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I. Introduction

There is a vast literature analyzing the sources of output, labor productivity, and technical change in the manufacturing sectors, particularly in the US and other OECD countries. Research has been particularly focused on comparing the structure of production and behavior of total factor productivity in the US and Japanese manufacturing sectors. What has not been systematically analyzed is the contrast of the experiences of some of the newly industrialized countries like South Korea with those of the advanced countries such as the US and Japan. In this paper we shall specifically contrast the sources of productivity growth between the US, Japanese, and Korean manufacturing sectors for the period 1974-1990. Of particular interest is assessing the role and effect of R&D capital on the productivity performance of these three sectors. Considerable resources have been devoted to R&D investment in both the US and Japan, and since 1980 the Korean government and private industry have vigorously increased their R&D effort to enhance technological capacity and efficiency of the manufacturing industries.

Several specific issues are analyzed:

(1) We have developed an econometric model to analyze the sources of growth of output, labor productivity, and estimate the rate of technical change in each of these industries. The econometric model used to identify the sources of labor productivity growth 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. The model is fitted to cross-section time-series data for the US, Japanese, and Korean total manufacturing sectors for the period 1974-1990. Physical and R&D capital are treated in the model as quasi-fixed inputs subject to adjustment costs. In addition, to capture the effect of the demand on productivity growth, we estimate the degree of mark-up in each sector by including the slope of the demand curve as a parameter of the model.

(2) The basic characteristics of the production process in the total manufacturing sectors of these countries are identified. We have estimated the degree of scale and substitution among
the inputs and the adjustment costs associated with the quasi-fixed factors of production, such as physical and R&D capital. Using the parameter estimates of the model, we have calculated:

(a) the price and cost elasticities, degree of scale economies, and markup in each industry;

(b) the rates of return on physical and R&D capital investment for each industry;

(c) the sources of growth of output and labor productivity are identified. The rate of technical change is estimated in each industry;

(d) the role of R&D capital in enhancing productivity growth in the three industries.

An important issue analyzed in this paper is the calculation of the probable time period that it will take for the manufacturing sector in Korea to catch up with that in Japan in terms of the level of labor productivity. The catch-up period will depend on how fast the level of labor productivity grows in Japan and Korea in the years to come. To compare the levels of labor productivity in the manufacturing sectors of the two countries, we establish a reference case in terms of the level of labor productivity for the Japanese sector, and compare the evolution of the Korean manufacturing level with this reference case over the period 1991-2001. The effect of increased R&D investment on labor productivity for the projection period is examined under several circumstances, particularly the case where the ratio of total R&D expenditure to GNP is increased to 5% by the year 2000, the announced objective of the Korean government.

The rest of the paper is organized as follows: In section II we provide some descriptive characteristics of the data used in our analysis and provide a brief description of the R&D policy and expenditure in South Korea in recent years. 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 identified. 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 analyzed 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. In section VIII we describe the methodology and quantitative estimates of the factors that may allow the level of labor productivity of the Korean manufacturing sector to catch up with that of the Japanese manufacturing sector. We also provide results on the effect of accelerated R&D expenditure policy in Korea in the catch-up process. We provide the estimated time that the catch-up process in the manufacturing sector may complete itself if the Korean government target of 5% R&D expenditure to GNP is reached by the year 2000. The paper concludes with a brief summary and conclusion.

II.A Some Descriptive Characteristics

Before discussing the evolution of the productivity indices and the growth rates of the output and inputs, we should note that the manufacturing sectors of these three countries differ considerably in size, and that the types of industries comprising each of the manufacturing sectors are quite different. For example, in terms of output, level of labor productivity, physical capital, and R&D intensity, US manufacturing is still the dominant sector. At the end of 1990 the US manufacturing sector was about 1.8 times and 7.5 times bigger in terms of gross output and value added than the Japanese and Korean sectors, respectively. The magnitude of total man hours worked in US manufacturing was about 1.6 times that of Japan, and about 4.5 times that of Korea. Similarly, the size of physical and R&D capital stock in the US manufacturing sector are much larger than those in the Japanese and Korean manufacturing sectors. Output of capital ratio and output/R&D capital stock varied considerably among the three sectors. This is particularly true when we look at the ratio of output to R&D capital stock. This ratio for US manufacturing is three times greater than that in Japanese manufacturing, and almost fifty times
larger than in the Korean manufacturing sector. Finally, in terms of level of labor productivity, measured as the ratio of gross output to man-hours, the level of US manufacturing labor productivity stood at 74.9, while those for the Japanese and Korean manufacturing sectors stand at 58.5 and 46.31 in 1990.

However, when the growth rates of output, gross or value added, and factors of production are considered, the increases in output growth and labor productivity in 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. It is clear that during the entire 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 very rapid, 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 period 1975-1990. 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 rates of labor measured in hours worked showed markedly different patterns in the manufacturing sectors of the three countries. In the US, the growth rate of labor input was negative for the period as a whole, -0.5%. The major decline in growth of labor input in US manufacturing was experienced in 1981-85, when it fell by over a full percentage point. The growth of man hours in the Japanese manufacturing sector was positive but modest over the period 1975-90, about 0.3%. This growth rate varied over the sub-periods; it declined at an average rate of -0.6% in the late 1970s, but grew at 1.3% in 1980-85, and moderated in 1986-90, when man hours grew at about 0.3% per annum. The growth rate of labor input in Korean
manufacturing was quite different, growing at the high rate of over 8% in the second half of the 1970s, but slowing down in the next two periods to 3.7 and 2.6 percent, respectively. Compared to US and Japanese manufacturing, Korean manufacturing sector employment increased substantially, particularly in the early period of Korean economic development.

The same picture seems to be true for the growth rate of materials in the manufacturing sectors of these countries since the mid-1970s. Material input grew much faster in Japanese and particularly Korean manufacturing than in the US. The growth of materials in US manufacturing was less than 1% in 1975-85, then rose slightly to over 3% in 1986-90. The corresponding growth rates for the Japanese manufacturing sector for the same periods were approximately over 2% and nearly 6%. The growth rates of materials in Korean manufacturing were in the double digits, about 12% for the entire period of 1975-90; it grew at a rate of over 12% in 1975-90, declined to 8.6% in the early 1980s, but resumed its high growth rate after 1985, growing at an average of almost 15% over the period 1986-90.

