-year economic development plan, Korea has shown $6,498 per capita GNP and $283 billion total GNP.

Korea's rapid progress may be attributed to a number of economic, technological, social and cultural factors. The most important of all may be the educated, motivated and diligent manpower, proactive and entrepreneurial top management, deliberate government policies and accumulated technological capability. Although accumulated technological capability, mostly obtaining from imitation and importation, has enabled Korea to assimilate, use, adapt or change technology and develop new products and process, until the 1970s, Korea had been a perfect example of imitative learning, simply relying on technology transfer and highly skilled manpower. In accordance with the growing needs of technology development, especially after the oil shocks and economic recession in the late 1970s, the government and private sector have strengthened their strategies to develop future-oriented, long-term, large-scale research and development projects.

Korea has drastically increased R&D investments to promote science and technology activities, recording remarkable achievements since 1980s. As a result, R&D expenditures of Korea reached $4.48 billion, 1.91 percent of GNP in 1990, up from $33 million, 0.38 percent of GNP in 1970. The total number of qualified scientists and engineers in Korea stood at 70,500, representing 16.4 persons per 10,000 population as of 1990, compared with 5,600 scientists and engineers and 1.7 persons per 10,000 population in 1970. More than 1,300 firms have their own R&D laboratories and more than 20 research institutes in the public sector support their innovation.

Science and technology activities have made significant improvements, however, the figures show that Korea is still short of high-caliber manpower and R&D investment, compared to those of advanced countries: R&D expenditure in 1989 ;U.S, $140.5 billion; Japan, $79.1 billion; West Germany, $34.5 billion; France, $22.5 billion; U.K, $18.4 billion; Italy, $10.7 billion and Korea, $4 billion :For R&D personnel in 1988; U.S, 949,000; Japan, 442,000; China, 410,000; Germany, 166,000; France, 115,000; U.K, 102,000; India, 85,000; Italy, 71,000 and Korea, 57,000.[4)]

4 Science and Technology Agency, Trend of Industrial Scientific Technology, Japan, 1991.

CHAPTER THREE

THEORETICAL FRAMEWORK

Productivity change is both the cause and the consequence of the evolution of dynamic forces operating in economic, technological progress. Its measurement and the interpretation of its behavior at the microeconomic and macroeconomic levels require the untangling of many complex factors. The issuses of productivity change are too numerous and too complex, and the available empirical evidence too sketchy (and often inconsistent) to allow bold conclusions about the measurement- and the determinants- of changes in productivity. This chapter comprises measures of productivity, a brief review of the theoretical models that enable us to calculate technological change and a theoretical framework concerning the rate of return to research and development investment.

Measurement of Factor Productivity

Productivity is often measured as a ratio of output to inputs. There are as many indices of productivity as there are factors of production. While each index has its own use, the most important and most often used are the partial productivity indices of labor and capital and the total or multifactor productivity index. The former indices are simply the average products of labor, or capital, while total factor productivity, often referred to as the "residual"[5] or the index of

5 Domar, E.,"On the Measurement of Technological Change",Economic Journal,Dec. 1961,Vol. 71, No.284,710-726.

"advance of knowledge"[6] or "coefficient of ignorance"[7] or "technical change"[8], is defined as output per unit of labor and capital combined. Symbolically, these indices are

(a) Partial indices: $AP_L = Q/L$, $AP_K = Q/K$

(b) Total productivity index: $A = Q/(aL + bK)$

where Q, L, and K are respectively, the aggregate level of output, labor, and capital inputs; a and b are some appropriate weights. There are many ways of measuring total factor productivity, but the two indices most often used in empirical research are Kendrick's arithmetic measure (1961) and Solow's geometric index (1957).

Kendrick approches measurement of dA/A using a distribution equation. He implicitly assumes a homogeneous production function and the Euler condition to obtain the following measure.

$$\frac{dA}{A} = \frac{Q_1 / Q_0}{(wL_1 + rK_1)/(wL_0 + rK_0)} - 1$$

where w and r are the wage rate and the rate of return on capital respectively, and variables with the subscript 1 refer to the current period and those with the subscript 0 refer to the base period. In empirical estimates the weights for calculating the total factor productivity are often permitted to change smoothly over time.

Solow's measure is based on the Cobb-Douglas production function with

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6 Denison, E., Why Growth Rates Differ?, Washington D.C., Brookings Institution, 1967.

7 Aramovitz, M., "Resource and Output Trends in the U.S. Science 1870", American Economic Review, May 1956, Vol.46, No.2, 5-23.

8 Solow, R., 312-320.

constant returns to scale and autonomous and neutral technological change, i.e.,

$$\frac{dA}{A} = \frac{dQ}{Q} - [\alpha \frac{dL}{L} + \beta \frac{dK}{K}], \beta = 1 - \alpha.$$

where α and β are the shares of labor and capital and dQ, dL, and dK are the time derivatives of Q, L, and K. Under the assumption of competitive equilibrium the Kendrick measure of his total factor productivity equation above can be stated as

$$\frac{dA}{A} = \frac{Q_1 / Q_0}{\alpha_0(L_1/L_0) + \beta_0(K_1/K_0)} - 1$$

This is equal to Solow's measure for small change in the quantities of inputs and outputs[9].

Technical Change and Production Function

As mentioned earlier, the productivity indices are deduced either from an explicitly defined production function or from a distribution theory where the production function is implicit. Thus the accurate specification of the form and estimation of the parameters of the production function, such as α and β in the equation above are crucial to the measurement of these indices.

The Solow Model

Consider the aggregate, two-factor, two-differentiable production function. If Q represents output and K and L represent capital and labor inputs, then the aggregate production function can be written as $Q = F(K, L; t)$ and the production function with neutral technical change takes the special form

9 Nadiri, M. I., "Some Approaches to the Theory and Measurement of Total Factor Productivity: A Survey", Journal of Economic Literature, Vol. 8, No. 4(Dec.), 1970, 1137-1177.

$Q = A(t)f(K, L)$. The variable t appears in F to allow for technical change and the multiplicative factor $A(t)$ measures the acumulated effect of shifts over time.[10] Differentiating totally with respect to time and dividing by Q, one obtains

$$\frac{\dot{Q}}{Q} = \frac{\dot{A}}{A} + A\frac{\partial f}{\partial K}\frac{\dot{K}}{Q} + A\frac{\partial f}{\partial L}\frac{\dot{L}}{Q}$$

where dots indicate time derivatives. Defining $w_k = \frac{\partial Q}{\partial K}\frac{K}{Q}$ and $w_L = \frac{\partial Q}{\partial L}\frac{L}{Q}$ the relative shares of capital and labor, substituting in the above equation and then,

$$\frac{\dot{Q}}{Q} = \frac{\dot{A}}{A} + w_k\frac{\dot{K}}{K} + w_L\frac{\dot{L}}{L} \tag{4}$$

From time series of $\dot{Q}/Q$, w_K, $\dot{K}/K$, w_L, and $\dot{L}/L$ or their discrete year to year analogues, one can estimate $\dot{A}/A$ and $A(t)$ itself. Let $Q/L=q$, $K/L=k$, $w_L=1-w_K$: Note that $\dot{q}/q = \dot{Q}/Q - \dot{L}/L$ etc., and the above equation becomes

$$\frac{\dot{q}}{q} = \frac{\dot{A}}{A} + w_K\frac{\dot{k}}{k} \tag{4.1}$$

Now all we need to disentangle the technical change index $A(t)$ are series for output per man hour, capital per man hour, and the share of capital. So far neutral technical change has been assumed, but if we go back to the original production function and carry out the same reasoning as the very like (4.1), namely

$$\frac{\dot{q}}{q} = \frac{1}{F}\frac{\partial F}{\partial t} + w_k\frac{\dot{k}}{k} \tag{4.2}$$

$\dot{F}/F$ is constant in time, say equal to a, then $A(t)=e^{at}$ or in discrete approximation

10 For simplicity, time subscripts have been omitted throughout the paper except where necessary.

$A(t)=(1+a)^t$.[11]

Suppose $A(t)$ increases exponentially every year and then the Solow Model is defined as $Q=Ae^{\lambda t}K^{\alpha}L^{\beta}$ where λ is the rate of disembodied technical change and α and β are the output elasticities of each input. With assumption of constant returns to scale, that is $\alpha+\beta=1$, we can transform the function in terms of output per unit of labor input taking natural logarithms to obtain

$$\ln (Q/L) = \ln A + \alpha \ln (K/L) + \lambda t$$

(5.1)The generalized function which doesn't assume the constant returns to scale is

$$\ln Q = \ln A + \alpha \ln K + \beta \ln L + \lambda t \qquad (5.2)$$

We can calculate the rate of technical change and its concentration to economic growth(output) with λ and the economic effect of the factor inputs such as capital(K) and labor(L) on economic growth with the parameters, α and β.

