NBER WORKING PAPER SERIES

R&D, PRODUCTION STRUCTURE AND PRODUCTIVITY GROWTH: A COMPARISON OF THE US, JAPANESE, AND KOREAN MANUFACTURING SECTORS

M. Ishaq Nadiri
Seongjun Kim

Working Paper 5506

NATIONAL BUREAU OF ECONOMIC RESEARCH
1050 Massachusetts Avenue
Cambridge, MA 02138
March 1996

An earlier version of this paper was presented at the Pacific Rim Conference of the Western Economic Association International held at Hong Kong, January 10-15, 1996. The authors would like to thank Marilyn Harris and Frances Hui for their help in preparing this manuscript. Support from the C.V. Starr Center for Applied Economics of New York University is also gratefully acknowledged. This paper is part of NBER's research program in Productivity. Any opinions expressed are those of the authors and not those of the National Bureau of Economic Research.

NBER Working Paper 5506
March 1996

R&D, PRODUCTION STRUCTURE AND PRODUCTIVITY GROWTH: A COMPARISON OF THE US, JAPANESE, AND KOREAN MANUFACTURING SECTORS

ABSTRACT

We estimate and compare the production structures of the US, Japanese, and Korean total manufacturing sectors for the 1974-1990 period. We employ a translog variable cost function that includes such inputs as labor, materials, physical and R&D capital with the physical and R&D capital treated as quasi-fixed subject to adjustment costs. The paper provides estimates for markups, returns to scale, rates of return on physical and R&D capital, and technical change. The paper also identifies the sources of the growth of output, labor productivity, and total factor productivity. The results show that resource accumulation, not technical change, is the key factor in rapid output growth, and that the R&D capital and technical change have been major contributors of the TFP growth in the US and Japanese manufacturing but not in the Korean manufacturing sector.

M. Ishaq Nadiri
Department of Economics
New York University
New York, NY 10009
and NBER

Seongjun Kim
Department of Economics
New York University
New York, NY 10009

I. Introduction

Contributions of capital formation, research and development effort and technical change to growth of output and productivity are critical concerns in growth models and are major public policy issues. Measuring the contribution of resource investments to growth of output and the rate of return on these investments and identifying correctly the rate of technical change, are major preoccupation of academic and policy research. The conventional measures of total factor productivity growth used in many studies often mismeasure the contribution of technical change to the output growth. In this paper, we compare the growth experience of the US, Japanese and Korean manufacturing sectors for the period 1970-1990 and examine the sources of productivity growth and the role of investment in physical and R&D capital in the evolution of these sectors in the last two decades.

These industries are at different stages of their development: the US manufacturing is a fairly developed and "mature" sector while the Japanese manufacturing sector is an expanding and highly competitive force in international markets. The Korean manufacturing is growing very rapidly and is engaged in strategic effort to expand in international markets. The pattern of investment in physical and R&D capital have been quite different in these sectors and the outcomes to such efforts may provide an answer to whether technical change or resource investment has been the major promoter of output and productivity growth in industries at different stages of their evolution.

In this paper, we develop an econometric model to analyze the sources of growth of output, labor productivity, and properly estimate the rate of technical change in each of these sectors.

The econometric model used is a translog cost function that includes such inputs as labor, materials, physical capital, and R&D capital; the output is measured by gross output. Physical and R&D capital are treated as quasi-fixed inputs subject to adjustment costs. In addition, we estimate the degree of mark-up in each sector by estimating the parameters of the demand function facing each sector. The model is fitted to cross-section and time-series data for the US, Japanese, and Korean total manufacturing sectors for 1974-1990 period.

Using the parameter estimates of the model, we estimate the degree of economies of scale, substitution among the inputs, and the adjustment costs associated with the quasi-fixed factors. We also calculate the degree of mark-up, the rates of return on physical and R&D investments and identify the sources of growth of output and productivity in each sector. We are particularly interested in estimating the rate of technical change in each sector with special attention to the role of R&D capital in enhancing productivity growth in these sectors.[1]

The paper is organized as follows: In section II we provide a brief description of the data used in our analysis. Section III is devoted to specification of the underlying econometric model; the properties of the model are described, and price and output elasticities of interest are formulated. Section IV describes the sources of data and the construction of the variables of the model. Estimates of the model and the empirical results are presented in section V. The sources of output and productivity growth and measures of technical change are discussed in section VI. Section VII provides estimates of the rate of return on physical and R&D capital and compares these returns among the three manufacturing sectors. The paper concludes with a brief summary and conclusion.

II. Some Descriptive Characteristics

The manufacturing sectors of these three countries differ considerably in size. The US manufacturing sector is dominating the other two: in 1990 the US manufacturing sector was about 2 and 7 times bigger in terms of gross output than the Japanese and Korean sectors, respectively. The difference is most compelling in the size of R&D capital stock. However, when the growth rates of output and inputs and their associated productivity are compared, the performance of the Japanese and particularly Korean manufacturing sectors are quite dramatic. Average growth rates for gross output and factor inputs for three sub-periods are given in table 1. During the period of 1975-90, the output of the US manufacturing sector grew by an average of 1.91%, with particularly slower growth in the late 1970s and early 1980s. The growth of Japanese manufacturing in comparison to that of the US was twice as fast for the period 1975-90, and even faster in the first two sub-periods. The output growth in the Korean manufacturing sector was truly phenomenal, growing at double-digit figures ranging from 10% to 15% for different sub-periods, and averaging about 13% for the entire period. This growth rate is almost 6.5 times faster than the output growth in US manufacturing, and over three times as fast as the already impressive growth of output of the Japanese manufacturing sector.

The growth of production inputs also showed markedly different patterns in the manufacturing sectors of these three countries. In the US, the growth of labor input was negative for the period as a whole, -0.5%, and the average growth rate of physical and R&D capital was almost same for the entire period but with the opposite trends: the growth of physical capital has been decreasing while the growth of R&D capital increasing over the 1975-1990 period. For the

Japanese manufacturing, the growth of labor input was only marginal, but both types of capitals showed a strong growth during the whole period, particularly in the 1980s. The factor growth in the Korean manufacturing sector is again remarkable: the average annual growth rate of labor, intermediate input, physical capital and R&D capital for 1975-1990 period was 5.0%, 11.9%. 14.3% and 29.9% respectively.[2] The growth of labor input in Korean manufacturing shows a different pattern than the growth of other inputs, growing at the high rate of over 8% in the second half of the 1970s, but then slowed down abruptly in the next two periods to 3.7 and 2.6 percent, respectively.[3] Setting aside the growth of R&D capital, which can be explained by the relatively smaller base of R&D capital in the beginning, the fact that the physical capital could grow continuously at double-digit number is very impressive and entitles a further question on the rate of return to investment. One common growth pattern among the three sectors, not the growth rate obviously, can be found in the growth of intermediate input: reflecting the energy crisis, the growth of intermediate input was below average during 1970s and the early 1980s, only to see its rapid rise in the late 1980s in all three sectors.

When we consider the input shares in total cost in the three manufacturing sectors, certain similarities and differences are apparent. The cost shares of inputs shown in table 2 indicate that materials input is the largest factor of production taking account of 64%, 66%, and 72% of the total cost of the US, Japanese, and Korean manufacturing respectively, and the R&D capital is the smallest, its total cost share ranging from less than 1% in Korea to as much as 7.5% in the US If we compare the fluctuations in the factor shares in three sectors, the share of materials in the Korean and Japanese sectors has been drifting downward since 1981, but no such trend is observable in US manufacturing, except that because of the 1981-82 recession, the share of materials did decline in the period 1981-85. The share of capital, however, was at its highest level during the first half of 1980s in the US and Korean manufacturing sectors while it steadily increased over the 1975-1990 period in the Japanese manufacturing sector. The share of R&D in total cost has been rising in all three sectors. We can see that in the Korean manufacturing the R&D capital is gaining its importance as a production input through its dramatic increase in total cost share.