The average growth of physical capital was also quite different in the three manufacturing sectors. This input grew at a modest rate of 2.5% over the period 1975-90 for the US, while for Japan it was 5.4% over the same period. In the Korean manufacturing sector capital stock increased at an impressive rate of over 14% over this period. The growth rate of capital in the US manufacturing sector seems to have declined steadily over the period 1975-90; in 1986-90 it was less than half that in the period 1975-80. The Japanese industry's experience was exactly the opposite: the growth rate of physical capital rose from 3.6% to 7.0% in these two periods. Korean manufacturing once again had a remarkably different experience: The growth rate of capital was extremely fast, particularly in the period 1975-80, over 18%; it declined to about 8% in the first half of the 1980s, but resumed its fast pace once again in 1986-90, when it grew at over 15%. For the entire period, the growth rate of physical capital averaged 14.3%.
As indicated in table 1, the R&D capital stock grew at a much more rapid rate in the Japanese and particularly Korean manufacturing sectors than in that of the US. The growth rate of R&D stock in Japan was over three times larger than that for the US in the period 1975-90, while Korea's was over twelve times that of the US, and 3.6 times that of the Japanese sector in this period. The growth rate of R&D stock in Korea was particularly rapid during 1975-80, when Korea embarked on a program of R&D expenditure. It is true that the Korean and for that matter the Japanese manufacturing sectors started from a lower base of R&D capital than that of the US sector. Nonetheless, the remarkable pace of investment in R&D by the Japanese and particularly the Koreans in their manufacturing sectors is quite noticeable.

When we consider the input shares in the three manufacturing sectors, certain similarities and differences are apparent. The cost base input shares are shown in table 2. The labor share in total cost seems to be similar in the US and Japanese manufacturing sectors with some minor variations over the sub-periods. The share of labor in Korean manufacturing has fluctuated somewhat, but it is smaller by about one third than those observed for the other two manufacturing sectors. Materials input is the largest factor of production in all the manufacturing sectors of all three countries. The share of this input ranges from 64% to 72% of total cost across the three sectors. The share of materials is lowest in US manufacturing compared to those in Japanese and Korean manufacturing. For the period as a whole, the share of materials in total cost is 63.6% for the US, 66.1% for the Japanese sector, and 71.4% for the Korean manufacturing sector. The share of materials in the Korean and Japanese sectors is 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 in total cost is higher in Korean manufacturing than that in the Japanese and US manufacturing sectors. Capital shares increased between the periods 1975-80
and 1981-85 in all three sectors, but the share of capital declined in the US and, to a lesser extent, the Korean manufacturing sectors, while it increased in Japanese manufacturing. The share of R&D capital in total cost is quite different across the three sectors. In terms of level, the share of R&D is very large in US manufacturing in comparison to the other two sectors; it is over twice as large as the share of R&D stock in the Japanese and more than eleven times as large as that in the Korean manufacturing sector. The share of R&D in total cost is rising in all three sectors. The share of R&D in total cost increased by about 17% between the periods 1975-80 and 1980-85, but its growth rate moderated to an average of 6% between 1980-85 and 1986-90. In Japanese manufacturing, the share of R&D in total cost increased between the first two periods by 20% and 31% between the second and third periods. The increase in share of R&D was dramatic in Korean manufacturing; between the first and second periods, it grew at about 145%, and between the second and third periods the share of this input increased even faster, by approximately 167%. Although the magnitude of R&D share in total cost is very small in the Korean manufacturing sector, the growth rate of R&D expenditures has been extremely rapid in Korean manufacturing, leading to the increase noted in the shares of R&D capital.

Total and partial productivity growth rates based on gross output measurement framework are shown in table 3. Total factor productivity in US manufacturing averaged about .51% for the period 1975-90. The corresponding indices for Japanese and Korean manufacturing were .69% and 1.26%. The TFP growth rate was particularly slow in the US manufacturing during 1975-80, approximately .08%. The manufacturing sectors of the other two countries did not experience such a dramatic slowdown. The difference in the growth rate of labor productivity in the three manufacturing sectors were quite substantial. The average growth of labor productivity was low in the period 1975-80, but increased thereafter. For Japanese manufacturing, labor productivity growth was much higher than in the US in 1975-80; the growth rate of labor productivity increased
by an average of slightly over 4.0% in Japan in 1975-85, but since then has declined to an average of 3.4%, similar to the growth rate of labor productivity in US manufacturing in the 1986-90 period. The growth rate of labor productivity in Korean manufacturing has been outstanding, growing at a high rate of about 5.2% in 1975-80, then accelerating to about 6.4% in the first half of the 1980s, and to an impressive rate of over 12.5% in 1986-90.

Thus the elements of the differences in the growth rates of TFP and labor productivity in the manufacturing sectors of the US, Japan, and Korea are quite clear. High growth rates of labor productivity, accompanied by rapid growth rates of output, and other inputs such as materials, capital, and R&D, seem to have been the forces that produced the so-called Korean "miracle" and have also been responsible for the growth pattern of the Japanese manufacturing sector. 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. To explore the reasons for these productivity patterns, we proceed to estimate the production structure of the manufacturing sectors of the US, Japanese, and Korean economies.

II.B R&D Policy in Korea

Science and technology investment has been an important element of the Korean development strategy in recent years. The strategy has evolved over time, and three separate stages seem to be discernable. In the 1960s, when the foundation of industrialization was being developed, the emphasis was on strengthening scientific and technical education, building up the technological infrastructures, and promoting foreign technology imports. During the second stage, in the 1970s, technology policy concentrated on strengthening technical and engineering education in heavy and chemical industries, improving the capacity to adopt foreign technology more efficiently, and increasing the efficiency and deepening the structure of the manufacturing
industries through technological programs. In the third stage, in the late 1980s, industrial policy was directed at transforming the industrial structure by expanding technology-intensive industries such as machinery and electronic, and encouraging technical manpower development and enhancement of productivity.