The Johansen Model

One of the problems in empirical growth studies is that of obtaining appropriate statistical information about capital accumulation. Usually the figures used do not correspond to the definition of capital which would be most relevant for analyses of production, and the figures are unreliable measurements of what they should measure according to their definitions. For this reason Johansen presented a model which employs only figures for income shares and increases in labor productivity rather than employing capital figures. The method introduces some more restrictive theoretical assumptions.[12] It assumes (i) a production function of

11 Solow, R., 312-320.

12 Johansen, L., "A method for separating the Effects of Capital accumulation and Shifts in production functions upon Growth in Labor Productivity," Economic Journal, Vol.71, No.284, Dec.1961, 775-782.

the Cobb-Douglas type, (ii) constant factor shares, (iii) neutral technological change, (iv) cost minimization by each producer and (v) the same relative increase in wage rates in all industries.[13] The defining equation of the model is derived as follows :

By assumption (i), $X_{it}=A_{it}N_{it}^{\alpha_i}N_{it}^{\beta_i}$ (6.1)

where X_{it} is the output of the *i*th industry at time *t*; A_{it}, technological change; N_{it}, labor input; K_{it}, capital input; α_i, labor share; and β_i, capital share. Labor productivity(a_{it}) can thus be expressed as $a_{it}=X_{it}/N_{it}=A_{it}N_{it}^{\alpha_i-1}K_{it}^{\beta_i}=A_{it}[K_{it}/N_{it}]^{\beta_i}$ (6.2)

When two periods are compared, equation (6.2) gives

$$\frac{a_{i2}}{a_{i1}} = \frac{A_{i2}}{A_{i1}}\left[\frac{K_{i2}/N_{i2}}{K_{i1}/N_{i1}}\right]^{\beta i} = \frac{A_{i2}}{A_{i1}}\left[\frac{K_{i2}/K_{i1}}{N_{i2}/N_{i1}}\right]^{\beta i} \quad (6.3)$$

By assumption (iv), let W_{it} be the wage rate, and R_{it} , rate of return to capital $W_{it}N_{it}\ /\alpha_i = R_{it}K_{it}\ /\beta_i$ (6.4)

When two periods are compared, (6.4) gives $W_{i2}N_{i2}\ /W_{i1}N_{i1} = R_{i2}K_{i2}\ /R_{i1}K_{i1}$ (6.5)

or

$$\frac{K_{i2}\ /\ N_{i2}}{K_{i1}\ /\ N_{i1}} = \frac{W_{i2}\ /\ W_{i1}}{R_{i2}\ /\ R_{i1}} = w_i \quad (6.6)$$

where, wi is the increase in wage relative to the rate of return to capital. By assumption (v), $w_1=w_2=w$. Substituting (6.6) into (6.3), $a_{i2}/a_{i1}=(A_{i1}/A_{i1})\ w^{\beta}$(6.7) Take the natural logarithm of equation (6.7), $\ln(a_{i2}/a_{i1})=(\ln\ w)\beta_i+\ln(A_{i2}/A_{i1})$ (6.8)

Let $e_i=\ln(A_{i2}/A_{i1})$, then $\ln(\ a_{i2}/a_{i1})=(\ \ln w\ )\beta_i + e_i$ (6.9)

Equation (6.9) is the defining equation. Since ln w and e_i can be obtained by regression, the effect of capital accumulation on labor productivity can be measured

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13 Minimize; $C=P_L.L+P_K.K$, subject to $Q=f(L,K)$. Solving the minimization by Lagrangian, we get $P_L/P_K = MP_L\ /MP_K$.

by anti-ln of (ln $w.\beta_i$)-1, and the disembodied technical change, by the anti-ln of e_i-1. This method cannot be applied to single industries. It requires cross section data for a set of several industries. Hsia(1973) estimated the rate of technological change and technology diffusion in the manufacturing sector of Hong Kong by this model.

Technical Change and R&D Expenditure

The theoretical model underlying the analysis of the effects of industrial research and development(R&D) on the economic growth treats the R&D capital as a third input in addition to the labor and capital inputs. The possible contribution of R&D expenditure to growth and the rate of returns to R&D investments have been discussed in three ways: analyzing the relationship between labor productivity and knowledge(R&D) capital stock estimating the marginal rate of R&D capital stock with respect to labor productivity (Griliches and Mairesse, Terleckyj, Jorgenson), measuring the total factor productivity from the production function and estimating the rate of returns to R&D expenditure rather than R&D stock by means of R&D expenditure ratio to output (Mansfield), and setting the general relationship between the level of output and variables affecting the output level and estimating the coefficients from the regression model directly without the specific production function (Leonard). I will concentrate on the first two approaches which deal with the conventional three - input Cobb-Douglas production function.

The Griliches Model

Griliches and Mairesse(1984) estimated the contribution of private R&D spending to productivity performance, using the Cobb-Douglas production function:

$$Q \quad = \quad Ae^{\lambda t}K^{\alpha}L^{\beta}R^{\gamma} \qquad (7)$$

or in log form:

$$\ln Q = \ln A + \lambda t + \alpha \ln K + \beta \ln L + \gamma \ln R \quad (7.1)$$

where (in addition to already defined symbols) K is physical capital stock; R is R&D capital stock. With constant returns to scale ($\alpha+\beta+\gamma=1$) equation (7) and (7.1) transformed:

$$q=Ae^{\lambda t}k^{\alpha}r^{\gamma} \quad (7.2)$$

and $$\ln q = \ln A + \lambda t + \alpha \ln k + \gamma \ln r \quad (7.3)$$

where $q=Q/L$, $k=K/L$, $r=R/L$ (output, physical and knowledge capital per capita)

Marginal product of R&D capital stock is defined as the increment in value added generated by a marginal increase in R&D capital stock, i.e., $\partial Q/\partial R$.

By differentiating (7) with respect to R, we obtain $\partial Q/\partial R=\gamma(\overline{Q/R})$ (7.4) where γ is the coefficient of R(R&D stock) in the production function and ($\overline{Q/R}$) is the average ratio of value added to R&D capital stock in sample periods.

Previously, other researchers have presented $\partial Q/\partial R$ as the private marginal rate of return to R&D investments. In estimating the private marginal rate of return based on the formula (7.4), they implicitly assumed that the R&D investments instantaneouly yielded the return with no lag. Pakes and Schankerman (1984) first pointed out this problem and corrected the private rate of return to investment in research to consider the proper R&D lags.[14] In general the private

14 Pakes, A. and Schkerman, M., "The rate of Obsolescence of Patents, Research Gestation Lags, and the Private Rate of Return to Research Resources", in Zvi Griliches, (ed.), R&D, Patents and Productivity, University of Chicago Press, 1984, 73-88.

internal rate of return is found by solving the following equation for r :

$$e^{\theta r}(r+\delta) - \partial Q/\partial R = 0 \qquad (7.5)$$

where θ, δ and r are mean R&D lag, the rate obsolescence of knowledge and the private (internal) rate of return to R&D investment, respectively.

<u>The Mansfield Model</u>

Mansfield (1980) introduced a method which could analyze the effect of R&D expenditure on total factor productivity without using the stock of R&D capital. He used essentially the same model as that employed by Griliches(1980) and Terleckyj(1974), except that research and development is disaggregated into two parts: applied R&D and basic research. The production function is assumed to be:

$$Q_t = A\ e^{\lambda t}\ R_{tb}^{\alpha 1}\ R_{ta}^{\alpha 2}\ L_t^{\beta}\ K_t^{1-\beta} \qquad (8)$$

where Q is value added, R_b is the R&D expenditure on basic research and R_a is the expenditure on applied R&D. The annual rate of change of total factor productivity is:

$$\rho = \lambda + \theta_1 \frac{dR_{tb}/dt}{Q_t} + \theta_2 \frac{dR_{ta}/dt}{Q_t} \qquad (8.1)$$

where θ_1 is the marginal rate of R&D expenditure on basic research $(\partial Q_t/\partial R_{tb})$ and θ_2 is the marginal rate of expenditure on applied R&D $(\partial Q_t/\partial R_{ta})$. 15)

Griliches(1980) also presented the similar approches regarding total factor productivity(TFP) and the marginal rate of returns to R&D stock. That is,

$$TFP\ (\rho) = \lambda + \gamma\ (\dot{R}\ /\ R) = \lambda + \delta\ (\ I_r\ /\ Q_t\ ) \qquad (8.2)$$

15 Mansfield,E.,"Rates of Return from Indusrial Reseach and Development",American Economic Review, Vol.55, No.2,May 1965,310-322.

where TFP(ρ) is total factor productivity,δ is the marginal rate of R&D stock, R is R&D stock, I_r is net expenditure on R&D and (I_r / Q_t) means the ratio of R&D expenditure to output (R&D intensity).[16] Then data for total factor productivity and R&D intensity are needed to estimate the marginal rate of R&D stock.

16 Griliches, Z., "Research Expenditures and Growth Accounting", Technology, education, and productivity, Basil Blackwell Inc., 1988, 244-267.

CHAPTER FOUR

METHODOLOGY

To estimate the empirical technical change and its contribution to economic growth, I used the model developed by Solow. It appears to be more suitable for the purpose of this studies than the method using total factor productivity by Kendrick or using labor productivity by Johansen. While Kendrick's model needs the ratio of compensation of employees to national income as a weight of total factor productivity, compensation of employees in Korea has some limitations on estimating technical change because the low wage rate, manuplated by the government's strategy for export-led development based on low wage rate, underestimated the weight of labor earnings in national income. Namely, a relatively low wage rate could cause a distortion in labor earnings and overestimation of capital earnings and technological change. In the Johansen model, one of the assumptions is a uniform relative increase in wage rates in all industries, which proved invalid empirically on the basis of the inter-industry wage pattern in Korea.

Construction of Aggregate Production Function

Before going on to estimate technical change in a production function, a specific production function should be determined first. I estimated technical change without a specific production function, using Solow's residual concept for technical change with the assumption of neutral technical change and constant factor share. The production function was constructed based on the estimated value.

Calculation of Technical Change[17)]

From the Solow's equation for technical change $\dot{q}/q = \dot{A}/A + w_k \dot{k}/k$ three time series are needed to compute technical change : output per unit of labor, capital per unit of labor and the share of capital. I used Gross Domestic Product for measure of aggregate output. Capital input was measured by employed capital stock, that is capital stock multiplied by operation ratio, because what belongs in a production function is capital in use, not capital in place. I used net capital stock estimated by the Korean Industrial Bank and Hak-Kil Pyo. Labor input was calculated by total average hours worked per year, which is employed labor force multiplied by total working hour per year. The share of capital series came from [1-employment costs to gross value added] in annual report on Financial Statements Analysis by the Bank of Korea, which means 1- share of labor in income. In addition, this study covers only manufacturing sector. This is an advantage (1) because it skirts the problem of measuring government output and (2) because eliminating service sector is at least a step in the direction of homogeneity. The results of calculation are given in Table 1. Thence, by arbitrarily setting $A(1971)=1$ and using the fact that $A(t+1)=A(t)(1+dA(t)/A(t))$ the $A(t)$ time series can be constructed. Figure 1 shows $A(t)$, a profile of technical change.