Conventional total and partial factor productivity growth rates using gross output as the measure of production are shown in table 3.[4] Total factor productivity growth in the US manufacturing averaged about 0.51% for the period 1975-90. The corresponding indices for Japanese and Korean manufacturing were 0.69% and 1.26%. The TFP growth rate was particularly slower during 1975-80 period in the US and Korean manufacturing sectors (0.08 and 0.35% respectively) while it was not the case in the Japanese manufacturing sector. The growth of partial factor productivity, of course, shows a very much different pattern in its magnitudes and trends among three sectors, reflecting the noted differences in the output and input growth of these sectors.

A clear picture emerges from the descriptive comparison of the manufacturing sectors of the US, Japan, and Korea. High growth rates of labor productivity and total factor productivity is accompanied by rapid growth rates of output, and inputs such as labor, materials, capital, and R&D. This pattern seems to be responsible for producing the so-called Korean economic "miracle." The low growth rates of these factors, on the other hand, have accounted to a large extent for the slow growth of productivity in the US manufacturing sector. These propositions are deduced from the quantitative estimates of the econometric model described below.

III. Modeling the Structure of Production

To analyze the sources of growth of productivity and output, and to estimate the contributions of R&D and physical capital stock to growth of labor productivity, we formulate a variable cost function and an output demand equation. We assume that physical and R&D capital are quasi-fixed in the short run and subject to the cost of adjustments. The variable cost function assumed for our analysis is of the form:

$$\begin{aligned}
\ln C^v = \; & \beta_0 + \beta_L \ln w_L + \beta_Y \ln Y + \beta_K \ln K_{-1} + \beta_R \ln R_{-1} + \beta_T \cdot T \\
& + \tfrac{1}{2} \cdot \{\beta_{LL} \ln w_L{}^2 + \beta_{YY} \ln Y^2 + \beta_{KK} \ln K_{-1}{}^2 + \beta_{RR} \ln R_{-1}{}^2 + \beta_{TT} \cdot T^2\} \\
& + \beta_{LY} \ln w_L \cdot \ln Y + \beta_{LK} \ln w_L \cdot \ln K_{-1} + \beta_{LR} \ln w_L \cdot \ln R_{-1} + \beta_{LT} \ln w_L \cdot T \\
& + \beta_{KY} \ln Y \cdot \ln K_{-1} + \beta_{RY} \ln Y \cdot \ln R_{-1} + \beta_{KR} \ln K_{-1} \cdot \ln R_{-1} + \beta_{YT} \ln Y \cdot T \\
& + \beta_{KT} \ln K_{-1} \cdot T + \beta_{RT} \ln R_{-1} \cdot T
\end{aligned} \tag{1}$$

where C^v, w_L and Y are the variable cost, relative wage rate, and level of output; K and R are the level of physical and R&D capital stock measured at the end of period, and T is an index of autonomous technical change proxied by a time variable. Variable cost and wage rate are normalized by the price of materials. There are two variable inputs: labor and materials, and one output. Normalizing the variable production cost and the factor price of labor by the price of materials has the effect of imposing the condition of homogeneity of degree one in the input prices on the variable cost function. Two quasi-fixed factors, physical capital and R&D capital are assumed to be subject to adjustment costs in the short run, which are assumed to be quadratic in net investment in physical and R&D capital,

$$c^a(\Delta K, \Delta R) = \tfrac{1}{2}[\,\mu_{KK}(\Delta K)^2 + \mu_{KR}\Delta K \cdot \Delta R + \mu_{RR}(\Delta R)^2\,] \tag{2}$$

where $\Delta K = K - K_{-1}$ and $\Delta R = R - R_{-1}$.

Although the cost function is written in terms of variable cost (1), it is well known that the properties of the underlying production technology can be deduced from the parameter estimates of it. The duality theorems which link transformation function with restricted cost function guarantee that the structure of production can be inferred from the restricted equilibrium framework.[5] The production structure is summarized by the long-run output elasticity of costs and the partial elasticities of substitution, and we now show how to derive the long-run output elasticity of costs from the restricted cost function.[6] It can be shown that

$$\eta = (1 - \pi^*)^{-1}\eta_V \tag{3}$$

where η_V and η are the output elasticities of the variable cost and long-run cost functions and π^* denotes the short-run elasticity of cost w.r.t. the fixed factors.

As noted by Hanoch (1975), the proper measure of scale economy is given by η^{-1}. It is important to note that the long-run cost elasticity can be retrieved from the variable cost elasticity only in the neighborhood of the static equilibrium levels of fixed factors.[7] This would require that the level of fixed factors K and R be simultaneously estimated with the level of variable costs and variable inputs.

A set of cost-share equations associated with the translog cost function is implied by the duality theory. According to Shephard's lemma, the derived demand for an input, is obtained by partially differentiating the cost function with respect to the factor (service) price of the input[8]. Applying Shephard's lemma to our translog cost function (1), we obtain the following equation for variable cost share of labor input,

(4) $$S_L = \beta_L + \beta_{LL} \ln w_L + \beta_{LY} \ln Y + \beta_{LK} \ln K_{-1} + \beta_{LR} \ln R_{-1} + \beta_{LT} T.$$

The Euler equations for the quasi-fixed factors take the following form,

(5) $$\mu_{KK}\Delta K(t) + \mu_{KR}\Delta R(t) + q_K(t) + E(t)\alpha(t, t+1)\{ -S_K(t+1)\cdot\left(\frac{C^v(t+1)\cdot w_K(t+1)}{K(t)}\right) + \mu_{KK}\Delta K(t+1) + \mu_{KR}\Delta R(t+1) - (1-\delta_K)\cdot q_K(t+1) \} = 0$$

(6) $$\mu_{KR}\Delta K(t) + \mu_{RR}\Delta R(t) + q_R(t) + E(t)\alpha(t, t+1)\{ -S_R(t+1)\cdot\left(\frac{C^v(t+1)\cdot w_R(t+1)}{R(t)}\right) + \mu_{KR}\Delta K(t+1) + \mu_{RR}\Delta R(t+1) - (1-\delta_R)\cdot q_R(t+1) \} = 0$$

where E is the expectations operator, α is the discount factor, q_K and q_R are the purchase price of physical and R&D investment and S_K and S_R are the variable cost share of physical and R&D capital stock, that is,

$$S_K = -(\beta_K + \beta_{LK} \ln w_L + \beta_{YK} \ln Y + \beta_{KK} \ln K_{-1} + \beta_{KR} \ln R_{-1} + \beta_{KT} T).$$

$$S_R = -(\beta_R + \beta_{LR} \ln w_L + \beta_{YR} \ln Y + \beta_{KR} \ln K_{-1} + \beta_{RR} \ln R_{-1} + \beta_{RT} T).$$

We assume an inverse demand function of the form

(7) $$\ln p_Y = \alpha_0 + \alpha_Y \cdot \ln Y + \alpha_S \cdot \ln S$$

where p_Y is the output price, Y is output level, and S is a vector of variables such as per capita income that shifts the demand function. α_Y is the inverse of the price elasticity of output demand. From the "MR = MC" condition, we can derive a revenue share equation

$$(8) \quad S_Y = (1+\alpha_Y)^{-1}(\beta_Y + \beta_{LY}\ln w_L + \beta_{YY}\ln Y + \beta_{KY}\ln K_{-1} + \beta_{RY}\ln R_{-1} + \beta_{YT}T).$$

Estimating the equation system (1), (4) - (8) enables us to obtain the properties of the underlying production technology, such as the degree of economies of scale, substitution and complementarities among the factors of production, as well as the response of costs to exogenous technical change and degree of capacity utilization. We can also determine the degree of mark-up that may prevail in the output market, and the effect of the changes in physical and R&D capital stocks on the behavior of variable costs, variable inputs, and output supply.