The Korean government has followed multiple policy options to increase the technological capacity of the economy. The policies have included:

(1) high-skill manpower development programs to increase the number of qualified scientists from 56,000 in 1988 to 150,000 in the year 2001;

(2) an increase in government R&D by 15% per annum in the past six years, and likely to continue. The government R&D expenditure has risen from $9.5 million in 1963 to $325 million in 1980 and almost one billion dollars in 1988;

(3) substantial incentives to the private sector to increase its R&D investments:

--technology development reserve funds are exempt from taxes;

--10% of the costs of investment in R&D equipment and the adaptation of new technologies are exempt from taxes;

--special depreciation is permitted for 90% of the investment in testing and research facilities;

--direct financial grants given in conjunction with national projects; and

--long-term, low-interest technology development funds are provided.

The private sector, responding to these incentives, has increased its R&D expenditure from $155 million in 1980 to $2,882 million in 1988. As the result of very rapid growth of the private sector R&D investment, the ratio of government R&D to that of the private sector investment has fallen from 97.5% in 1963 to 68% in 1980, and 27% in 1988.

(4) The distribution of R&D expenditures has been mainly concentrated in two
industries. Fabricated metal products, machinery and equipment has received the lion's share of R&D expenditures, 74% in 1990, while the chemical and petroleum, coal and rubber sector has received 14%. Textile, food and beverages, basic metal industries, and non-metallic mineral products have received 2 to 3% of total R&D expenditures. The ratio of R&D expenditure to value added has risen substantially in almost all sectors of the manufacturing sector, and dramatically in fabricated metals and machinery, and chemicals and allied products; in 1978 the ratio of R&D expenditure to industry GDP was .007 in chemicals and allied industry and .0147 in fabricated metals and machinery sector, and in 1990 these ratios stood at .034 and .093 respectively.

(5) Great emphasis has been placed on increasing university-based research. Large firms are encouraged to establish at least one research center per company, while small and medium-size firms are encouraged to organize R&D consortiums in related fields. In addition, the government initiated a number of "National R&D Projects" as centers of large-scale efforts by public, private, and academic institutions to address long-term technological progress.

(6) The government has been very active in encouraging technological know-how from abroad. In the period 1962-1976, the number of cases of technology borrowing was around 75, and the royalties paid to the US in this period was a mere $114 million. By 1989, the cases increased to 452, and the royalties to $930 million. The government also has set up various centers to disseminate science and technology information obtained from abroad, or domestic sources to firms and institutions.

Thus, the effort of the Korean government in the area of R&D policy and R&D effort has been quite extensive. This can be observed from a range of policies to increase the technological
capacity of Korean industries as well as extend the effort to increase R&D investment both by the public and private sectors. The government has announced plans to increase the share of R&D expenditure in national output, GNP, over the decade of the 1990s, so that by the year 2000, it is 5% of GNP. The seventh Five-Year Economic and Social Development Plans projected the following:

Table 4: GNP, R&D Expenditure (in current Billion Won)

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<tr>
<td>GNP</td>
<td>141</td>
<td>227</td>
<td>255</td>
<td>288</td>
<td>325</td>
<td>367</td>
</tr>
<tr>
<td>R&amp;D Exp.</td>
<td>2.99</td>
<td>5.98</td>
<td>7.20</td>
<td>8.73</td>
<td>10.58</td>
<td>12.82</td>
</tr>
<tr>
<td>R&amp;D/GNP</td>
<td>2.72%</td>
<td>2.63%</td>
<td>2.82%</td>
<td>3.03%</td>
<td>3.25%</td>
<td>3.49%</td>
</tr>
<tr>
<td>Public Sector R&amp;D</td>
<td>.74</td>
<td>1.40</td>
<td>1.65</td>
<td>2.10</td>
<td>2.50</td>
<td>3.20</td>
</tr>
<tr>
<td>Private Sector R&amp;D</td>
<td>2.24</td>
<td>4.57</td>
<td>5.55</td>
<td>6.63</td>
<td>8.04</td>
<td>9.62</td>
</tr>
</tbody>
</table>

Source: The Seventh Five-Year Economic and Social Development Plan

The ratio of public to private sector R&D expenditure is assumed to be about 24:76 through the period of 1992-1996, and is likely to continue to be the same for the period 1997 to 2000, when the ratio of total R&D expenditure to GNP is hoped to increase to 5%.

Two issues are important to note at this point:

1. Productivity growth at the aggregate economy and total manufacturing sector will undoubtedly be increased if the projected increase in R&D is carried out. This is borne out by the estimates we have presented in section VIII of this paper. The most dramatic effect of increased R&D, however, will be visible at the disaggregated
industry level. Those industries which receive a large percentage of projected R&D expenditure increase are likely to show dramatic contributions of R&D to their productivity growth rates.

(2) Since wages in general, but particularly those of highly skilled labor are increasing very rapidly in Korea, a substantial part of the increase in projected R&D expenditure may be eaten up by wage increases. If bottlenecks developed in producing the required number and types of scientists and engineers, or if the quality of the scientists and researchers is not adequately high, the likelihood of the planned increase in R&D expenditure to achieve a substantial increase in the rate of technological progress may diminish considerably.