The over-all result for the whole 19 years is an average upward shift of about 2.4 percent per year. This may be compared with a figure of about 1.5 percent per year obtained by Solow by the same method, for the period 1909-1949. While Solow's figures covered private non-farm economic activity in the U.S,

17 Solow, R.M., ibid, 312-317.

this paper covers manufacturing sector of Korea for the period of 1971-1989 . Over the 19 year period output per man hour approximately tripled. At the same time the cumulative upward shift in the production function was about 50 percent. The real GDP per man hour increased from 1126.91 won to 3213.81 won. Dividing the latter figure by 1.52538, which is the 1989 value for A(t), and therefore the full shift factor for the 19 years. The result is a "corrected" GDP per man hour, net technical change, of 2106.89 won. Thus 979.98 won out of 2086.90 won can be imputed to increased capital per man hour, and the remainder, 1106.92, to icreased productivity.

In summary, the upward shift in the production function was, apart from fluctuations, at the rate of about 2.4 percent per year. The gross output per man hour tripled over the interval, with 53 percent of the increase attributable to technical change and the remaining 47 percent to increased capital intensity. Solow attributed 87.5 percent of the increase to technical change and 12.5 percent to increased use of capital. Fabricant has estimated that over the period 1871-1951 about 90 percent of the increase in output per capita is attributable to technical progress.

Table 1

Calculation of A(t)

YEAR	Q(1)	L(2)	K(3)	MH(4)	OR(5)	q(6)	k(7)
1971	4083.1	1336.0	15592.1	226.0	0.693	1126.91	2982.23
1972	4625.7	1445.0	19135.3	224.4	0.728	1188.78	3580.10
1973	5953.7	1774.0	21890.2	223.2	0.763	1253.02	3515.16
1974	6918.4	2012.0	24684.6	216.9	0.757	1321.10	3568.23
1975	7749.7	2205.0	27719.5	219.2	0.730	1336.15	3488.81
1976	9576.2	2678.0	31714.6	228.2	0.821	1305.83	3550.54
1977	11017.6	2798.0	37122.5	229.8	0.847	1427.94	4075.13
1978	13335.2	3016.0	44579.3	230.0	0.916	1601.98	4905.56
1979	14721.7	3126.0	52826.5	225.7	0.851	1738.82	5309.82
1980	14611.6	2972.0	59153.5	230.6	0.763	1776.67	5488.02
1981	16055.2	2872.0	65208.3	233.1	0.772	1998.52	6266.32
1982	17131.2	3047.0	72062.7	233.4	0.763	2007.39	6442.89
1983	19768.5	3275.0	80198.1	236.1	0.832	2130.52	7191.16
1984	23195.7	3351.0	89772.5	235.8	0.885	2446.29	8378.90
1985	24846.0	3504.0	99682.1	233.5	0.870	2530.60	8832.92
1986	29390.8	3826.0	111219.6	237.7	0.908	2693.12	9253.62
1987	34903.3	4416.0	124556.9	234.6	0.938	2807.55	9397.93
1988	39592.2	4667.0	140876.8	228.6	0.922	3092.53	10145.54
1989	41064.8	4840.0	161909.8	220.0	0.890	3213.81	11277.53

NOTES AND SOURCES :

Column(1): Gross Domestic Product, in billion won(1987value), from Bank of Korea, National Accounts, selected years.

Column(2): Labor force employed, 1,000 persons, from Ministry of Labor, Labor Statistics Yearbook, selected years.

Column(3): Capital Stock(net), in billion won(1987value), from Korea Industrial Bank and Pyo, Estimates of Capital Stock and Capital/Output Coefficients by Industries for the Repubic of Korea.

Column(4): Total Average Hours Worked per Month, from Ministry of Labor, ibid.

Column(5): Manufacturing Operation Ratio, from Bank of Korea, Economic Statistics Yearbook, selected years.

Column(6): GDP per Man Hour(1987value), q=(1)/{(2)*(4)*12}.

Column(7): Employed Capital per Man Hour(1987value),k={(3)*(5)}/{(2)*(4)}.

YEAR	kK(8)	lL(9)	dq(10)	dk(11)	w_k(12)	dA/A(t)(13)	A(t)(14)
1971	10805.3	3.6232	157.528	337.499	0.588	0.07324	1.00000
1972	13930.5	3.8911	61.867	597.862	0.619	-0.05133	1.07324
1973	16702.2	4.7515	64.246	-64.935	0.672	0.06369	1.01816
1974	18686.2	5.2368	68.074	53.072	0.623	0.04226	1.08300
1975	20235.2	5.8000	15.048	-79.419	0.592	0.02474	1.12877
1976	26037.7	7.3334	-30.315	61.730	0.574	-0.03319	1.15669
1977	31442.8	7.7158	122.106	524.587	0.524	0.01806	1.11830
1978	40834.6	8.3242	174.046	830.425	0.488	0.02603	1.13849
1979	44955.4	8.4665	136.840	404.261	0.497	0.04086	1.16813
1980	45134.1	8.2241	37.850	178.202	0.490	0.00539	1.21586
1981	50340.8	8.0336	22.844	778.296	0.525	0.04580	1.22242
1982	54983.8	8.5340	8.877	176.572	0.516	-0.00972	1.27840
1983	66724.8	9.2787	123.121	748.272	0.520	0.00368	1.26597
1984	79448.7	9.4820	315.775	1187.743	0.509	0.05693	1.27063
1985	86723.4	9.8182	84.310	454.016	0.517	0.00674	1.34297
1986	100987.4	10.9133	162.521	420.705	0.533	0.03611	1.35203
1987	116834.4	12.4319	114.433	144.310	0.530	0.03262	1.40085
1988	129888.4	12.8025	284.975	747.607	0.511	0.05449	1.44655
1989	144099.7	12.7776	121.279	1131.987	0.488	-0.01125	1.52538

NOTES AND SOURCES :

Column(8): Employed Capital, in billion won, kK=(3)*(5).

Column(9): Total Hours Worked per year, in billion M-H, lL=(2)*(4)*12.

Column(10):Change in GDP per Man Hour.

Column(11):Change in Employed Capital per Man Hour.

Column(12):Share of Property in Income, (1-Share of Labor in Income), from Bank of Korea, Financial States Statistics.

Column(13):dA/A=(10)/(6)-(12)*(11)/(7).

Column(14):From(13).

All data are related to the Manufacturing Sector.

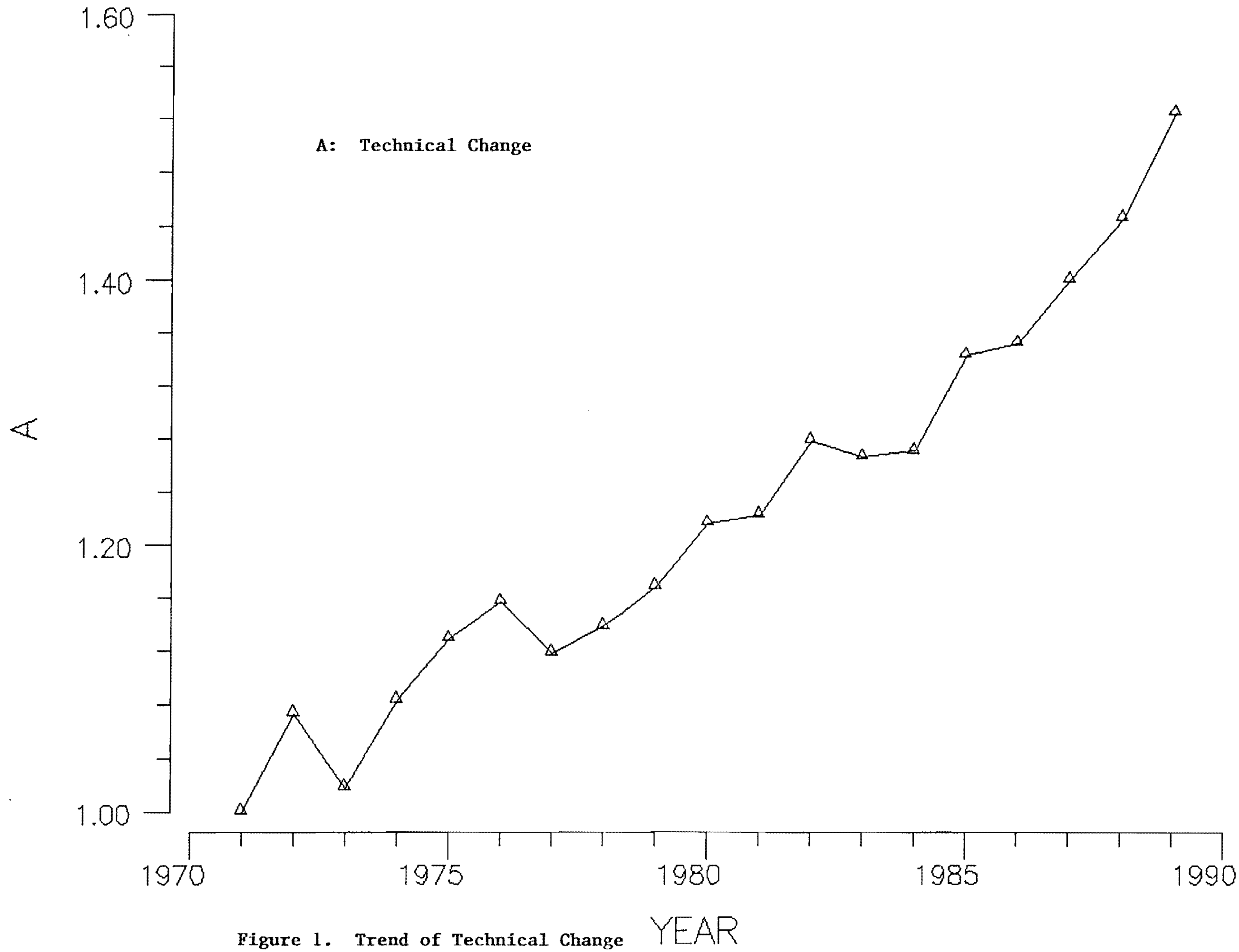

Figure 1. Trend of Technical Change

Aggregate Production Function

The aggregate production function takes the special form $Q=A(t)f(K,L)$ or simplified form $q=A(t)f(k,1)$. If one simply plots Q or q against K, $k(=K/L)$ or year, one would get a distorted picture because of the shift factor $A(t)$. As denoted by QA in Figure 2, the aggregate production function isolated from technical change can be obtained from Q divided by $A(t)$ or equivalently q divided by $A(t)$. Technical change is the difference between Q and QA in Fig.2. To construct the aggregate production function, I limited myself to two parameter families of curves, linear in the parameters (for computational convenience) and at least capable of exhibiting diminishing returns. The particular possibilities tried were the following:

$$q/A = \alpha + \beta \ln k + \varepsilon \quad \text{(semilog)}$$

$$q/A = \alpha - \beta \, (1/k) + \varepsilon \quad \text{(reciprocal)}$$

$$\ln (q/A) = \alpha + \beta \ln k + \varepsilon \quad \text{(loglinear)}$$

$$\ln (q/A) = \alpha - \beta \, (1/k) + \varepsilon \quad \text{(logreciprocal)}$$

Loglinear form is Cobb-Douglas case; reciprocal and logreciprocal have upper asymptotes; the semilogarithmic and the reciprocal must cross the horizontal axis at a positive value of k and continue ever more steeply but irrelevantly downward. The regression results of fitting these curves are shown in Table 2.