IV. Data Sources and Methods of Construction

The data on output, factors of production, and prices of inputs and outputs are for the total manufacturing sectors of the US, Japan, and Korea for the period 1971 to 1990. All the output and input data for Japan and Korea were converted to 1982 constant US dollars using the purchasing power parity exchange rates of 1982 taken from Summers and Heston (1991).

Gross output of the total manufacturing sector is used for the output measure. For the US, the gross output series both in current and constant prices are obtained from the Bureau of Labor Statistics. For Japan, we obtain the gross output in current prices from the UN, *Industrial Statistics Yearbook*, and we used the industrial production index for the manufacturing sector published by OECD in *Main Economic Indicators* as proxy for real output. For Korea, the gross output data is taken from *Report on Mining and Manufacturing Survey* (RMMS) of the

Economic Planning Board (EPB) of Korea.

The value of materials is calculated as the difference between the value of gross output and value-added, and the value-added data is obtained from OECD, *National Accounts* (vol.2) for US and Japan, while for Korea the value-added data is taken from the *RMMS*.

Labor is also expressed in real value terms by multiplying total man-hours by the base year wage rate. Data on the number of employees is from OECD, *National Accounts* for the US and Japan, and *RMMS* for Korea. Data on the working hours is from ILO, *Yearbook of Labor Statistics* for US and Japan (weekly), and Ministry of Labor, *Report on Monthly Labor Survey* for Korea (monthly). We assume 50 weeks in computing total man-hours for US and Japan. For the wage rate, we use an hourly earning rate from the ILO for the US and from the BLS for Japan. For Korea, we compute the hourly wage rate by dividing the total labor cost by total man-hours.

Net capital stock measured at the end-of-period is used for our physical capital stock. For US manufacturing, we use the net capital stock series constructed by Musgrave in *Survey of Current Business* (Jan. 92) and we take Pyo's capital stock series for Korean manufacturing. For Japan we construct the net capital stock by the perpetual inventory method where the benchmark estimate is taken from BLS (1988, p.68). The sources for the Japanese manufacturing investment data are BLS (1988) for 1971-80 and OECD, *Flows and Stocks of Fixed Capital* for 1980-90.

The R&D capital stock is constructed by the perpetual inventory method where the benchmark value (1971) is proxied by the R&D investment in 1972 divided by the sum of the depreciation rate of R&D capital stock and the average growth rate of output in each sector.

R&D expenditures data is taken from NSF, *Research and Development in Industry* for US, and the Ministry of Science & Technology of Japan and Korea, *Report on the Survey of R & D* for each country.

The output price series were generated as the ratio of real output and nominal output. The same procedure was used in deriving the price deflator for material. For Korea, we calculate a weighted average of the price deflators for materials and energy as our measure of the price deflators for materials. In the estimation, we used the prices for output and inputs (labor and material) as the net of corporate income tax. The corporate income tax rate for Japan was set to a constant (0.54) over the estimation period; for the US, we used the corporate income tax rate series collected by Pierre Mohnen for 1960-86 period and set to 0.46 for 1987-90: for Korea, it is from Korea Development Institute, *Statistics of Public Finance*.

The rental rate of physical capital is calculated as $w_K = p_K*(r + \delta_K)$, where r is the real rate of return, δ_K is the depreciation rate of capital, and p_K is the price deflator for capital investment. We used the long-term government bond yield rate as real rate of return, which is obtained from IMF, *International Financial Statistics*. For Korea, we use the average borrowing rate obtained from the Bank of Korea, *Financial Statements Analysis*. The depreciation rates used for physical capital are 10.9%, 12%, and 9%, for the US, Japan, and Korea, respectively, which are computed as weighted averages of depreciation rates for buildings and structures and plant and equipment.

We used the same formula to derive the rental rate of R&D capital with the depreciation rate assumed at 0.15 for all three countries. The price deflator for R&D investment is obtained from the following sources. For US, we use Jaffe-Griliches R&D deflator for private non-farm business sector, which was then extended to 1990 with GDP deflator; for Japan, we take the GDP deflator as a proxy for the price deflator for R&D investment; and for Korea it is provided by the Ministry of Science & Technology.

V. Estimation and Empirical Results

We estimate the system of equations consisting of the variable cost equation (1), the share equation (2) to (6) and the revenue share equation (8) jointly, using the aggregate data for the manufacturing sectors of the three countries. Error terms are appended to the estimating equations under the assumption that they represent optimizing errors, and are jointly normally distributed with zero expected value. The sample period is 1974-1990 and we employ a panel data for the three sectors with appropriate dummy variables to capture the differences in parameter estimates among the three sectors. The estimations was carried out by the nonlinear maximum likelihood method in TSP where the convergence criterion was set at 0.001.

V.1 Parameter Estimates

The model fits the data quite well as shown in table 4, the R-squares for the estimating equations are very high.[9] Moreover, the good fits of the share equations are not due predominantly to the time variable. Variations in factor prices and output quantity account for about 80 to 85% of total variations in factor shares and revenue share. The levels of the inputs, output and price level predicted by the fitted share equations correlate extremely closely with their actual levels, the correlation coefficients all being about 0.98.

With the exception of two parameters, the parameter estimates in table 4 are all statistically significant. All the coefficients for the dummy variables are statistically significant, suggesting differences in the production structures among the three manufacturing sectors. It is also clear that the partial elasticities of substitutions among the inputs are not unitary and that the cost shares are affected by technical change. The parameter estimates for the non-neutral technical change suggest that technical change is capital-using and labor- and research-saving as well as material-using.[10] There is also evidence of a neutral time drift of the cost functions for each of the three manufacturing sectors. Finally, the estimates of factor-price and output interaction terms suggest the underlying production technology is non-homothetic. Similarly, the interaction terms between output and quasi-fixed or fixed variables, such as physical and R&D capital, and time variable, are statistically significant, further confirming the non-homotheticity of the production technology.

V.2 Price and Cost Elasticities, Scale and Mark-up

In table 6, we present the own price elasticity of variable input demand and the variable cost elasticities with respect to output and index of technical change. The asymptotic standard errors of the elasticities are shown in parentheses. With few exceptions, the elasticities are statistically very significant. The own-price elasticity of labor, ε_{LL}, in the three manufacturing sectors, is estimated to be about -0.50. The own-price elasticity of materials input is much smaller in the range of -0.10.

The inverse of the price elasticity of output demand, ε_{PY}, varies among the three manufacturing sectors. The magnitude of ε_{PY} for the Japanese and manufacturing sectors are small implying a very elastic output demand structure while for the Korean manufacturing, it is about one third higher than those of the US and Japan. The degree of mark-up, θ, is calculated as

$$(9) \qquad \theta = \frac{(p_Y - MC)}{MC} = \frac{p_Y}{MC} - 1 = \frac{-\alpha_Y}{(1+\alpha_Y)}$$

where MC is the marginal cost. The estimated mark-up rates presented in table 5, are about 17% for the US, 20% for the Japanese, and approximately 30% for the Korean manufacturing sector suggesting that the Korean manufacturing sector is relatively more monopolistic than those of US and Japan. Our estimates are much smaller than those reported in Hall (1988) for the US, and by Park and Kwon (1995) for the Korean manufacturing sector.[11] The output elasticity of the variable cost is obtained by the expression $\eta_V = \varepsilon_{CY} = \partial \ln C^v / \partial \ln Y$ which allows the calculation of the short-run returns to scale, i.e., η_V^{-1}. The output elasticity of the variable cost is quite similar among the three sectors: 1.08 for the Korean and 1.10 for the US and Japanese manufacturing sectors in 1990. The elasticity of the variable cost with respect to time is an index of variable cost reduction due to technical change. The value of this elasticity, ε_{CT}, shown in table 5, is highest for the US, followed by Japan, while for Korea this elasticity is small and statistically not significant. We also report the estimated degree of scale and the mark-up for the three manufacturing sectors. The degree of economies of scale is measured by

$$(10) \qquad \eta^{-1} = \frac{(1-(\varepsilon_{CK} + \varepsilon_{CR}))}{\varepsilon_{CY}}$$

where $\varepsilon_{CK}, \varepsilon_{CR}$ and ε_{CY} are the elasticities of variable cost with respect to physical and R&D capital stock, and output. As shown in table 5, we found increasing returns to scale in all three sectors and they were all statistically significant; in 1990, it is about 1.14 for the US and Japanese manufacturing sectors, while somewhat lower for Korean manufacturing, about 1.05. These estimates suggest the total cost elasticities of about 0.87 for the US and Japanese, and 0.95 for the Korean manufacturing sector.