III. Modelling 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 a simple output demand equation. The theoretical formulation of these types of models and their applications are discussed in the literature (see Pindyck and Rotemberg (1982), Bernstein and Nadiri (1984), Bernstein and Mohnen (1991), and Nadiri and Prucha (1990)). We assume the adjustment costs are external to the firm. The variable cost function assumed for our analysis is a second-order approximation in the logarithms to any variable production cost function

\[
\ln VC = \beta_0 + \beta_L \ln W_L + \beta_Y \ln Y + \beta_K \ln K + \beta_R \ln R + \beta_T \ln T \\
+ \frac{1}{2} \left\{ \beta_{LL} (\ln W_L)^2 + \beta_{YY} (\ln Y)^2 + \beta_{KK} (\ln K)^2 + \beta_{RR} (\ln R)^2 + \beta_{TT} (\ln T)^2 \right\} \\
+ \beta_{LY} \ln W_L \ln Y + \beta_{LK} \ln W_L \ln K + \beta_{LR} \ln W_L \ln R + \beta_{LT} \ln W_L \ln T \\
+ \beta_{KY} \ln K \ln Y + \beta_{RY} \ln R \ln Y + \beta_{KR} \ln R \ln K \\
+ \beta_{YT} \ln Y \ln T + \beta_{KT} \ln K \ln T + \beta_{RT} \ln R \ln T
\]
where VC, WL 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, and T is an index of autonomous technical
change. Variable cost, VC, and wage rate WL are normalized by the price of materials. There
are two variable inputs: labor, L, and materials, M, and one output, Y. 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.

There are two quasi-fixed factors: capital, K, and R&D capital, R. These two factors
are assumed to be subject to adjustment cost in the short run. The adjustment costs
associated with changes in K and R are assumed to be quadratic, and depend on net
investment in physical and R&D capital. That is

\[ C(\Delta K, \Delta R) = \frac{1}{2} [ \mu_{KK} (\Delta K)^2 + 2\mu_{KR} \Delta K \Delta R + \mu_{RR} (\Delta R)^2 ] \]

where \( \Delta K \) and \( \Delta R \) are the net investment in physical capital and R&D capital.

Although the cost function is written in terms of variable cost, it is well known that the
properties of the underlying production technology can be deduced from the parameter
estimates of the restricted cost function (1). The duality theorems which link transformation
and restricted cost functions guarantee that the structure of production can be inferred from
the restricted equilibrium framework (see, for example, Lau (1976)). The structure of
production is summarized by the long-run output elasticity of costs and the partial elasticities
of substitution, and we now show how to derive these measures from the restricted cost
function. It can be shown that

\[ \eta_L = (1 + \pi^*)^{-1} \eta_V \]

where \( \eta_V \) and \( \eta_L \) are the cost elasticities of the variable cost and long-run cost functions.\(^1\)

As noted by Hanoch (1975), the proper measure of scale economies is given by \( \eta_L^4 \).
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. 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 duality theory. According to Shephard’s lemma, the derived demand for an input, \( X_i \), is obtained by partially differentiating the cost function with respect to the factor (service) price of the input (see Shephard (1970)). Partially differentiating the translog function (1) and using Shephard’s lemma, we obtain the conditional demand for labor cost-share equations

\[
S_L = \beta_L + \beta_{Ll} \ln W_L + \beta_{Ly} \ln Y + \beta_{Lk} \ln K + \beta_{Lr} \ln R + \beta_{Lt} \ln T
\]

where \( S_L = (W_L L)/VC \) is the share of variable costs accounted for by labor. The Euler equations for the quasi-fixed factors can be shown to take the form

\[
\begin{align*}
- S_K &= \beta_K + \beta_{Kk} \ln K + \beta_{Ky} \ln Y + \beta_{Lk} \ln W_L + \beta_{Kr} \ln R + \beta_{Kt} \ln T \\
&+ \mu_{Kk} \Delta K \left( \frac{K}{VC} \right) + \mu_{Kr} \Delta R \left( \frac{R}{VC} \right). \\
- S_R &= \beta_R + \beta_{Rr} \ln R + \beta_{RY} \ln Y + \beta_{Lr} \ln W_L + \beta_{Kr} \ln K + \beta_{Rt} \ln T \\
&+ \mu_{Rr} \Delta R \left( \frac{R}{VC} \right) + \mu_{Kr} \Delta K \left( \frac{K}{VC} \right).
\end{align*}
\]

We assume an inverse demand function of the form

\[
\ln P_Y = \alpha_o + \alpha_y \ln Y + \alpha_s \ln S
\]

where \( P \) 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. \( \alpha_y \) is the inverse of the price elasticity of demand. Assuming that \( MR = MC \), we can derive a revenue share equation

\[
S_Y = (1 + \alpha_y)^{-1} [\beta_Y + \beta_{YY} \ln Y + \beta_{LY} \ln W_L + \beta_{KY} \ln K + \beta_{RY} \ln R + \beta_{YT} \ln T]
\]
where $S_y = \frac{P_y Y}{VC}$ is the ratio of revenue and variable cost.

Estimating the equation system (1), (4) - (7) 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 market, and the effect of the changes in stocks of R&D and physical capital 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 US dollars using the purchasing power parity exchange rates for 1982 taken from Summers and Heston (1991). All quantities are expressed in billion $US in 1982 prices.

IV.A Output ($Q$)

Gross output of the total manufacturing sector is used for the output variable. For the US, the gross output series both in current and constant prices are obtained from the Bureau of Labor Statistics, Office of Employment Projections. 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. More specifically, we first normalize the industrial production index so that the base year value is one, and then multiply this normalized index series by the 1982 value of gross output in current prices to generate the gross output in 1982 constant prices. For Korea, the original source of gross output data is Economic Planning Board (EPB) of Korea, *Report on Mining and Manufacturing Survey* (RMMS).
IV.B Materials (M)

The material series is calculated as the difference between the gross output and value-added, and the value-added data are obtained from OECD, National Accounts (vol. 2) for Japan and the US, while Korean value-added data are from EPB, RMMS. 1990 value for US was taken from Harper's data set on US manufacturing sector.

IV.C Labor (L)

Labor is also expressed in real value terms by multiplying the man-hours series by the 1982 wage rate. Data on the number of employees were obtained from OECD, National Accounts for the US and Japan and EPB, RMMS for Korea. The average working hours data are from International Labor Organization, Yearbook of Labor Statistics for US and Japan and Ministry Of Labor, Report on Monthly Labor Survey for Korea. For the wage rate, we use an hourly earning rate for the US (ILO) and Japan (BLS). For Korea, we obtain an hourly wage rate by dividing the total labor cost by total man-hours. 50 weeks is assumed in deriving the annual man-hours and labor variable.