Curve	α	β	R^2	Durbin-Watson
semilog	-5523.37	819.16	0.9746	1.9414
reciprocal	2389.24	-4329170	0.9223	0.9274
loglinear	2.7670	0.5273	0.9805	2.7121
logreciprocal	7.8673	-2820.55	0.9503	1.4729

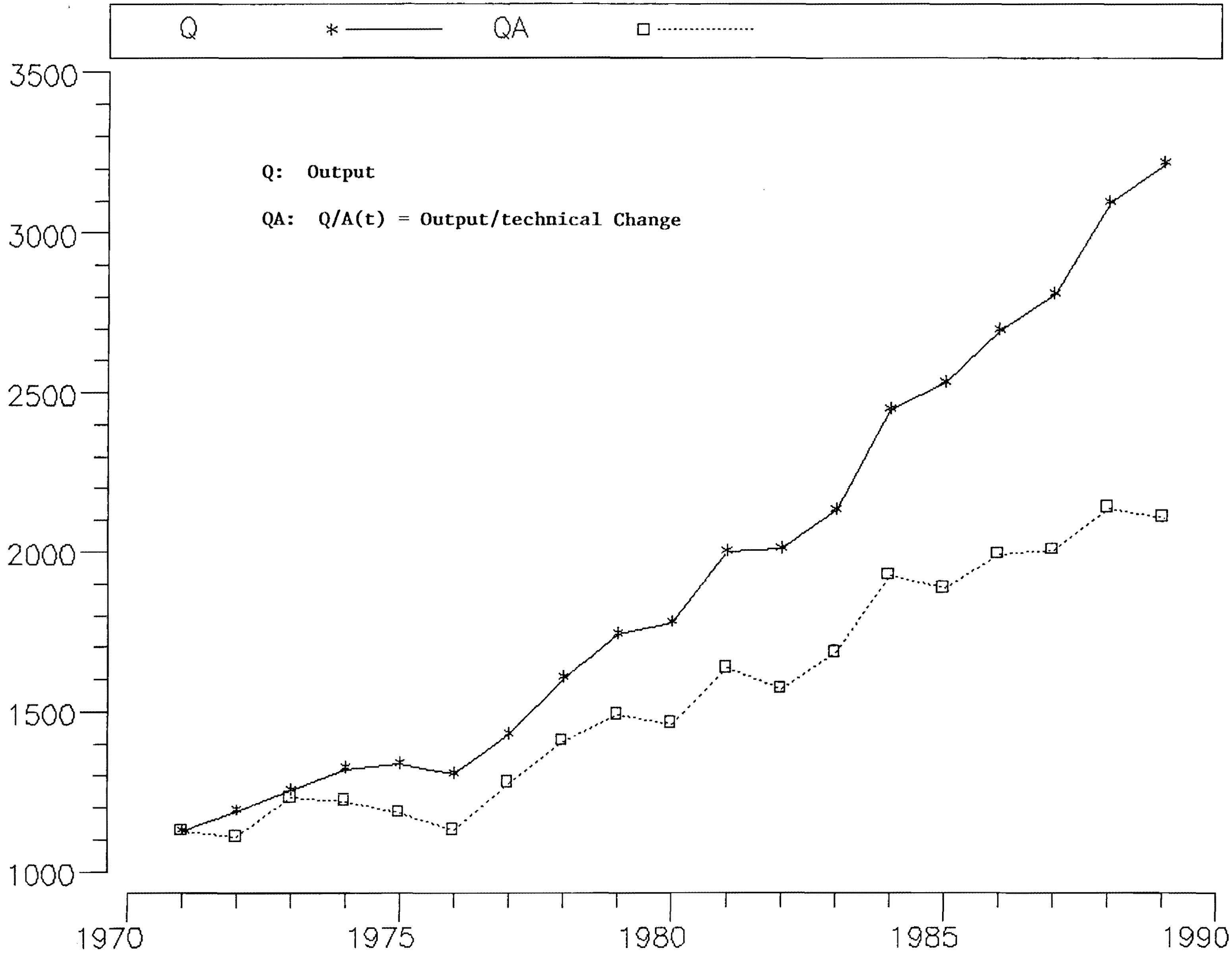

Figure 2. Technical Change and output

Table 2

Regression Results of Output on Capital Input

	semilog	reciprocal	loglinear	logreciprocal
Variable				
constant	-5523.37	2389.24	2.7670	7.8673
(standard error)	(277.2)	(63.24)	(0.1558)	(0.0324)
ln *k* (*k*=*K*/*L*)	819.16	-	0.5273	-
(standard error)	(32.03)		(0.0180)	
1 / *k* (*k*=*K*/*L*)	-	-4329170	-	-2820.55
(standard error)		(304700)		(156.3)
R - squared	0.9746	0.9223	0.9805	0.9503
D-W Statistic	1.9414	0.9274	2.7121	1.4729
F-statistic	653.91	201.86	857.58	325.59
(p-value)	(0.0000)	(0.0000)	(0.0000)	(0.0000)
Observations	19	19	19	19
Degrees of freedom	17	17	17	17
Sum of Squared Residuals	59245	181616	0.01872	0.04779
Standard Error of Regression	59.034	103.35	0.0332	0.0530

The coefficients of determination are uniformly so high that it is not easy to select the best fitting, but it appears that the Cobb-Douglas function (loglinear) is a bit better than the others in terms of the Durbin-Watson statistic and R^2.[18]

Recalculation of Technical Change in the given Production Function

I reestimated technical change in the production function using the Solow Model discussed in the previous chapter. I regressed output per man-hour on technical change and capital input per man-hour in the production function $(\dot{q}/q) = (\dot{A}/A) + \alpha(\dot{k}/k)$ with assumption of constant returns to scale(Model 1). And then I regressed output on technical change, capital input and labor input in the production function $(\dot{Q}/Q) = (\dot{A}/A) + \alpha(\dot{K}/K) + \beta(\dot{L}/L)$ without assumption of constant returns to scale(Model 2). The regression results of both cases are shown in Table 3. Estimates of a constant and the coefficients in the two models could be obtained by least squares, the results being

$$(\dot{q}/q) = \underset{(0.0131)}{0.0325} + \underset{(0.1473)}{0.4078}(\dot{k}/k) \quad \text{(Model 1 : } \alpha+\beta=1) \qquad (9.1)$$

*standard error in parenthesis

$$(\dot{Q}/Q) = \underset{(0.0160)}{0.0281} + \underset{(0.1240)}{0.4777}(\dot{K}/K) + \underset{(0.1193)}{0.4355}(\dot{L}/L) \quad \text{(Model 2 : } \alpha+\beta\neq 1) \qquad (9.2)$$

*standard error in parenthesis

Although Model 1 doesn't have as high a coefficient of determination, 0.3108 as that of 0.7737 in Model 2 the coefficients in the two models are statistically significant at the 0.05 level. F-statistics in both models are significant at the 0.02 level and the Durbin-Watson statistics are greater than the upper bound d_u=1.132,

18 The method of analysis was adopted from that of Solow. See Solow, "Technical Change and the Aggregate Production Function", ibid, Aug. 1957, Vol. 39, No. 3, 312-320.

1.265[19) , respectively in Model 1 and Model 2, from the Savin-White tables, indicating that we would not reject the hypothesis of no autocorrelation at the 1 percent critical value. The rate of technical change of 0.0281 in Model 2 appears closer to the estimated annual growth of A(t) time series of 0.0237 in Table 1 than that of 0.0325 in Model 1. Model 2 seems to have a stronger power of explanation in terms of the rate of technical change and the higher R-squared which means that the variation in input factors are explained by the variation in output, indicating that the factor markets in Korea were not considered so competitive.

19 For the D-W statistic in the former model dL=0.928 and dU=1.132 from the Savin-White tables, cited in William H. Greene, Econometric Analysis(New York, Macmillan Publishing Company, 1993), 738-744. For the latter , dL=0.835 and dU=1.265 at the 1 percent critical value.

Table 3

Regression Results of Output on Technical Change(I)

Variable	MODEL 1($\alpha+\beta=1$)	MODEL 2($\alpha+\beta\neq1$)
constant	0.0325	0.0281
(standard error)	(0.0131)	(0.0160)
$\dot{k}/k$	0.4078	-
(standard error)	(0.1473)	-
$\dot{K}/K$	-	0.4777
(standard error)		(0.1240)
$\dot{L}/L$	-	0.4355
(standard error)		(0.1193)
R-squared	0.3108	0.7736
Durbin-Watson statistic	2.3404	2.6650
F-statistic	7.6669	27.3443
(p-value)	(0.0131)	(0.0000)
Observations	19	19
Degree of Freedom	17	16
Standard Error of Regression	0.0370	0.0278
Sum of Squared Residuals	0.0233	0.1240

Estimating the Effect of Technical Change on Economic Growth

As mentioned in the previous section, the level of technology $A(t)$ with exponential increase becomes $Ae^{\lambda t}$ and the Cobb-Douglas production function would be $Q=Ae^{\lambda t}K^{\alpha}L^{\beta}$. The coefficients of the production function can be obtained easily in the loglinear form of the two models ; $\ln(Q/L) = \ln A + \alpha \ln(K/L) + \gamma t$ $(\alpha+\beta=1)$ and $\ln Q = \ln A + \alpha \ln K + \beta \ln L + \gamma t$ $(\alpha+\beta\neq1)$. I ran the regression of ln Q/L (ln Q) on a constant, capital per unit labor(capital and labor input) and technical change with the assumption of $\alpha+\beta=1$(Model 1) and without it, $\alpha+\beta\neq1$(Model 2).