We next look at the impact of changes in the two types of capital on the variable inputs such as labor and materials, and on the variable cost. Two sets of elasticities are derived depending on whether output level is fixed or not. In the case of fixed output level, the estimated elasticities measure only the direct effects of capital while in the other case, the elasticities take into account both the direct and indirect effect of changes in physical and R&D capital. The differences between two elasticities will be the indirect effects through output adjustment.

Now, let's begin with the fixed output case. When output level is assumed to be fixed, the effects of physical and R&D capital on the variable input demand can be calculated using the expressions,

$$(11) \qquad \varepsilon_{Li} = \varepsilon_{Ci} + \frac{1}{S_L} \cdot \beta_{Li}, \qquad \varepsilon_{Mi} = \varepsilon_{Ci} + \frac{1}{S_M} \cdot (-\beta_{Li}) \qquad i = K, R$$

The figures in table 6 indicate that a one percentage increase in physical capital stock induces an increase of about 0.14 percentage of labor demand (complementary)[12], but its relationship with the materials is substitutional with the greatest effect for Japan and the US, followed closely by Korea. One percentage point increase in physical capital stock shifts down the average variable cost by the amount of -0.22 percent (Japan) to -0.13 percent (Korea). The effect of increase in R&D capital stock on labor and materials is negative, suggesting a substitutional relationship.

R&D capital also shifts variable costs downward, but the magnitudes of the shift are much smaller, particularly in Japan and Korea, than that of the physical capital.

So far we have assumed that the output level is not adjusted to the change in capital stocks but changing the level of capital stocks induces changes in the level of output, which in turn induces indirect effects on demand for variable inputs and variable cost.[13] First of all, the output elasticity w.r.t. capital stocks can be calculated by the following formula,

$$\text{(12)} \qquad \eta_{Yi} = \frac{\partial \ln Y}{\partial \ln K_i} = \frac{\varepsilon_{Ci} S_Y + \beta_{iY}(1+\varepsilon_{PY})^{-1}}{[S_Y(1+\varepsilon_{PY} - \varepsilon_{CY}) - \beta_{YY}(1+\varepsilon_{PY})^{-1}]} \qquad i = K, R$$

When the output level is allowed to vary, the elasticities of variable costs and variable factor demands w.r.t. capital stocks should be modified to include the indirect effect through output change. These elasticities are calculated as:

$$\eta_{Ci} = \left.\frac{\partial \ln C^v}{\partial \ln K_i}\right|_{\text{Y free}} = \varepsilon_{Ci} + \varepsilon_{CY} \cdot \eta_{Yi}$$

$$\text{(13)} \qquad \eta_{Li} = \left.\frac{\partial \ln L}{\partial \ln K_i}\right|_{\text{Y free}} = \varepsilon_{Li} + \eta_{Yi}(\varepsilon_{CY} + \frac{1}{S_L} \cdot \beta_{LY}) \qquad i = K, R$$

$$\eta_{Mi} = \left.\frac{\partial \ln M}{\partial \ln K_i}\right|_{\text{Y free}} = \varepsilon_{Mi} + \eta_{Yi}(\varepsilon_{CY} - \frac{1}{S_M} \cdot \beta_{LY})$$

As can be seen from table 6, the elasticities of output, variable inputs and variable cost, with respect to physical capital (η), are largest in Japanese manufacturing, followed by those in US manufacturing. These elasticities are much smaller, except for the labor elasticity, in Korean manufacturing. Furthermore, the induced output expansion effect of the increase in physical capital stock is sufficiently large to offset any direct substitution effects between physical capital stock and other variable factors. As a result, the demand for the variable inputs, and therefore, variable cost, increases when we take into account the output expansion effect followed by physical capital stock increase. Similarly, in response to an increase in R&D capital stock, output supply expands in all three sectors but it is by far the largest in the US manufacturing and almost nil (and insignificant) in the Korean manufacturing. The Japanese estimates fall in between the estimates for the US and Korea. Another observation is that in the case of R&D capital stock, the induced effects through the output expansion is not large enough to overcome possible substitution effects or direct cost-reducing effects. In addition, the magnitudes of the elasticities w.r.t. R&D capital stock are much smaller than the corresponding elasticities w.r.t. physical capital stock, reflecting a relatively limited role played by R&D capital stock compared to physical capital stock.

VI. Output and Productivity Growth

VI.1. Sources of Output Growth

The contributions of the factor inputs, and technical change to output growth are shown in table 7. The decomposition is based on the following approximation:

$$\Delta \ln Y(t) = \tfrac{1}{2}\sum_{i=1}^{4}[\varepsilon_{YX_i}(t) + \varepsilon_{YX_i}(t-1)]\Delta \ln X_i(t) + \tfrac{1}{2}[\varepsilon_{YT}(t) + \varepsilon_{YT}(t-1)] \quad (14)$$

where X = (L, M, K, R), ε_{YX} denote the respective output elasticities and ε_{YT} is a primal measure of technical change, i.e., $\varepsilon_{YT} = \partial \ln Y / \partial T$. The output elasticities can be retrieved from our structural parameter estimates of the restricted cost function using standard duality theory. For both variable and quasi-fixed factors, those output elasticities exceed long-run cost shares because of the increasing returns to scale. The contribution of each of the variables in (14) is calculated by the product of the respective (average) output elasticities with the growth rate of the corresponding variable.[14]

As shown in table 7, average growth rate of gross output was extremely high for the Korean manufacturing over the sample period, more than three times higher than that of Japanese and six times higher than that of US manufacturing. The contributions of various inputs to the growth of output differ considerably among the three sectors and over different sub-sample periods. The most significant source of output growth in all three sectors was the materials growth. It was responsible for 59%, 62%, and 76%, respectively, of gross output in the US, Japanese, and Korean manufacturing. The contribution of physical capital stock to output growth was similar in US and Japanese manufacturing, about 22%, while it was about 16% in Korean manufacturing. The contribution of labor input, on the other hand, differed significantly among the three sectors: it contributed negatively to the growth of output in the US, almost none in the Japanese manufacturing and positively in the Korean manufacturing (4.3%).

The R&D capital stock contributed significantly to the growth of output, particularly in the US and Japanese manufacturing sectors: it accounted for over 9% and 6% of growth of output in the US and Japan, while in Korea it was as small as about 1% of output growth. Considering the extremely rapid growth of R&D capital stock in the Korean manufacturing, this finding reflects a very small measure of output elasticity of R&D capital, which in turn can be explained by the limited role played by the R&D capital as a factor of production measured by its small cost share and the relatively smaller return to scale for the Korean manufacturing. In terms of absolute magnitude, however, the contribution of R&D capital stock in Korea, is not too far off: it is 0.12% compared with 0.18% and 0.12% for the Japanese and US manufacturing respectively.