IV.D Physical Capital (K)

The net capital stock measured as beginning-of-period value is used for our physical capital stock. For US and Korea, we used the net capital stock series constructed by Musgrave (published in Survey of Current Business (Jan. 92)) and Kwack respectively. For Japan we construct the net capital stock by the perpetual inventory method, and the benchmark estimate was taken from BLS, Working Paper #189, p.68 (1988). Since this benchmark estimate is expressed in 1970 constant prices, we convert this into 1982 constant prices by the investment price deflator. The investment series used in constructing capital stock are obtained from various sources: BLS, WP#189 for 1960 - 80; OECD, Flows and Stocks of Fixed Capital for 1980 - 89; and 1990 value from the extrapolation method with
the GDP growth rate.

IV.E R & D Capital (R)

The R&D capital stock was constructed by the perpetual inventory method: the benchmark estimates were calculated by dividing real R&D investment in 1971 by the sum of the depreciation rate of R&D capital stock (0.15) and the average growth rate of output in each sector. For the US, the R&D investment data were obtained from various sources: NSF for 1960 - 80, OECD for 1981 - 88, and NSF estimates for 1989 and 1990. For Japan and Korea, the R&D investment data are from the Ministry of Science & Technology, Report on the Survey of R & D for each country.³

IV.F Prices of Output and Inputs

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, since RMMS presents materials and energy and respective price deflators separately, we calculate a weighted average of two price deflators 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 .46 for 1987-90: for Korea, the source is the Korea Development Institute, Statistics of Public Finance.

The rental rate of physical capital is calculated as \( w_k = p_k \times ( r + \delta_k ) \), where \( r \) is the real rate of return, \( \delta_k \) is the depreciation rate of capital, and \( p_k \) is the price of capital. 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. The price deflator for physical investment is used as \( p_k \), which is derived from various sources. For the US, it is calculated as the ratio of the value of investment flow expressed in current dollars and constant 1982 dollars, which we get from OECD, *National Accounts*. For Japan, we take the aggregate investment deflator (UN; for 1960-80) and extrapolate the series with the GDP deflator. For Korea, the investment price deflator is provided by Bank of Korea. We try to smooth the price deflators for investment and R & D by taking a three-year moving average and using the smoothed series for estimation.

We used the same formula to derive the rental rate of R&D capital, except for a few adjustments: the depreciation rate is assumed as 0.15 for all three countries and \( p_r \), the price deflator for R&D investment, is obtained from the following sources. For US, we used 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 \( p_r \); 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 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. 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.

As indicated earlier, exploiting duality theory and estimating the cost-share equations jointly with the cost function increases the statistical degrees of freedom, since the cost-share equation parameters are a subset of the cost-function parameters. The limited time series
(1974-1990) and the multicollinearity in the data make this procedure imperative. Including
the cost function itself in the multivariate regression system is important because certain
coefficients needed to evaluate the scale elasticity ($\beta_o$, $\beta_r$, $\beta_{rr}$) do not appear in the share
equations. We follow the literature in specifying additive disturbances in each share equation
and the cost function; the former represent errors in optimizing behavior (for example,
Christensen and Greene (1976)). The disturbances are specified to have a joint normal
distribution (as required for formal testing), but contemporaneous correlation across equations
is allowed. The system can be estimated by Zellner's (1962) seemingly unrelated regression
technique, which is a generalized least-squares technique.

We employ the iterative Zellner method. Since we obtain maximum-likelihood estimates of the parameters, the various parameter restrictions are tested with the likelihood ratio test. We compute $\lambda = \Omega(R) - \Omega(U)$ where $\Omega(R)$ and $\Omega(U)$ are the log likelihood values under the restricted and unconstrained versions, respectively. Then $-2\lambda$ is distributed asymptotically as a chi-squared variate with degrees of freedom equal to the number of independent restrictions being tested.

V.A Parameter Estimates

Before turning to table 5, we note that the model fits the data quite well, both for cost function and the share equations. The $R^2$s for the cost function labor share and R&D stock share are above 0.95, while those for the revenue share, capital stock share and the inverse output demand equation range about .90. This is encouraging, since translog models often yield relatively poor fits for cost share equations (Denny and Fuss (1977)). Moreover, the share equation fits are not due predominantly to the time variable. Variation in factor prices and output account for about 80 to 85% of total variations in factor shares and revenue share. The levels (rather than shares) 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 .98.

With the exception of two parameters, the parameter estimates in table 5 are all statistically significant. All the coefficients of the dummy variables were statistically significant, suggesting that the parameter estimates of the model differ among the three manufacturing sectors. It is also clear that the partial elasticities of substitutions among the inputs are not unitary. The cost shares have been affected by technical change. The pattern of the biased technical change coefficients suggests that technical change is capital-using and labor- and research-saving as well as material-using. 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 statistically significant non-homotheticity of the underlying production technology. Similarly, the interaction terms between output and other variables, such as physical capital, R&D capital, and time, are statistically significant, further confirming the non-homotheticity of the production technology. A concise description of the production structure, the role of technical change, the effect of R&D capital and output price elasticity can be provided by calculating the relevant elasticities using the estimates in table 5. We use the TSP analysis routine to calculate the standard errors of these elasticities using the 1990 values of the variables.

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

In table 6, we present price elasticity of demand and elasticities of variable cost 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}, for the US and Japanese manufacturing sectors, are about -.50, while for the Korean manufacturing sector it is about -.49. The own-
price elasticity of materials, on the other hand, is very small for both the US and Japanese sectors—about -.10—while for Korean manufacturing, demand for materials also seems to be inelastic—about -.09.