The results are given in Table 4. The regression equations are

$$\ln(Q/L) = \underset{(12.51)}{-44.9383} + \underset{(0.0866)}{0.4740}\ \ln(K/L) + \underset{(0.0066)}{0.0244t} \quad (\text{Model 1}: \alpha+\beta=1) \qquad (10.1)$$

*standard error in parenthesis

$$\ln Q = \underset{(21.81)}{-81.2377} \underset{(0.1121)}{+0.3192}\ \ln K \underset{(0.0799)}{+0.5419}\ \ln L \underset{(0.0121)}{+0.0450t} \quad (\text{Model 2}: \alpha+\beta\neq1) \qquad (10.2)$$

*standard error in parenthesis

The coefficients on the output variable are all significant and the R-squared is quite high (0.99), indicating that 99 percent of the variation in input factor and technical change is explained by the variation in output. The F-statistics for testing the hypothesis that the coefficients are jointly zero are quite high, indicating a strong rejection of this hypothesis. This indicates a strong relationship between input factors including technical change and output. The Durbin-Watson statistics indicate no autocorrelaton in both cases[20)]. The estimates of the elasticity to capital

20 Coefficients are all significant at the 0.02 level and F-statistics are significant at the level of 0.0000. For the D-W statistics, dU=1.265 (n=19, k'=2) and 1.415 (n=19, k'=3).

per Man-Hour, and technical change in Model 1 are 0.4740 and 0.0244, respectively and then elasticity of labor will be 0.5360. The estimates of the elasticity to capital, labor and technical change in Model 2 are 0.3192, 0.5419 and 0.0450 respectively. Compared to the previous Models, which didn't assume exponential increase in technical change, the rates of technical change lie in the range of 0.02-0.04.[21)]

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21 Technical changes in two Models developed by Solow are expressed in constant terms, 0.0325 and 0.0281 respectively. The rates of technical change in (10.1) and (10.2) are 0.0244 and 0.0450. Some researchers argu constant terms in the latter case mean the level of productivity in the base year and yet we cannot get distint interpretation of the sign and size of the constant term.

Table 4

Regression Results of Output on Technical Change(II)

Variable	MODEL 1($\alpha+\beta=1$)	MODEL 2($\alpha+\beta\neq1$)
constant	-44.9383	-81.2377
(standard error)	(12.51)	(21.81)
ln *K/L*	0.4740	-
(standard error)	(0.0866)	-
ln *K*	-	0.3192
(standard error)		(0.1121)
ln *L*	-	0.5419
(standard error)		(0.0799)
t	0.0244	0.0450
(standard error)	(0.0066)	(0.0121)
R-squared	0.9948	0.9990
Durbin-Watson statistic	1.4693	1.8008
F-statistic	1530.0	5118.1
(p-value)	(0.0000)	(0.0000)
Observations	19	19
Degree of Freedom	16	15
Standard Error of Regression	0.0262	0.0241
Sum of Squared Residuals	0.0110	0.0086

Estimating the Relationship between R&D and Economic Growth

The theoretical model underlying the present analysis treats the research and development capital (R&D Capital) as a third input in addition to the labor and capital inputs. In this model the production function for time, *t*, is represented by:

$$Q=Ae^{\lambda t}K^{\alpha}L^{\beta}R^{\gamma} \qquad (11.1)$$

or in log form:

$$\ln (Q/L) = \ln A + \alpha \ln (K/L) + \gamma \ln (R/L) + \lambda t \quad (\alpha+\beta+\gamma=1) \qquad (11.2)$$

$$\ln Q = \ln A + \alpha \ln K + \beta \ln L + \gamma \ln R + \lambda t \; (\alpha+\beta+\gamma\neq 1) \qquad (11.3)$$

where Q, K, L, and R are the output, and the inputs of physical capital stock, labor input and R&D capital stock, respectively ; α, β, and γ are the respective elasticity parameters for the three inputs . And as usual, denote the constant returns to scale by Model 1 $(\alpha+\beta+\gamma=1)$ and the generalized case by Model 2 $(\alpha+\beta+\gamma\neq 1)$.

Technical change need not involve the domestic development of new products and processes. International transfer of technology could have the same effect - firms could take out licences to produce new goods or new technology could be imported, embodied in new machines. In the initial stage of industrial development most developing countries have benefit from the importation of technology. It is difficult to convert the royalty payments for imported technology to knowledge stock-a kind of R&D stock because it has the different time lags between spending on importation and commercialization of technology, the different lengths of technical life and rates of obsolescence from R&D stock. I treated R&D stock in two ways. (1)RD(stock); R&D domestically performed and accumulated as a result of expenditure on domestic R&D, that is, the stock of imported technology is excluded. (2) RT(stock); total R&D stock including imported technology. I ran the regressions for RD(domestic R&D stock only) and RT(total R&D stock) in each Model.

Table 5 gives the regression results in Model 1. The equations are

$$\ln (Q/L) = \underset{(11.26)}{-39.9773}+\underset{(0.0954)}{0.3413}\ \ln(K/L)+\underset{(0.0405)}{0.0947}\ \ln(RD/L)+\underset{(0.0059)}{0.0222}t \quad \text{(domestic R\&D)} \quad (11.4)$$

$$\ln (Q/L) = \underset{(11.67)}{-35.4375}+\underset{(0.0936)}{0.3428}\ \ln(K/L)+\underset{(0.0457)}{0.1099}\ \ln(RT/L)+\underset{(0.0061)}{0.0199}t \quad \text{(total R\&D)} \quad (11.5)$$

The coefficients on the variables in both cases are all significant at the level of 0.04 and the R-squared is quite high, 0.99. I also reported the F-statistics are significant at the 0.0000 level. The Durbin-Watson statistics tell us that we should not reject the hypothesis of no autocorrelation. The sign of all the coefficients are positive, as expected. The coefficients of physical capital per unit labor are 0.3413 and 0.3428 and those of labor input are 0.6587 and 0.6572 respectivly in the case of domestic R&D and total R&D. The coefficients of domestic R&D stock per unit labor and total R&D stock per unit labor are 0.0947 and 0.1099. These results indicate that there is a strong relationship between R&D and output. Note that the coefficient of total R&D is apparantly greater than that of domestic R&D.

The regression equations in Model 2 ($\alpha+\beta+\gamma\neq 1$) are given as follows.

$$\ln Q=\underset{(37.15)}{-47.0352}+\underset{(0.1128)}{0.3275}\ \ln K+\underset{(0.0820)}{0.5616}\ \ln L+\underset{(0.0704)}{0.0803}\ \ln RD+\underset{(0.0199)}{0.0271}t \quad \text{(domestic R\&D)} \quad (11.6)$$

$$\ln Q=\underset{(37.52)}{-43.0739}+\underset{(0.1117)}{0.3274}\ \ln K+\underset{(0.0795)}{0.5477}\ \ln L+\underset{(0.0751)}{0.0936}\ \ln RT+ \underset{(0.0199)}{0.0252}t \quad \text{(totalR\&D)} \quad (11.7)$$

Table 5

Regression Results of Output on R&D in Model 1($\alpha+\beta+\gamma=1$)

Variable	MODEL 1(domestic R&D)	MODEL 2(total R&D)
constant	-39.9773	-35.4375
(standard error)	(11.26)	(11.67)
ln *K/L*	0.3413	0.3428
(standard error)	(0.0954)	(0.0936)
ln *RD/L*	0.0947	-
(standard error)	(0.0405)	
ln *RT/L*	-	0.1099
(standard error)		(0.0457)
t	0.0222	0.0199
(standard error)	(0.0059)	(0.0061)
R-squared	0.9961	0.9962
Durbin-Watson statistic	2.1050	2.0815
F-statistic	1306.0	1326.6
(p-value)	(0.0000)	(0.0000)
Observations	19	19
Degree of Freedom	15	15
Standard Error of Regression	0.0232	0.0230
Sum of Squared Residuals	0.0080	0.0079

The regression results are shown in Table 6. The coefficients of determination (R-squared) are quite high and the F-stastistics are significant at the 0.0000 level. The Durbin-Watson statistics tell us no autocorrelation. The coefficients, however, on the variables in the two cases are not statistically significant. Although the coefficients of R&D and disembodied growth of technology in both cases and constant in domestic R&D case are insignificant, most of the coefficents are almost the same level as the previous regressions, which assume the constant returns to scale.[22]

Estimating the Effect of Imported Technology

The result in the previous section shows that output has a strong relationship with R&D stock, especially stronger with total R&D stock. In this section, I tried to test the hypothesis that there is a positive effect of imported technology on economic growth and on the domestic R&D stock. I regressed output($\ln Q$) on R&D stock coming from imported technology ($\ln RI$) and other input variables($\ln A$, $\ln K$, $\ln L$). I summerized the regression results in Table 7.

$$\ln(Q/L) = -10.0753 + 0.4399(K/L) + 0.1408(RI/L) + 0.0067t \quad \text{(Model 1 : } \alpha+\beta+\gamma=1) \qquad (11.8)$$
$$(22.21) \quad (0.0829) \quad (0.0763) \quad (0.0144)$$

$$\ln Q = -44.8837 + 0.3277\ln K + 0.4583\ln L + 0.1057\ln RI + 0.027t \quad \text{(Model 2 : } \alpha+\beta+\gamma\neq 1) \qquad (11.9)$$
$$(34.25) \quad (0.1105) \quad (0.0997) \quad (0.0776) \quad (0.0177)$$

22 The t-ratio of coefficient of ln RD and t are 1.140 and 1.362 in the domestic R&D, whose significant levels are 0.2735 and 0.1946 in two- tail test,respectively.And the level of significance of constant is 0.2261.In the total R&D case,the significant levels of coefficients of ln RT and t are 0.2330 and 0.2272.The sign and size of the coefficients are very similar to those in Model 1.