Pure technical change estimated by the time derivative of the variable cost suggests that it contributes significantly in the US and Japanese manufacturing sectors. This is particularly true for the US, where technical change accounts for 28% of the output growth. Its contribution in Japanese manufacturing is about 13%, while in Korean manufacturing the contribution of autonomous technical change accounts for about 4% of the output growth. As in the case of R&D capital stock in three sectors, the differences shrink a lot if we look at the contribution of technical change in terms of the absolute size: 0.55%, 0.50%, and 0.33% for US, Japanese, and Korean manufacturing during the period of 1975-1990. Finally, when the contributions of the various inputs to the growth of gross output are accounted for, the size of the unexplained residuals in the decomposition of output growth is very small in each of the three sectors.

VI. 2 <u>Labor Productivity Growth</u>

In table 8 we provide a decomposition of labor productivity growth. The results are based on the approximation similar to that of output growth:

$$\begin{aligned}\Delta \ln Y(t) - \Delta \ln L(t) &= \tfrac{1}{2}\sum_{i=2}^{4}[\varepsilon_{YX_i}(t) + \varepsilon_{YX_i}(t-1)](\Delta \ln X_i(t) - \Delta \ln L(t)) \\ &\quad + \tfrac{1}{2}[\varepsilon_{YT}(t) + \varepsilon_{YT}(t-1)] + (\rho - 1)\Delta \ln L(t)\end{aligned} \tag{15}$$

where ρ is the scale elasticity. This approximation is readily obtained from (14) by noting that the sum of the output elasticities must equal scale elasticity. In the decomposition of labor productivity, the most significant contribution again stems from the growth of materials, particularly in the Japanese and Korean manufacturing sectors. The contribution of physical capital stock is the second most important factor in the growth of labor productivity in all three countries.[15]

The relative contribution of R&D capital stock to the labor productivity growth is largest in the US (7.2%), followed by the Japanese manufacturing sector (6.8%). For the Korean manufacturing it is a mere 1.4% over the period 1975-90. However, the absolute size of the contributions of R&D capital stock is 0.18%, 0.25%, and 0.11% for the US, Japanese and Korean manufacturing respectively. Autonomous technical change also plays an important role in the US and Japanese manufacturing, accounting for about 10-13% of labor productivity growth while its role becomes minimal in the Korean manufacturing, explaining less than 6% of labor productivity growth. Again we can observe only a small gap, if any, between the Korean manufacturing on one side and the US and Japanese manufacturing on the other as far as the absolute magnitude is concerned. The last term on the right hand side of equation (15) follows from the fact that degree of scale is not equal to one. The contribution of this term to labor productivity is shown in column 3 of table 8. Its effect is positive and sizable (as large as the sum of R&D capital stock and technical change effects) in the Korean, almost none in the Japanese, and negative for the US manufacturing. This reflects the growth pattern of the labor input in the three manufacturing sectors over the period 1975-90; since all three sectors have increasing returns to scale, the negative contribution of labor input to the labor productivity growth implies nothing but negative growth of labor in the US manufacturing sector.

VI. 3 Total Factor Productivity Growth

The total factor productivity (TFP) is basically a measure of output per unit of total factor input. Total factor input is a weighted sum of all factors of production, where the weights depend on the underlying production function. As is well known, TFP growth is an appropriate measure of technical change under certain conditions such as perfect competition in input and output markets, constant return to scale technology, and the instantaneous adjustment of factors (i.e., all factors are variable and utilized at a constant rate). These conditions are often assumed *apriori* and imposed in calculating the traditional measures of TFP growth.[16] However, in our approach we allow for the degree of mark-up, the adjustment cost, and the degree of economies of scale to be estimated. This permits us to decompose the conventional TFP growth further into the possible bias ascribed to the assumptions violated and factor out the contribution of pure technical change, i.e., a shift in the production frontier itself.

This is easier to visualize in terms of the long-run average-cost curve. Suppose we observe over time that the average cost of production (in real terms) has fallen. With constant returns to scale, the average cost does not depend on the level of output, so that the average cost curve is horizontal. It follows that the observed decline in average cost must be due solely to the downward shifts of the average-cost curve over time, which we shall label as the contribution of pure technical change. If there are economies of scale, however, average cost declines with increases in the level of output. Then the observed reductions in average cost over time will be due partly to movements along a given downward-sloping average-cost curve, and partly to downward shifts in the curve. However, since technical change raises the output produced with the existing level of inputs and thereby shifts the derived demands for inputs, part of the growth in total factor input is indirectly induced by technical change (Hulten (1979)). In the presence of increasing returns, this raises the level of TFP. This indirect contribution of technical change illustrates one aspect of interaction between scale economies and technical change, which should be taken into account if a proper attribution of the TFP growth is to be made. The TFP growth can be defined as,

$$(16) \qquad T\dot{F}P = \dot{Y} - \sum_{i=L,M,K} \left(\frac{w_i X_i}{p_Y Y}\right)\dot{X}_i$$

where a dot represents the rate of growth. The quasi-Divisia index of inputs is a weighted sum of rates of growth of traditional inputs, where the weights are the value shares of inputs.[17] Recall that we defined the pricing rule as $p_Y = (1+\alpha_Y)^{-1} \cdot MC$. The TFP growth equation (16) can be written as,

$$(17) \qquad T\dot{F}P = \dot{Y} - (1+\alpha_Y)\sum_{i=L,M} \left(\frac{w_i X_i}{C}\right)\dot{X}_i - (1+\alpha_Y)\left(\frac{w_K K}{C}\right)\dot{K}$$

To account for the effect of economies of scale, consider the variable cost function

$$C^v = w_L \cdot L + w_M \cdot M = G(w_L, w_M, Y, K; R, T).$$

Differentiating this function and rearranging a little bit, we get,

$$(18) \qquad \sum_{i=L,M} \left(\frac{w_i X_i}{C}\right)\dot{X}_i = \eta\dot{Y} + \frac{1}{A}\left(\frac{\partial \ln C^v}{\partial \ln K}\right)\dot{K} + \frac{1}{A}\left(\frac{\partial \ln C^v}{\partial \ln R}\right)\dot{R} + \frac{1}{A}\frac{\partial \ln C^v}{\partial T}$$

where η is the output elasticity of long-run cost function and $A = 1 - \dfrac{\partial \ln C^v}{\partial \ln K}$.

Substituting (18) into TFP growth expression (17), we get the decomposition of TFP growth,

(19)

$$\dot{TFP} = (1-\eta)\dot{Y} + \sum_{i=L,M} (A^{-1}\varepsilon_{Ci} - S_i)\dot{X}_i - (A^{-1}\varepsilon_{CK} + S_K)\dot{K}$$

$$- A^{-1}\varepsilon_{CR}\dot{R} - A^{-1}\varepsilon_{CT}$$

$$- [(1+\alpha_Y)-1]\cdot\{\eta\dot{Y} - \sum_{i=L,M} (A^{-1}\varepsilon_{Ci} - S_i)\dot{X}_i + (A^{-1}\varepsilon_{CK} + S_K)\dot{K} + A^{-1}\varepsilon_{CR}\dot{R} + A^{-1}\varepsilon_{CT}\}$$

where ε_{Ci} denotes the variable cost elasticity w.r.t. the input i as defined before.

The TFP growth is decomposed into five components: scale effect, disequilibrium effect, R&D effect, pure technical change effect, and mark-up effect.Table 9 presents the decomposition of total factor productivity growth based on (19) for the three manufacturing sectors for the period 1975-1990 and its two sub-periods. The TFP growth of the US manufacturing sector was the smallest (0.73%), while that of Korean manufacturing was the largest (3.32%) among the three sectors over the 1975-90 period. The TFP growth rates based on the Divisia index shown in column (1) of table 9 are clearly not an accurate measure of technical change in the three manufacturing sectors. As noted earlier, only under very specific conditions of perfect competition, constant return to scale technology, and instantaneous adjustment of all inputs could the conventional measure of TFP growth be an appropriate measure of technical change and these conditions are clearly absent from these three sectors.