The inverse of the price elasticity of output demand, $\varepsilon_{py}$, as shown in table 6, varies considerably among the three manufacturing sectors. The magnitude of $\varepsilon_{py}$ for the Japanese manufacturing sector is somewhat higher than that of the US, which is about -.14. For Korean manufacturing, the magnitude of $\varepsilon_{py}$ is about one third higher than that in the US. The degree of mark-up is calculated as

$$M = \frac{P_y - MC}{P_y} = 1 - \frac{MC}{P_y} = \frac{\alpha_y}{1 + \alpha_y}$$

where $P_y$ is the output price and MC is the marginal cost. The estimate suggests a degree of mark-up of about 17% for the US, 20% for the Japanese, and approximately 30% for the Korean manufacturing sector. This suggests that the Korean manufacturing sector is relatively more monopolistic than those of Japan and the US. Our estimates of the mark-up are much lower than those reported by Hall (1988) for the US, and by Kwon and Yuhn (1990) for the Korean manufacturing sector. The output elasticity of the variable cost is obtained by the expression $\eta_v = \varepsilon_{cy} = \frac{\partial \ln VC}{\partial \ln Y}$ which allows the calculation of short-term returns to scale, i.e., $1/\eta_v$. The output elasticity of the variable cost is quite similar among the three sectors. They range between 1.08 for the Korean and 1.1 for the US and Japanese manufacturing sectors for 1990. The elasticity of the variable cost with respect to time is an index cost reduction due to technical change. The value of this elasticity, $\varepsilon_{ct}$, shown in table 6 is highest for the US, followed by Japan, while for Korea this elasticity is small and statistically not significant.
The impact of changes in physical capital and R&D capital on the variable cost function is shown in table 7. We 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. These effects are calculated using the expressions

\[
\begin{align*}
\varepsilon_{LK} &= \frac{\partial \ln L}{\partial \ln K \mid y} = \frac{\beta_{LK}}{S_L} + \varepsilon_{CK} \\
\varepsilon_{LR} &= \frac{\partial \ln L}{\partial \ln R \mid y} = \frac{\beta_{LR}}{S_L} + \varepsilon_{CR} \\
\varepsilon_{MK} &= \frac{\partial \ln M}{\partial \ln K \mid y} = \frac{\beta_{MK}}{S_M} + \varepsilon_{CK} \\
\varepsilon_{MR} &= \frac{\partial \ln M}{\partial \ln R \mid y} = \frac{\beta_{MR}}{S_M} + \varepsilon_{CR}
\end{align*}
\]

(10)

The figures in table 7a indicate that a one percent change in capital induces an increase of about .14 for labor, but the relation between increase in K and materials is substitutional with the greatest effect for Japan and the US, followed closely by Korea. The effect of an increase in capital stock is to shift average variable cost downward. The effect ranges between -.22 for Japan and -.13 for Korea. The effect of change in R&D stock on employment and materials is negative, suggesting a substitutional relationship. R&D capital, like that for physical capital, shifts variable costs downward, but the magnitudes of the shift are much smaller, particularly in Japan and Korea, than that of the physical capital. This reflects the small share of R&D in gross output as noted earlier.

In table 6, 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

\[
(11) \quad SC = \frac{(1 - (\varepsilon_{CK} + \varepsilon_{CR}))}{\varepsilon_{CY}}
\]

where \(\varepsilon_{CK}, \varepsilon_{CR},\) and \(\varepsilon_{CY}\) are the elasticities of variable cost function with respect to capital, R&D stock, and output. The degree of scale seems to be 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.

The elasticities shown in table 7a refer to the direct effect of changes in physical and R&D capital on variable inputs, labor and materials, and variable costs. These elasticities are calculated assuming that the level of output is fixed. However, 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. In table 7b, we present elasticities of variable inputs, L and M, cost and output with respect to changes in K and R. The output elasticities are calculated using the expression

\[
\eta_{YK} = \frac{\partial \ln Y}{\partial \ln K} = \frac{\epsilon_{CK} S_Y + \beta_{KY}}{(1 + \epsilon_{PY})} \left[ \frac{\beta_{XY}}{(1 + \epsilon_{PY})} - \frac{1}{\epsilon_{PY}} \right] \frac{\beta_{XY}}{(1 + \epsilon_{PY})}
\]

(12)

\[
\eta_{YR} = \frac{\partial \ln Y}{\partial \ln R} = \frac{\epsilon_{CR} S_Y + \beta_{RY}}{(1 + \epsilon_{PY})} \left[ \frac{\beta_{XY}}{(1 + \epsilon_{PY})} - \frac{1}{\epsilon_{PY}} \right] \frac{\beta_{XY}}{(1 + \epsilon_{PY})}
\]

The elasticities of output price, variable costs and variable factor demands when the level of output is not held fixed are derived as

\[
\eta_{PK} = \frac{\partial \ln P_Y}{\partial \ln K} = \epsilon_{PY} \eta_{YK}
\]

\[
\eta_{CK} = \frac{\partial \ln VC}{\partial \ln K} = \epsilon_{CK} + \epsilon_{CY} \eta_{YK}
\]

(13)

\[
\eta_{LK} = \frac{\partial \ln L}{\partial \ln K} = \epsilon_{LK} + \eta_{YK} \left( \frac{\beta_{LY}}{S_L} + \epsilon_{CY} \right)
\]

\[
\eta_{MK} = \frac{\partial \ln M}{\partial \ln K} = \epsilon_{MK} + \eta_{YK} \left( \frac{\beta_{LY}}{S_M} + \epsilon_{CY} \right)
\]

\[
\eta_{PR} = \frac{\partial \ln P_Y}{\partial \ln R} = \epsilon_{PY} \eta_{YR}
\]

\[
\eta_{CR} = \frac{\partial \ln VC}{\partial \ln R} = \epsilon_{CR} + \epsilon_{CY} \eta_{YR}
\]

\[
\eta_{LR} = \frac{\partial \ln L}{\partial \ln R} = \epsilon_{LR} + \eta_{YR} \left( \frac{\beta_{LY}}{S_L} + \epsilon_{CY} \right)
\]

\[
\eta_{MR} = \frac{\partial \ln M}{\partial \ln R} = \epsilon_{MR} + \eta_{YR} \left( \frac{\beta_{LY}}{S_M} + \epsilon_{CY} \right)
\]
These elasticities take into account both the direct and indirect effect of changes in physical and R&D capital. The difference between the corresponding elasticities in table 7a and table 7b are the indirect effects of these variables.