Table 6

Regression Results of Output on R&D in Model 2($\alpha+\beta+\gamma\neq 1$)

	domestic R&D	total R&D
Variable		
constant	-47.0352	-43.0739
(standard error)	(37.15)	(37.52)
ln K	0.3275	0.3274
(standard error)	(0.1128)	(0.1117)
ln L	0.5616	0.5477
(standard error)	(0.0820)	(0.0795)
ln RD	0.0803	-
(standard error)	(0.0704)	
ln RT	-	0.0936
(standard error)		(0.0751)
t	0.0271	0.0252
(standard error)	(0.0199)	(0.0199)
R-squared	0.9990	0.9991
Durbin-Watson statistic	2.0897	2.0777
F-statistic	3810.1	3882.6
(p-value)	(0.0000)	(0.0000)
Observations	19	19
Degree of Freedom	15	15
Standard Error of Regression	0.0242	0.0239
Sum of Squared Residuals	0.0081	0.0080

Table 7

Regression Results for Imported Technology

Variable	Model 1($\alpha+\beta+\gamma=1$)	Model 2($\alpha+\beta+\gamma\neq 1$)
constant	-10.0753	-44.8837
(standard error)	(22.21)	(34.25)
ln *K/L*	0.4399	-
(standard error)	(0.0829)	
ln *K*	-	0.3277
(standard error)		(0.1105)
ln *L*	-	0.4583
(standard error)		(0.0997)
ln *RI/L*	0.1408	-
(standard error)	(0.0763)	
ln *RI*	-	0.1057
(standard error)		(0.0776)
t	0.0067	0.0272
(standard error)	(0.0114)	(0.0177)
R-squared	0.9957	0.9991
Durbin-Watson statistic	1.5413	1.8455
F-statistic	1174.2	3965.3
(p-value)	(0.0000)	(0.0000)
Observations	19	19
Degree of Freedom	15	14
Standard Error of Regression	0.0245	0.0237
Sum of Squared Residuals	0.0089	0.0780

In these regressions, the R-squareds are very high (0.9990) as usual and the F-statistic is significant at the 0.0000 and the Durbin-Watson statistic indicates no autocorrelation. The coefficients of ln *RI* and ln *RI/L* and *t* are not statistically significant. Note the coefficient of imported technology (0.1057) is greater than that of domestic R&D(0.0803) in equation (11.9) or Table 6, implying that imported technology has greater effect than domestic R&D has on economic growth for the period.

To analyze the relationship between R&D and importation of technology I also regressed domestic R&D stock on imported technology stock and the rate of disembodied technology. The Durbin-Watson statistic in the ordinary least squares regression indicates the presence of autoregression. The generalized least squares was obtained for the Autoregressive(1) process using Cochrane-Orcutt estimator.[23)]

$$\ln RD = \underset{(74.78)}{-242.446} + \underset{(0.1914)}{0.4604} \ln RI + \underset{(0.0382)}{0.1245}\, t \quad \text{(GLS regression)} \qquad (11.10)$$

The results of ordinary least squares (OLS) and generalized least squares(GLS) regression are shown in Table 8. The implication of the regression results is that there is a strong relationship between R&D and imported technology for the period of 1971-1989 in Korea. According to the result one unit increase in imported technology stock entails 46 percent increase in domestic R&D stock. An empirical study shows that R&D spendings and payment for imported technology are complements at the early stage of economic development but that the

23 For Autoregressive progresses, testing statistics and estimator can be referred to Greene, W., Econometric Analysis, Macmillan Publishing Company, New York, 1993, 413-440.

Table 8

Regression Results of R&D on Imported Technology

	OLS Regression	GLS Regression
Variable		
constant	-355.002	-242.446
(standard error)	(80.60)	(74.78)
ln *RI*	0.0496	0.4604
(standard error)	(0.1977)	(0.1914)
t	0.1825	0.1245
(standard error)	(0.0412)	(0.0382)
R-squared	0.9935	
Durbin-Watson statistic	0.4499	
F-statistic	1225.0	
(p-value)	(0.0000)	
Observations	19	
Degree of Freedom	16	
Standard Error of Regression	0.0930	
Sum of Squared Residuals	0.1384	

relationship becomes weaker as the domestically developed research gets stabilized with economic growth and finally their relationship may turn to substitutes.[24] Impoerted technology and domestic R&D seems to be complements at least for the period. Figure 3 reveals complementary relationship between the R&D expenditures and the royalty payments for imported technology for the period 1971-1989.

Data Source

Below is a discussion of the sources for the data used in the regressions described above and reasons why these particular sources were chosen.

Data for Output and Input Factors

The basic inputs of the economy are the productive services of the factors of production. Input is the time-flow of services of the human and non human factors available for use in the productive processess; the results of the productive services is output, which is distributed as income to the factors.

I used data on Gross Domestic Product (GDP) as a measure of output. The majority of persons engaged in productive employment ase paid by the hour; and manhours can also be estimated roughly for not on an hourly rated basis, and their compensation translated to average hourly earnings for weighting purposes. There are man-hour, man-day and total earnings per year available for data on labor input, of which man-hour has the highest R-squared when it was used for regression. Although the quality and quantity of labor input, however, depends on

24 The coefficient of payment for imported technology became from 0.671 for 1957-1969 to 0.265 for 1970-1982 in Japan's Manufacturing Sector.See Wakamoto.T.,Economic Analysis of Innovation and R&D, Far Eastern Economic Newspaper Publishing Company, 1986, 8-27. In my study it was 0.2929 for 1971-1989 in Korea's Manufacturing Sector.

the level of workers' education, working experience and working condition including incentives and welfare, workers' productivity was treated on average concept because of lack of data concerned. Because technical change may absorb the change in productivity caused by the above factors, the contribution of labor input to economic growth may be underestimated.

The first step in measuring real capital services is to estimate the real net capital stock employed in the industries; the next is to weight these figures by the base-period rates of return. Data on capital stock are from the estimates by Hak-Kil Pyo and Korean Industrial Bank. They used the perpeptual inventory model basically and applied polynomial-benchmark method. All figures are indexed with a base year of 1987 and related to the manufacturing sector in Korea.

Data for Research and Development

There are three major issues in the measurement of such capital:[25] *(1)The fact that the research and development process takes time and that current research and development may not have an effect on measured productivity until several years have elaspsed forces one to make assumptions about the relevant lag structure. (2) Past research and development investments depreciate and become obsolete. Thus the growth in the net stock of research and development capital is not equal to the gross level of current resources invested in expanding it. (3)…….*

R&D activity is an investment flow and what affects industrial growth is the accumulated stock of the previous results of such investment, i.e, knowledge

25 Zvi Griliches,"Issues in assessing the contribution of research and development to productivity growth.",the Bell Journal of Economics Spring,1979,p100.

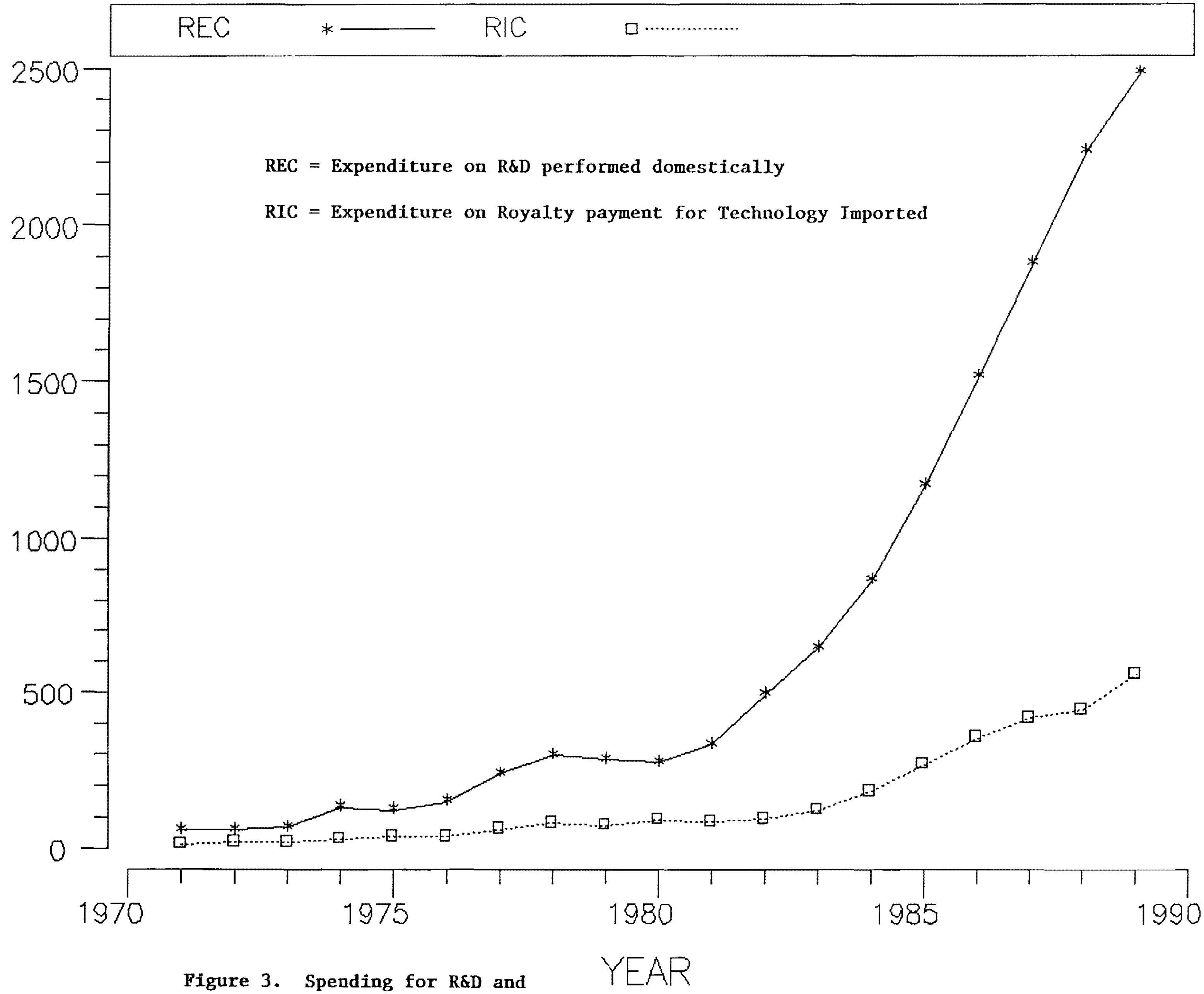

Figure 3. Spending for R&D and Technology Imported

capital. Formally, knowledge capital can be obtained by the summation of the past investment weighted by the assumed R&D lag and obsolesence schemes. A number of serious difficulties, however, arises when one turns to the operational construction of the unobservable research capital measure because it is too broad a concept: it contains too much. Because of the difficulties in determining R&D lags and obsolescence rate of technology, these factors have been largely ignored by most studies. In fact the most common practice has been to include no lag and no obsolescence. On the other hand, some researchs such as Pakes and Schankerman (1984) and Schott (1976) obtained figures for R&D lags from survey data, and constructed knowledge capital taking into account these lags.