The most important contributor to TFP growth is the scale effect in all three sectors. This effect is responsible respectively for about 35%, 38%, and 30% of TFP growth in the US, Japanese, and Korean manufacturing sectors. The contribution of the mark-up is unusually high in the Korean manufacturing (1.9%). This is mainly due to the extremely high growth rate of output experienced by the Korean manufacturing sector, which (according to the last term in (19)) magnifies the effect of price elasticity of demand on total factor productivity.[18] The mark-up effect was minor for the US, about 2.6% of TFP growth, and moderately large for Japanese manufacturing, about 15% of TFP growth. In contrast, it accounted for almost 57% of TFP growth in Korean manufacturing. The disequilibrium effect due to adjustment costs was fairly small, as one would expect, in all of the three sectors.

The contribution of R&D capital to TFP growth in absolute term was the largest in Japanese manufacturing 0.23%. For the US, this contribution was 0.16%, while for Korean manufacturing, it was 0.09%, the smallest of all. In terms of relative contribution to TFP growth, the growth of R&D capital accounted for about 23% of the estimated TFP growth for the US, 20% for the Japanese, and about 4% for the Korean manufacturing sector. The contribution of technical change follows the same pattern. The magnitude of technical change is fairly similar across the three sectors, ranging from 0.30% for the US to 0.34% for Japanese manufacturing and 0.40% for Korean manufacturing. However, in terms of relative contribution to TFP growth, technical change's largest contribution is in the US, about 43%, followed by Japan with about 32%; it contributes about 13% in the Korean manufacturing sector. The Korean manufacturing seems to lag significantly behind the Japanese and US sectors in both types of technological effects associated with R&D capital and autonomous technology.

VII. Rates of Return on Physical and R&D Capital

An important issue to consider is to estimate, using our econometric model, the rates of return to physical and R&D capital in the three manufacturing sectors. There are several ways to calculate the rates of return. The gross rates of return would include the depreciation rates of the two types of capital while the net rates of return will be exclusive of the depreciation rate; our results are in terms of net rates of return which include the adjustment costs of the quasi fixed inputs, K and R.[19]

The rates of net return on capital stock is given by

$$r_i = \frac{\left(-\partial C^v / \partial K_i\right)}{p_i} - \delta_i \qquad i = K, R \tag{20}$$

where δ_i is the depreciation rate.[20]

The internal rates of return using (20) for the two types of capital are shown in table 10. The results are quite suggestive: the rates of return on physical capital for the US manufacturing sector is about 11% for the period 1980-1990, and higher than that for Japanese manufacturing; the two rates of return are almost the same in 1990. The rates of return on R&D in the US and Japanese sectors are quite similar, and somewhat higher than the corresponding rates on physical capital. However, the net internal rate of return on R&D in Japanese manufacturing is rising rather rapidly in the 1980s, and by 1990 it exceeds the rate of return on R&D of the US manufacturing sector by almost 40%. The gap between the rates of return on physical and R&D capital also seems to have widened over time in the Japanese manufacturing sector.

What is remarkable is the situation in the Korean manufacturing sector. The internal rates of return for both physical and R&D capital are quite high compared to those in the Japanese and US manufacturing sectors. For the sample period 1980-1990, the rate of return for physical capital, r_K, is consistently about 18% for the Korean manufacturing, while those in the other two countries are about 10% or lower. The most significant difference can be observed in the rates of return on R&D capital. The internal rate of return in the Korean manufacturing is about 50% to 60% higher than that of the corresponding rates in the US and Japanese manufacturing sectors. The rates of return on both types of capital vary somewhat over the period and generally they have been declining in recent years. The rates of return in Korea in the mid-1980s declined from the very high levels experienced in the early 1970s, but rose in the late 1980s. What these rates suggest is that R&D investment in Korea has been quite productive when compared to that in the US and Japanese manufacturing sectors. It has had a higher net rate of return than the physical investment, in most years in Korea; only in the last two years, 1989 and 1990, the rates of return on R&D and physical capital seem to have converged in the Korean manufacturing sector.

IX. Summary & Conclusion

The estimation results of this paper suggest that the output and productivity growth experienced by the Japanese and particularly by the Korean manufacturing sector in the period under consideration has been mainly due to the commitment of substantial resources of labor, investment in physical and R&D capital. The converse is also true; the slow growth of output in the US manufacturing sector has been mainly due to slow growth of capital and labor.

R&D investment has been a significant contributor to growth of output and productivity in the US and Japan. The contribution of R&D capital to the growth of output and productivity in the Korean manufacturing has been relatively small over this period, though it has been rising rapidly over time and the contribution of R&D in Korean manufacturing in absolute terms is not that far from that of other two countries. The net rates of return to both physical and R&D capital in the Korean manufacturing have been very impressive and has played a significant role in inducing a steadily high growth of investment in physical and R&D capital.

The analysis also suggests that the rate of technical change measured by the diminution of costs over time is similar among the three sectors. This rate is rather small, being about 0.3% to 0.5%, in contrast to the magnitudes of the traditional TFP growth rate estimates reported in the literature. The conventional TFP growth is not an appropriate measure of technical change when perfect competition does not prevail or when the economies of scale or the adjustment costs are present. When the contribution of these sources are removed from the traditional measure of TFP growth, the actual rate of technical change is rather small.

The conclusion that we reach is that if higher growth of output is the desired objective, the main stimulant in the growth process is the factor accumulation. Autonomous technical change, though important, plays a much smaller role in all three sectors and its magnitudes indicating shift in the production frontier are surprisingly similar in these sectors. The same conclusion holds if we use a more comprehensive measure of technical change by adding the contributions of autonomous technical change, R&D investment, and the "residual" due to statistical estimation. It is the resource investment that is the main promoter of the phenomenal growth rates as observed in the Far Eastern economies; the conventional TFP growth mismeasures the contribution of technical change in all the sectors considered.

NOTES

An earlier version of this paper was presented at the Pacific Rim Conference of the Western Economic Association International held at Hong Kong, January 10-15, 1996. The authors would like to thank Marilyn Harris and Frances Hui for their help in preparing this manuscript. Support from the C.V. Starr Center for Applied Economics of New York University is also gratefully acknowledged.

[1] Park and Kwon (1995) estimated the production structures of 28 Korean manufacturing industries including total manufacturing, jointly with markups, scale economies, and capacity utilization rate based on the short-run generalized Leontief cost function. They found the evidence of market imperfection, scale economies, and the upward biases of the traditional TFP growth measure.

[2] Young (1995) reports that for 1966-90 period, the average growth of output (measured by value-added), capital, and labor for the Korean total manufacturing sector is 14.1%, 15.1%, and 6.3%, respectively.

[3] See Young (1995) for further discussion of growth of labor participation in Korea.

[4] The conventional total factor productivity growth with value added as measure of output is 1.91% for the US, 3.09% for the Japanese, and 12.90% for the Korean manufacturing during the period 1975-1990.

[5] See, for example, Lau (1976).

[6] See Caves, Christensen and Swanson (1981).

[7] See Schankerman and Nadiri (1986) for further discussion.

[8] See Shephard (1970).

[9] This is encouraging, since translog models often yield relatively poor fits for cost share equations. See, for example, Denny and Fuss (1977).

[10] Kwon and Yuhn (1990) also reports capital-using, labor-saving technical change in the Korean total manufacturing during 1961-81 period.