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.

As can be seen from table 7b, the elasticities of output, variable inputs and costs, with respect to physical capital, are highest in Japanese manufacturing, followed by those in US manufacturing. These elasticities are much smaller, except for the elasticity of labor with respect to capital of $\eta_{LK}$, in Korean manufacturing. Furthermore, the induced effect of changes in physical capital is sufficiently large and positive that the demand for the variable inputs and costs increases as output increases. Similarly, when the level of output is allowed to vary in response to an increase in R&D stocks, the results indicate the following: Output elasticity, $\eta_{YK}$, is positive and relatively large in US manufacturing; this elasticity is small for the Korean manufacturing sector; the Japanese estimates fall in between the estimates for the US and Korea. Another observation is that the induced effect of changes in R&D stock is not sufficiently large to overcome the sign of the elasticities with respect to R&D shown in table
7b. In addition, note that the magnitudes of the elasticities with respect to R&D capital are much smaller than the corresponding elasticities with respect to physical capital. This is partly because the share of R&D in output (or cost) in all three sectors is very small compared to that of physical capital.

VI. **Productivity Analysis**

Using the estimates of the production structure, we can quantitatively examine the sources of output and productivity growth. The contributions of the factor inputs, and technical change to output growth are shown in table 8. The decomposition is based on the approximation:

\[
\Delta \ln Y_t = \frac{1}{2} \sum_{i=1}^{4} \left( \varepsilon_{yzi}(t) + \varepsilon_{yzi}(t-1) \right) \Delta \ln Z_{it} + \frac{1}{2} \left[ \text{PGY}_t + \text{PGY}_{t+1} \right]
\]

with \( Z_1 = L, Z_2 = M, Z_3 = K, Z_4 = R \). The \( \varepsilon_{yzi} \)'s denote the respective output elasticities and \( \text{PGY}_t = (1/Y)(\partial F/\partial t) \) denotes technical change. The output elasticities are computed from the 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 increasing returns to scale. The contribution of each of the variables in (14) is calculated by multiplying the respective (average) elasticities with the growth rate of the corresponding variable.

As shown in table 8, the average growth rate of gross output was extremely rapid for Korean manufacturing over the sample period 1975-90. The average growth of gross output in this sector was more than three times that of Japanese and six times that of US manufacturing. The contributions of various inputs to the growth of output differ considerably among the three sectors and over different sub-samples. 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 US, Japanese, and Korean manufacturing over the period 1975-90. The contribution of capital to growth of gross output was similar in US and Japanese manufacturing, about 22%, while it contributed about 16% in Korean manufacturing. The contribution of labor input to the growth of gross output differed among the three sectors; it contributed negatively to the growth of output in the US, but positively in Japanese and Korean manufacturing. The largest contribution of labor--about 4.3%--was in Korea.

The stock of R&D and technical change contributed significantly to the growth of gross output, particularly in the US and Japanese manufacturing sectors. The contribution of R&D stock accounted for over 9% and 6% of growth of output in the US and Japan, while its contribution was about 11% in Korean manufacturing. The large contribution of R&D to output in the US and Japan mainly reflects two considerations: the share of R&D investment in gross output is larger than in Korea, and the estimated degree of economies of scale in the manufacturing sectors of these two countries is larger than that for the Korean manufacturing. In other words, the low percentage contributions of R&D stock in the Korean manufacturing sector reflect the fact that, while the growth rate of R&D stock has been extremely rapid, its share in a rapidly growing gross output has been fairly small. Still, in terms of magnitude, the contribution of R&D stock in Korea, though lower than in the other two countries, is not too far off. The contribution of R&D stock is .18%, .25%, and .11%, respectively, for US, Japanese, and Korean manufacturing. Technical change calculated by the derivative $\frac{\partial n_{V_C}}{\partial t}$ depicting the shift of variable cost over time suggests that autonomous technical change contributes significantly in the US and Japanese manufacturing sectors. This is particularly true for the US, where technical change accounts for about 18% of the growth of gross output. Its contribution in Japanese manufacturing is about 10%, while in Korean
manufacturing the contribution of autonomous technical change contributes only about 4% to the growth of gross output. Again, if we look at the contribution of technical change not as a percentage of the growth of output, but in terms of the absolute size of its contribution, the contributions are quite similar, about .34%, .38%, and .45% for US, Japanese, and Korean manufacturing. 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.

In table 9 we provide a decomposition of labor productivity growth. The results are based on the approximation:

\[ \Delta \ln \left( \frac{Y_t}{L_t} \right) = \frac{\rho}{2} \sum_{i=2}^{4} [\varepsilon_{YZ_i}(t) + \varepsilon_{YZ_i}(t-1)] \Delta \ln (Z_i/L_i) \]

\[ + \ \frac{\rho}{2} (PGY_t + PGY_{t-1}) + (\rho - 1) \Delta \ln L_t, \]

(15)

where \( \rho \) is the scale elasticity. This approximation is readily obtained from (14) by noting that the sum of the output elasticities must equal scale. In the decomposition of labor productivity, the most significant contribution again stems from the growth of materials, particularly in Korea and Japan. The contribution of physical capital is the second most important factor in the growth of labor productivity in all three countries. In comparison with the results reported by Norsworthy and Malmquist (1983) for the total manufacturing sector, its contribution is large in Korea and Japan, but substantially smaller for the US.

The contribution of R&D as a percent of growth of labor productivity is highest in the US, about 7.2%, while in the Japanese manufacturing sector it is about 6.8%; in Korean manufacturing, the contribution of R&D stock as a percentage of growth of labor productivity is about 1.4% over the period 1975-90. However, the absolute magnitude of the contributions of R&D stock are .18%, .25%, and .11% for the US, Japanese, and Korean
manufacturing. Contributions of autonomous technical change are also important. They range between about 35% for the US and Japanese and about 45% for the Korean manufacturing sector. However, the contribution of this factor as a percentage of average growth rate of labor productivity is the lowest in Korean manufacturing because of the extremely rapid growth of labor productivity (about 8%) in this sector. The contribution of the adjustment costs are small, as we noted earlier. The last term on the R.H.S. of (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 1 of table 9. Its effect is positive and sizeable in the US, but negative for Japanese and Korean manufacturing. This reflects the growth pattern of the labor output in the three manufacturing sectors over the period 1975-90. The negative contribution of labor input to growth of labor productivity in Korean manufacturing is quite substantial, indicating that the sizeable growth of man-hours labor input measured in man-hours dampened considerably the growth of labor productivity in the Korean manufacturing sector.