I estimated R&D stock following "Perpeptual Inventory Method" by Goldsmith.[26)]

$$R_0(\text{stock}) = R_0(\text{Expenditure})[\{g/(g+d)\}\{(1-e^{-\upsilon(g+d)})/(1-e^{-g})\}]$$

$$R_t(\text{stock}) = R_{t-\theta}(\text{Expenditure}) + (1-d)R_{t-1}(\text{stock})$$

where g; annual growth rate of R&D expenditure, d; the rate of obsolescence (depreciation allowance), υ; length of life of the technical knowledge, θ; time lag between R&D spending and R&D stock applied to the industrial production.

Fortunately I obtained measures for R&D lags from the business survey conducted by Ministry of Trade and Industry in 1987. This survey asked after R&D lag years in 28 projects which started in each research stage in 102 major manufacturing companies. So, in this paper, I measure knowledge capital stock taking into account these R&D lags. The mean R&D time lag and the rate of

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26 Goldsmith, R.W., The National Wealth of the United States in the Postwar Period, Princeton University Press, 1962.

obsolescence were 3 years and 15 percent per year respectively, and length of technical life was 6.7 years.[27] The base year was 1971. The annual growth rate of R&D expenditures in real term was 23.01 percent for the period 1971-1989.

Technical change needs not involve the development of new products and processes. International transfers of technology could have the same effect-firm could take out licences to produce new goods or new technology could be imported, embodied in new machines. So I have estimated knowledge not only for domestically developed technology but also for imported technology, by using royalty payment data for imported technology in real term in place of R&D investment. The stock of imported technology was estimated by the same method and the same data source. The R&D time lag was assumed 1 year, the rate of obsolescence, 20 percent and length of technical knowledge, 5 years. The annual growth rate of payments for imported technologies was 20.38 percent during 1971-1989. Comparing the mean R&D lag between domestically developed technology and imported technology, I can point out that the imported technologies had the shorter time lag because they were completed at the basic or applied research level in the original country. In addition, imported technologies had the larger rate of obsolescence and shorter length of technical life, indicating that most of imported technologies were in the matured or declining stage, that is, they were

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27 Bosworth estimated the rate of obsolescence,10 percent,using the patent renewal model.See Bosworth,O.I.,"The Rate of Obsolescence of Technical Knowledge- a Note ", Journal of Industrial Economics,March 1978. Pakes and Schankerman estimated the rate from average life span of R&D and the mean R&D lag in durable goods and nondurable goods.See "the Rate of Obsolescence of Patents, Research Gestation Lags, and the Private Rate of Return to Research Resources",in Zvi Griliches(ed.),R&D,Patents and Productivity, the University of Chicago,1984.

not brand new technologies or they were second handed technologies.

There is no official research and development deflator index available currently. National Science Foundation (NSF) is using the implicit GNP deflator which is not so high-skill labor intensive as would be appropriate for research and development input price index. Mansfield (1984) estimated that the rate of increase of the price index for R&D inputs exceeded the rate of increase of the GNP deflator.[28] The data, however, on R&D expenditures could not be decomposed into item by item until early 1980s in Korea. I had to use GNP deflator as R&D deflator. The stock of R&D and imported technology is calculated in Table 9.

28 Mansfield suggested two kinds of price index for R&D inputs;(1)Laspeyres price index and (2)Cobb-Douglas price index. See Mansfield,E.,"R&D and Innovation:Some Empirical Findings" in Zvi Griliches(ed.),ibid.

Table 9

Calculation of Stock of R&D and Imported Technology

YEAR	$R&D(1)	R&Ds(2)	$IT(3)	ITs(4)	T.R&Ds(5)
1971	59.88	163.12	12.74	26.64	189.76
1972	58.72	200.49	20.11	34.05	234.54
1973	68.41	230.30	20.05	47.35	277.65
1974	132.52	254.48	29.89	57.92	312.41
1975	123.23	284.72	37.02	76.23	360.95
1976	150.10	374.53	36.26	98.00	472.53
1977	240.06	441.59	62.33	114.66	556.25
1978	297.46	525.45	80.39	154.06	679.51
1979	283.84	686.69	74.14	203.64	890.34
1980	273.89	881.15	91.52	237.05	1118.20
1981	331.37	1032.81	84.82	281.16	1313.97
1982	492.72	1151.78	93.27	309.75	1461.53
1983	643.29	1310.38	123.06	341.06	1651.45
1984	864.63	1606.55	182.90	395.91	2002.46
1985	1170.22	2008.86	266.47	499.63	2508.48
1986	1514.33	2572.15	351.95	666.18	3238.33
1987	1878.00	3356.55	414.93	884.89	4241.44
1988	2232.79	4367.40	440.07	1122.84	5490.24
1989	2488.89	5590.29	555.63	1338.34	6928.63

NOTES AND SOURCES :

Column(1):Total expenditures for R&D financed by the private sector and government (excluding defense sector), in billion won(1987value), from Ministry of Science and Technology, Science and Technology Statistics Yearbook, selected years.

Column(2):R&D stock(net), in billion won(1987value), calculated by the Goldsmith's "Perpeptual Inventory Method".

Column(3):Payment for Imported Technology, in billion won(1987value), from Ministry of Science and Technology, ibid.

Column(4):Imported Technology stock(net), in billion won(1987value), calculated by the Goldsmith's "Perpeptual Inventory Method".

Column(5):Total R&D stock(net) including imported technology, in billion won (1987value), (5)=(3)+(4).

CHAPTER FIVE

INTERPRETATION OF THE RESULTS

The results of regressions indicate that there are strong relationships between technological change and output, and R&D stock and output. They also show that imported technology has a positve effect on output and domestic R&D. The results, in this chapter, will be analyzed and interpreted in terms of the economic situation and compared with other cases in some other countries.

Technical Change and Economic Growth

Regression equation (10.2), which does not assume the constant of returns to scale, is used for analysis of effect of technological change and its contribution to economic growth(output growth).

Output elasticities and output growth

Technical change rose 4.5 percent every year in the manufacturing sector for the period 1971-1989. The output elasticities of capital, labor input and technical change are 0.3192, 0.5419 and 0.0450 respectively. Value added in the manufacturing sector increased 13.7 percent per year and net capital stock and labor input increased 15.5 percent and 7.3 percent per year respectively.[29] While the

29 The annual growth rate of output, capital and labor input can be obtained from Table 1. I used GDP data, employed capital data, total hours worked per year data for the corresponding growth rate. For labor productivity, I used GDP per man hour and used GDP per man hour devided by employed capital per man hour for capital productivity.

productivity of capital input had actually minus growth rate of -1.6 percent per year, the productivity of labor input increased 6.0 percent per year for the period.

Contribution of factor input to output growth

The contribution of factor input to output growth(economic growth) is defined as its output elasticity multiplied by its growth rate. Output growth rate of 13.7 percent is decomposed into 4.9 percent by capital input, 3.9 percent by labor input and 4.5 percent by technical change. That is, output growth is attributable to capital input, 36.0 percent, to labor input, 28.7 percent and to technical change , 32.9 percent. The amount of contribution of technical change was larger than expected. Korea has pursed the six consecutive Economic Development Plans every five years from 1962 to 1991. In the first stage of the plan during 1962-1971, the high quality of labor and low wage rate contributed to her rapid economic growth. The contribution of technical change was insignificant. At that time technical progress depended on imitation and imported technology. In the second stage (1972-1981) and the third stage (1982-1991), industrial structure and technical progress have been remarkably deepened. The unexpectedly great contribution of technical change can be interpreted by the fact that the period for this study corresponds with the latter stage. As mentioned earlier, the productivity of capital input decreased 1.6percent per year but the net capital stock increased 15.5 percent per year for the period. These facts can be interpreted that the contribution of capital input to output growth was made by the enormous increase in quantities not by the efficient use of capital. The decrease in capital productivity was due to excess investments in facilities and equipments caused by the optimistic expectation for favorable export demand and by the industrial structure adjustments.

International comparison in technological change

We need not stress the international comparison in technical change because growth patterns are different from country by country and from analysis period and methods used. Table 10, however, can give the outline of the relationship between economic growth and technical change and factor inputs.

Christensen, Cummings and Jorgenson (1980) provided an international comparison of postwar patterns of aggregate economic growth, concluding that increases and decreases in average growth rates of real factor input for the period 1947-1973 are strongly associated with increases and decreases in average growth rates of real product.[30] The implication of their study is that the high growth countries had the highest average rates of growth of real factor input and that economic growth was imputed mainly to capital input and technical change. Their study indicates that contribution of technical change is greater than that of labor input to economic growth in almost of all the cases.

R&D Expenditure and Economic Growth

Equation (11.5) is used for the analysis of the effects of R&D stock which is treated as a third input in constant returns to scale and used for calculation of the rate of returns to R&D. Total R&D stock including the stock of imported technology is used for R&D stock basically but domestic R&D stock is

30 They analyzed the relationship between growth of real product and its sources-growth in real factor input and growth in total factor productivity for the United States and its major trading partners-Canada, France, Germany, Italy, Japan, Korea, the Netherlands, and the United Kingdom. See "Economic Growth, 1947-73:An International Comparison",in J.Kendrick and B. Vaccara(ed), New Developments in Productivity Measurement and Analysis,University of Chicago Press, 1980,595-698.

used when needed, especially the effects of imported technology are measured.