[11] Note that the mark-up rate is determined solely by the demand side, i.e., the output demand elasticity, and is constant over the sample period. Park and Kwon (1995) assume a variable mark-up rate and report more or less constant rate of 60%.

[12] Kwon and Yuhn (1990), however, found a relatively high elasticity of substitution between capital stock and labor (0.93).

[13] Suppose there is an initial equilibrium that is disturbed by a shift in the level of technology or levels of the quasi-fixed inputs. All else is kept constant, including factor prices, which are considered exogenous. At the old level of variable inputs, the shift in technology lowers the average variable cost curve and hence raises the equilibrium level of output, depending on the elasticity of product demand. Since the derived demand for a factor depends inter alia on the level of output, the

old levels of inputs will no longer be optimal. Some input expansion will be called for as long as inputs are not regressive. On the other hand, the shift in the technology level also lowers the input requirement per unit of output, that is, it shifts isoquants toward the origin. This lowers the total factor input required to produce a given level of output.

[14] See Nadiri and Prucha (1990a, 1990b) for a detailed derivation.

[15] Dollar and Sokoloff (1990) report a distinctive productivity growth pattern between the heavy industries and the light & medium industries in the Korean manufacturing sector. They find that the capital deepening is the principal source of labor productivity growth in the heavy sub-sector, contributing more than 70%, while the TFP growth accounts for over 60% of labor productivity growth in light and medium sector for 1963-1979 period. Their analysis is based on the value-added framework, not gross output.

[16] See Young (1995) for the TFP growth rates in East Asian countries; there are numerous other studies for other countries, especially OECD countries, that can be readily mentioned.

[17] Hulten (1973) demonstrates that the Divisia index conserves all the information contained in the components and that no other index can do better. It is well known that the Divisia index is a line integral and that its value may therefore not be path independent. The index will be path-independent if and only if the aggregate over which it is defined actually exists. Path independence is therefore an essential element of any acceptable Divisia index.

[18] The contribution of the elements other than output growth ($\eta \dot{Y}$) in the second bracket of the last term in equation (19) are relatively small.

[19] The parameter estimates used to calculate the net rate of return is given by

$$r_i = \frac{1}{p_i} \left[\hat{S}_i \left(\frac{\hat{C}^v}{K_i} \right) + (\mu_{ii} \, \Delta K_i + \mu_{ij} \, \Delta K_j) \right] \qquad i = K, R$$

where $\hat{C}^V$, $\hat{S}_i$ are respectively the estimate values of variable cost, estimate share of physical and R&D capital in variable cost; μ_{ii} and μ_{ij} are the own- and cross-adjustment cost coefficients.

[20] See Bernstein and Nadiri (1988) for further discussion.

Table 1. Growth of Output and Inputs in the Total Manufacturing Sector of the United States, Japan and Korea , 1975-1990 (in percentage)

	Output			**Labor**			**Materials**			**Physical Capital**			**R&D Capital**		
	US	**Japan**	**Korea**	**US**	**Japan**	**Korea**	**US**	**Japan**	**Korea**	**US**	**Japan**	**Korea**	**US**	**Japan**	**Korea**
1975-80	1.0	3.5	13.4	-0.2	-0.6	8.2	0.8	2.7	12.2	3.7	3.6	18.5	0.5	6.8	35.3
1981-85	1.6	4.0	10.1	-1.2	1.3	3.7	0.7	2.3	8.6	2.0	6.0	8.4	3.1	9.3	28.2
1986-90	3.3	4.5	15.2	-0.2	0.3	2.6	3.2	5.8	14.8	1.5	7.0	15.1	3.9	9.0	25.1
1975-90	1.9	4.0	12.9	-0.5	0.3	5.0	1.5	3.2	11.9	2.5	5.4	14.3	2.4	8.3	29.9

Table 2. Cost Shares of Inputs in the Total Manufacturing Sector of the United States, Japan and Korea, 1975-1990 (in percentage)

	Labor			**Materials**			**Physical Capital**			**R & D Capital**		
	US	**Japan**	**Korea**	**US**	**Japan**	**Korea**	**US**	**Japan**	**Korea**	**US**	**Japan**	**Korea**
1975-80	15.7	14.8	11.1	64.7	67.4	72.7	13.1	14.9	16.0	6.5	2.9	0.20
1981-85	14.3	14.1	9.7	61.6	67.0	71.0	16.2	15.4	18.8	7.8	3.5	0.49
1986-90	14.1	14.6	11.2	64.2	63.6	70.1	13.5	17.2	17.4	8.2	4.6	1.31
1975-90	14.8	14.5	10.7	63.6	66.1	71.4	14.2	15.8	17.3	7.5	3.6	0.64

*Input shares in total cost

Table 3. Average Annual Rates of Growth of Total and Partial Factor Productivity in the Total Manufacturing Sector of the United States, Japan and Korea, 1975-1990 (in percentage)

	Total Factor Productivity*			**Labor Productivity**			**Materials Productivity**			**Physical Capital Productivity**			**R&D Capital Productivity**		
	US	**Japan**	**Korea**	**US**	**Japan**	**Korea**	**US**	**Japan**	**Korea**	**US**	**Japan**	**Korea**	**US**	**Japan**	**Korea**
1975-80	0.08	0.99	0.35	1.25	4.07	5.19	0.30	0.76	1.21	-2.58	-0.08	-5.07	0.59	-3.28	-21.88
1981-90	0.77	0.51	1.80	3.22	3.44	9.51	0.49	0.76	0.93	0.74	-2.23	0.92	-1.05	-4.92	-13.99
1975-90	0.51	0.69	1.26	2.48	3.68	7.89	0.42	0.76	1.04	-0.51	-1.43	-1.32	-0.44	-4.31	-16.95

*TFP growth was calculated as a Tornqvist index approximation with labor, materials, capital and R&D as inputs and their total cost shares as weights.

Table 4. The Parameter Estimates: Physical Capital and R&D Capital Quasi-fixed.[a]

Parameter	Estimate	Standard Error	Parameter	Estimate	Standard Error
α_0	1.054	0.068	β_{LL}	0.056	0.006
α_Y	-0.144	0.009	β_{YY}	-0.011	0.030
α_{Y2}	-0.019	0.003	β_{RR}	-0.014	0.004
α_{Y3}	-0.082	0.006	β_{TT}	-0.0004	0.0002
β_0	-5.531	1.749	β_{LY}	-0.042	0.009
β_{02}	3.809	1.326	β_{LK}	0.052	0.006
β_{03}	5.123	1.639	β_{LR}	-0.004	0.003
β_L	0.227	0.054	β_{KY}	0.049	0.018
β_{L2}	-0.007	0.005	β_{RY}	0.071	0.011
β_{L3}	-0.071	0.015	β_{RY2}	-0.036	0.011
β_Y	0.444	0.191	β_{RY3}	-0.061	0.011
β_{Y2}	0.293	0.062	β_{RK}	-0.042	0.014
β_{Y3}	0.503	0.087	β_{RK2}	0.050	0.014
β_K	2.716	0.427	β_{RK3}	0.069	0.015
β_{K2}	-1.489	0.304	β_{LT}	-0.003	0.0003
β_{K3}	-2.412	0.409	β_{YT}	-0.001	0.001
β_R	-0.251	0.143	β_{KT}	0.010	0.002
β_{R2}	0.007	0.107	β_{RT}	-0.001	0.0006
β_{R3}	0.105	0.155	μ_{KK}	0.0002	0.0006
β_T	-0.053	0.014	μ_{KK2}	0.0003	0.0003
β_{T2}	0.006	0.003	μ_{KK3}	0.0042	0.0008
β_{T3}	0.017	0.008	μ_{KR}	0.0002	0.0001
β_{KK}	-0.474	0.055	μ_{RR}	0.0014	0.0006
β_{KK2}	0.145	0.043	μ_{RR2}	0.0030	0.0022
β_{KK3}	0.266	0.054	μ_{RR3}	0.0249	0.0940
Log of likelihood				962.81	
Variable Cost	$R^2 = 0.999$		Labor	$R^2 = 0.937$	
Output Supply	$R^2 = 0.700$		Physical Capital	$R^2 = 0.781$	
Output Demand	$R^2 = 0.669$		R&D Capital	$R^2 = 0.994$	

[a] Estimated standard errors are in parentheses. The subscripts *2* and *3* denote the country dummy variables, 2 for Japan and 3 for Korea respectively. α's are the parameters from the inverse demand function, β's from the translog variable-cost function, and μ's are the adjustment cost parameters.

Table 5. Price, Cost and Variable Input Elasticities and Estimated Scale and Markups in the Total Manufacturing Sectors of United States, Japan and Korea (1990 values).[a]

	U.S.	Japan	Korea
	Own Price Elasticities of Variable Inputs		
ε_{LL}	-0.501 (0.035)	-0.507 (0.034)	-0.491 (0.037)
ε_{MM}	-0.101 (0.007)	-0.107 (0.007)	-0.092 (0.007)
	Price and Variable Cost Elasticities		
ε_{PY}	-0.142 (0.022)	-0.163 (0.010)	-0.226 (0.014)
ε_{CY}	1.099 (0.015)	1.103 (0.014)	1.084 (0.018)
ε_{CT}	-0.003 (0.002)	-0.004 (0.002)	-0.003 (0.003)
	Scale and Markup		
SCALE	1.146 (0.018)	1.137 (0.020)	1.054 (0.023)
MARKUP	16.8% (0.012)	19.4% (0.014)	29.2% (0.023)

[a] Asymptotic standard errors are in parentheses.

Table 6. Short-Run Cost and Input Elasticities with respect to Physical and R&D Capital in the Total Manufacturing Sectors of United States, Japan and Korea (1990 values).[a]

	U.S.	Japan	Korea
	When Output Level is Fixed		
ε_{LK}	0.139 (0.037)	0.076 (0.037)	0.195 (0.047)
ε_{MK}	-0.231 (0.011)	-0.282 (0.015)	-0.192 (0.012)
ε_{CK}	-0.169 (0.007)	-0.219 (0.012)	-0.131 (0.013)
ε_{LR}	0.116 (0.021)	0.059 (0.019)	0.038 (0.024)
ε_{MR}	0.086 (0.005)	0.030 (0.007)	0.007 (0.004)
ε_{CR}	0.091 (0.004)	0.035 (0.006)	0.012 (0.005)
	When Output Level is Allowed to Vary		
η_{YK}	0.535 (0.068)	0.683 (0.094)	0.287 (0.083)
η_{LK}	0.592 (0.074)	0.664 (0.091)	0.429 (0.063)
η_{MK}	0.384 (0.075)	0.507 (0.100)	0.133 (0.085)
η_{CK}	0.419 (0.072)	0.534 (0.096)	0.180 (0.079)
η_{YR}	0.115 (0.045)	0.015 (0.043)	0.009 (0.028)
η_{LR}	-0.018 (0.041)	-0.045 (0.040)	-0.030 (0.026)
η_{MR}	0.046 (0.050)	-0.012 (0.046)	0.004 (0.029)
η_{CR}	0.035 (0.048)	-0.018 (0.044)	-0.002 (0.027)

[a] Asymptotic standard errors are in parentheses.

Table 7. Sources of Output Growth for the Total Manufacturing Sectors of the United States, Japan and Korea (in percentage)

	Gross Output	**Labor Effect***	**Materials Effect***	**Capital Effect***	**R&D Effect***	**Technical Change**	**Residual**
				United States			
1975-1980	1.09	-0.03	0.62	0.34	0.01	0.81	-0.66
1981-1990	2.47	-0.13	1.55	0.18	0.18	0.39	0.30
1975-1990	1.95	-0.09	1.20	0.24	0.12	0.55	-0.06
				Japan			
1975-1980	3.47	-0.11	2.32	0.30	0.12	0.75	0.08
1981-1990	4.27	0.15	3.32	0.60	0.21	0.36	-0.37
1975-1990	3.97	0.05	2.95	0.49	0.18	0.50	-0.20
				Korea			
1975-1980	13.39	0.99	10.47	2.53	0.02	0.46	-1.09
1981-1990	12.66	0.34	9.62	1.58	0.18	0.25	0.02
1975-1990	12.93	0.59	9.94	1.94	0.12	0.33	0.68

* Growth rate of inputs weighted by its output elasticity.

Table 8. Sources of Labor Productivity Growth for the Total Manufacturing Sectors of the United States, Japan and Korea, 1975-1990 (in percentage)

	Labor Productivity	**Labor Effect***	**Materials Effect***	**Capital Effect***	**R&D Effect***	**Technical Change**	**Residual**
				United States			
1975-1980	1.25	0.01	0.71	0.56	0.02	0.28	-0.32
1981-1985	2.86	-0.23	1.49	0.62	0.34	0.30	0.35
1986-1990	3.58	-0.04	2.61	0.27	0.40	0.45	-0.11
1975-1990	2.48	-0.08	1.54	0.49	0.24	0.34	-0.05
				Japan			
1975-1980	4.07	-0.09	2.54	0.68	0.25	0.36	0.34
1981-1985	2.69	0.18	1.36	0.72	0.26	0.39	-0.23
1986-1990	4.20	0.06	2.70	1.18	0.41	0.41	-0.56
1975-1990	3.68	0.04	2.22	0.85	0.30	0.38	-0.12
				Korea			
1975-1980	5.19	0.97	3.33	1.98	0.03	0.66	-1.78
1981-1985	6.36	0.43	3.99	0.81	0.06	0.32	0.75
1986-1990	12.67	0.22	9.72	2.08	0.33	0.34	-0.01
1975-1990	7.89	0.56	5.54	1.65	0.13	0.45	-0.44

Table 9. Decomposition of the Traditional Measure of Total Factor Productivity Growth for the Total Manufacturing Sectors of the United States, Japan and Korea, 1975-1990 (in percentage)

	Total Factor Productivity*	Technical Change	R&D Effect	Scale Effect	Disequilibrium Effect	Markup Effect	Residual
			United States				
1975-1980	0.16	0.24	0.02	0.12	0.06	0.04	-0.31
1981-1990	1.07	0.33	0.24	0.34	0.02	0.01	0.12
1975-1990	0.73	0.30	0.16	0.26	0.03	0.02	-0.04
			Japan				
1975-1980	1.31	0.32	0.19	0.36	0.03	0.18	0.24
1981-1990	1.04	0.35	0.25	0.47	0.06	1.13	0.18
1975-1990	1.14	0.34	0.23	0.43	0.05	0.18	-0.08
			Korea				
1975-1980	2.69	0.56	-0.02	1.14	-0.01	1.80	-0.79
1981-1990	3.43	0.31	0.19	0.81	-0.06	1.98	0.21
1975-1990	3.15	0.40	0.11	0.93	-0.04	1.91	-0.16

* The traditional TFP measure is the Tornqvist index approximation of total factor productivity growth where the revenue (not total cost) shares of labor, materials, and capital were used as weights for the relevant input growth.

Table 10. Internal Rates of Return on Net Investment in Capital and R & D for the Total Manufacturing Sectors of United States, Japan and Korea (in percentage).

Year	Physical Capital			R&D Capital		
	U.S.	Japan	Korea	U.S.	Japan	Korea
1980-90	10.63	7.69	17.84	12.39	11.73	19.42
1980	11.30	9.27	17.55	14.16	12.01	31.46
1985	11.74	7.96	15.06	11.56	12.31	18.94
1990	9.63	9.33	22.78	11.11	15.60	23.88