Output Elasticities and Output Growth

Output elasticity of total R&D stock per unit labor is 0.1099 in equation (11.5). The rate of disembodied technical change is 0.0199 and the coefficient of capital input is 0.3428 and then that of labor input is 0.5472. The contributions of factor inputs to output growth, 13.7 percent, are 38.7 percent by capital input, 28.7 percent by labor input, 17.8 percent by R&D stock and 14.5 percent by the rate of disembodied technical change. If technical change is treated as residual like equation (10.2), it would be 32.6 percent because 32.6% = 100% - 38.7% - 28.7%. This figures is very close to the estimate of technical change in equation (10.2), which was 32.9 percent. The weight of R&D stock out of technical change is 54.6 percent and that of disembodied technical change is 45.4 percent, indicating that technical change was made about 55 percent by R&D activities and about 45 percent by other unexplained factors which may come from quality of labor forces, economies of scale, external economies and changes in product mix and many others involved.

Output Elasticities and Labor Productivity

Since output per labor input means productivity of labor, the results of equation (11.5) shows contribution of each input to labor productivity. The growth rate of labor productivity(Q/L),which is 6.0 percent, comprises 2.6 percent by capital per unit labor(K/L), 1.5 percent by R&D stock per unit labor(RT/L) and 1.9 percent by disembodied technical change. That is, the growth of labor productivity can be attributed to capital per unit labor of 43.7 percent , R&D stock per unit labor of 25.2 percent and disembodied technical change of 33.2 percent. It can be interpreted that increase in labor productivity depends on more education and skill of the labor

Table 10

International Comparison of Technical Change

(unit:annual percent rate)

country & period	growth rate of output	technical change	contribution of tech.	capital	labor
United States					
1960-1973[1]	4.3	1.3	30.1	39.3	30.6
1973-1977[2]	1.04	1.12	107.7	n.a	n.a
United Kingdom					
1960-1973[1]	3.8	2.1	53.8	46.8	-0.6
France					
1960-1973[1]	5.9	3.0	51.3	44.4	4.3
Germany					
1960-1973[1]	4.01	3.0	55.6	52.0	-7.4
Japan					
1960-1973[1]	10.9	4.5	41.4	43.7	14.7
1973-1978[2]	12.11	3.67	30.3	n.a	n.a
Canada					
1960-1973[1]	5.1	1.8	36.1	43.0	20.9
Italy					
1960-1973[1]	4.8	3.1	65.9	43.5	-9.0
Netherlands					
1960-1973[1]	5.6	2.6	46.0	50.9	3.1
Korea					
1960-1973[1]	9.7	4.1	42.9	25.0	32.9
1971-1989[3]	13.68	4.50	32.9	36.0	28.7

Sources :

(1)Christensen,L., Cummings,D., and Jorgenson,D., "Economic Growth, 1947-73; An International Comparison", in J.Kendrick and B.Vaccara(ed),New Developments in Productivity Measurement and Analysis, University of Chicago Press,1980, 595-698.

(2)Norsworthy,J.R.and D.H.Malmquist,"Input Measurement and Productivity Growth in Japanese and U.S. Manufacturing", American Economic Review, Dec. 1983.

(3)Results from this study.

force, quality control activities, improved working and health conditions and better management which disembodied technical change contains rather than R&D activities.

International Comparison in Labor Productivity

The contribution of capital per unit labor and disembodied technical change to labor productivity seems high relatively to that of R&D stock per unit labor in Korea. The pattern is similar in Japan. The Japan Development Bank(1984) provided the results of labor productivity growth.31) The growth of labor productivity was attributable to 32.1 percent of capital input, 14.1 percent of R&D stock input and 43.6 percent of disembodied technical change in the manufacturing sector for 1970-1982. The disembodied technical change is large because improvement of quality of labor force was not calculated in labor input and because technology was aquired and learned through diffusion of know-how among industries in the process of industrialization rather than through R&D activities. Table 11 shows some comparison to other countries.

Returns to R&D Investment

The rate of returns to R&D stock can be obtained in two ways; first, from the relationship between total factor productivity and the ratio of R&D investment to output using equation (8.2) and second, by the definition of marginal product of R&D capital stock, which is the product of output elastictiy of R&D stock by the average ratio of output to R&D stock. From my regression equation

31 The Japan Development Bank, "Change in R&D investment and equipment investment", Economics and Business, 1984.

(11.5) the rate of return to total R&D stock is calculated 63.9 percent[32]. This value is overestimated because it is implicitly assumed that R&D investment instantaneously yielded the return with no lag. Equation (7.5) by Pakes and Schankerman corrects the rate of returns to R&D stock, 20.0 percent. Griliches (1975) estimated the rate of return to R&D for 883 large R&D-performing U.S. manufacturing companies. The average gross excess rate of return to R&D was 27 percent in 1963. Mansfield (1965) found that marginal rates of return to R&D averaged about 40 to 60 percent for a sample of petroleum firms; for a sample of chemical firms, returns averaged about 30 percent. Suzuki(1985) estimated the rate of return to R&D investments by the method in equation (8.2). The corrected rate of returns to R&D was 22 percent for manufacturing sector in Japan for the period of 1965-1982 and 17 percent for 1970-1982.[33]

Imported Technology and Domestic R&D

The results of estimates on the technical change with respect to imported technology give an indication that countries can benefit from it. Many researchers interested in the relationship between R&D and productivity increase seem to have paid too little attention to this subject because of lack of information or interest. Most of the developed countries are exporting technology and so it has little effect on their economy. By ignoring the importation of technology the

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32 I tried to obtain the rate of return to R&D by the equation (8.2). I ran the regression of TFP estimated on a constant, λ(rate of disembodied technical change) and R&D intensity but the results were statistically insignificant.So I calculated the rate by equation (7.4); γ=0.1099 and Q/RT=5.8127.The results in the latter method may be less acurate than that in the former because the rate would be overestimated when Q/RT is large,i.e.,RT is relatively small.

33 Suzuki K.,"Knowledge capital and the Private rate of Return to R&D in Japanese manufacturing industries",International Journal of Industrial Organization,Vol.3,1985.

Table 11

International Comparison of Parameter in Production Function

Country	Period	output elasticity of capital	output elasticity of R&D stock	disembodied technical change
United States	1966-1977[1]	0.31	0.073	0.011
	1966-1977[2]	0.203	0.223	0.025
	1966-1971[3]	0.17	0.24	0.007
France	1972-1977[4]	0.213	0.209	0.005
	1972-1977[5]	0.237	0.206	0.03
	1972-1977[6]	0.175	0.116	-0.019
Japan	1965-1982[7]	0.48	0.234	0.094
Korea	1971-1989[8]	0.343	0.110	0.020

Notes and Sources :

(1)total 133 firms, (2)77 scientific firms, (3)77 scientific firms from Griliches and J.Mairesse, "Productivity and R&D at the Firm Level", in Griliches (ed.), op.cit.,1984.

(4)total 182 firms, (5)98 scientific firms (6)84 other firms from Cuneo,P. and J.Mairesse, "Productivity and R&D at the firm level in French Manufacturing", in Griliches,(ed.),op.cit.,1984.

(7)Manufacturing sector from the Japan Development Bank, "Change in R&D investment and equipment investment",op.cit.,1984.

(8)results from this study.

measured return to domestic R&D can be overestimated. Mansfield (1984) raises the question of the importation of technology and suggests that taking account of imported technology reduces, in his sample, the measured rate of return from 28 percent to 19 percent. The coefficient of R&D stock was larger when the stock of imported technology was included. The coefficient of total R&D stock in equation (11.5) was 0.1099 and that of domestic R&D stock in equation (11.4) was 0.0947. It is notable that the coefficient of imported technology stock is larger than that of domestic R&D stock in equation (11.9) and imported technology has a strong positive relationship with domestic R&D. Equation (11.10) shows that 46 percent increase in domestic R&D occurs as imported technology increases one unit.

CHAPTER SIX

CONCLUSIONS

Technological change has played a key role in economic growth, and its impact can be viewed from various aspects. I have resricted attention to its effects on output growth and attempted to estimate the degree of contribution of each inputs in the production function.

In comparison to other factor inputs, the contribution of technological change is larger than generally recognized in Korea. The results of this study show a firm confidence that technological change has a strong relationship with econmic growth. Economic growth in the manufacturing sector of Korea had been led by three factors, capital input, labor input and technical change. The share of capital , labor input and technical change to economic growth was approximately 36-39 percent, 29-32 percent and 32 percent respectively for the period of 1971-1989.

If technological change is regarded as residual, it comprises knowledge capital from R&D stock and from disembodied technical change. Technological change was attributable to the similar degree of R&D stock (55 percent) and disembodied technical change (45 percent), indicating economic growth depended , relatively largely in compared with other countries, upon disembodied technical change which contains education and skills of labor force, econmies of scale, external economies, improved working condition, better management, changes in product mix and many others.

I found a relationship between R&D stock and economic growth. The primary estimate of rate of returns to R&D investment was 64 percent and was reduced to 20 percent in consideration of time lag, which seems not behind the level of other comparison countries. The output elasticity of total R&D stock is bigger than that of domestic R&D stock excluding imported technology. While total R&D stock contributed 17.8 percent to economic growth, domestic R&D contributed 15 percent. In addition, I also found that domestic R&D stock has a positive slope (0.46) against the stock of imported technology and high R-squared (0.99). This indicates imported technology has a strong relationship with domestic R&D stock and output as well.

This study has the limitation in two respects. First, data are not sufficient and there may be misclassification and misuse of data. Although this study is restricted to the manufacturing sector, data on royalty payments for imported technology covered for all sector. Man-Hours as a measure of labor input cannot be shown to reflect their own productivities and R&D deflator could not be used rather than GDP deflator when the stocks of R&D and imported technology were calculated. Second, it is more realistic and persuasive to make an embodied technology model. There is a possibility of bias regarding residual, assuming that technology does not embody input. All of these results should be interpreted cautiously because of the shortcomings mentioned previously.

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