TFP is basically a measure of output per unit of total factor input. Total factor input is a weighted average of inputs, where the weights depend on the underlying production function. If there are increasing returns to scale, part of the growth in TFP will reflect the change in the scale of operations, while the remainder can be ascribed to a shift in the production frontier itself. If there were constant returns to scale, the change in TFP would be identical to the technological shift (assuming other factors are exhaustive and accurately measured).

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 shifts of the average-cost curve downward over time, which we shall label
the direct contribution of 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 level of interaction between scale
economies and technical change, which should be taken into account if a proper attribution
of the growth in TFP is to be made. The output-side of TFP growth is defined as the

\[ TFP = \dot{Y} - \sum \frac{w_i X_i}{PY} \dot{X}_i \quad i = L, M, K \]

where \( Y \) is output and \( X_i \) are factor inputs consisting of labor, materials, and capital, and a dot
represents the rate of growth. The Divisia index of inputs \( \sum \frac{w_i X_i}{PY} \dot{X}_i \) is a weighted sum of
rates of growth, where the weights are components' share in total value.\(^5\) Suppose we define
the pricing rule as \( P = (1 + \gamma)^{-1} MC \), where \( \gamma = \alpha_y \) is the inverse price elasticity of output
demand. Recall that capital is treated as a quasi-fixed input in equation (1). The \( TFP \)
equation (16) can be written as

\[ TFP = \dot{Y} - (1 + \gamma) \sum \frac{w_i X_i}{C} \dot{X}_i - (1 + \gamma) \frac{w_k K}{C} \dot{K}, \quad i = L, M \]

where \( C \) is total cost, and it can be shown that \( C = (1 - \frac{\partial \ln VC}{\partial \ln K}) VC \). If \( \gamma \to 0 \) or the output
demand function becomes more elastic, even in the absence of any economies of scale, output increases.

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

\[ VC = \sum_i w_i X_i = VC \left(W_i, K, R, Y, T\right) \quad i = L, M \]

Differentiating this function and after rearranging terms we get:

\[ \sum \frac{w_i X_i}{C} \dot{X}_i = \rho^1 \dot{Y} + \left(\frac{\partial \ln VC}{\partial \ln K}\right) \dot{K} + \left(\frac{\partial \ln VC}{\partial \ln R}\right) \dot{R} + \frac{1}{A} \frac{\partial \ln VC}{\partial T} \]

where \( \rho \) is the scale parameter and \( A = 1 - \frac{\partial \ln VC}{\partial \ln K} \). Substituting (18) into TFP expression (17), we get the decomposition of TFP

\[ TFP = (1 - \rho^1) \dot{Y} + (1 - (1 + \gamma)) \rho^1 \dot{Y} + \left(\frac{1 + \gamma}{A}\right) \frac{\partial \ln VC}{\partial \ln K} - (1 + \gamma) S_k \dot{K} \]

\[ + \left(\frac{1 + \gamma}{A}\right) \frac{\partial \ln VC}{\partial \ln R} \dot{R} + \left(\frac{1 + \gamma}{A}\right) \frac{\partial \ln VC}{\partial T} \]

The TFP is decomposed into the scale effect, mark-up effect, disequilibrium effect, R&D effect, and technical change effect.

Table 10 presents the decomposition of total factor productivity based on (19) for the sample period used in estimating the production technology of the US, Japanese, and Korean manufacturing sectors. We also examine the decomposition of TFP for the sub-sample of the period 1975-90 to check whether the rate of different factors responsible for TFP has changed. The TFP growth rate of the US manufacturing sector was the smallest among the three sectors, while that of Korean manufacturing was the largest, 3.32% over the period
1975-90. The TFP growth rates based on the Divisia index shown in column (1) of table 10 are clearly not an accurate measure of technical change in the three manufacturing sectors. Only under very specific conditions of pure competition, constant return to scale, technology, and instantaneous adjustment of inputs could TFP be an appropriate measure of technical change. As noted earlier, these conditions are clearly absent from these three sectors.

The most important contributor to TFP 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 very high in Korean manufacturing, about 1.9%. This is mainly because of the extremely high growth rate of output experienced by the Korean manufacturing sector, which magnifies the effect of price elasticity of demand on total factor productivity. The mark-up effect was minor for the US, about 2.6% of TFP, and moderately large for Japanese manufacturing, about 15% of TFP. In contrast, it accounted for almost 57% of TFP 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 was the largest in Japanese manufacturing. For the US, this contribution was about 0.16, while for Korean manufacturing it was .09, almost half that of the US. In terms of percentage of TFP, the contribution of R&D stock was about 20% for the US, 17% for the Japanese, and about 2% 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 0.32% for Japanese manufacturing and 0.34% for Korean manufacturing. However, in terms
of relative contribution to TFP, technical change's largest contribution is in the US, about 30%, followed by Japan with about 27%; it contributes about 10% in the Korean manufacturing sector. 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; the rates of return include the adjustment costs of the quasi fixed inputs, K and R.⁶

The expression for the rates of return is given by

\[ r_i = \left( \frac{\Delta VC}{\Delta Z_i} \right) / P_i \]  

where \( Z_i \) refers to the quasi inputs.⁷

The internal rates of return using (20) for the two types of capital are shown in table (11). The results are quite suggestive. The rates of return on physical capital for the US manufacturing sector is about 10% 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 two 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, \( r_L \), is about 18% for 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 Korean manufacturing is about 50% to 60% higher than that of the corresponding rates in the US and Japanese manufacturing sectors. There are some fluctuations over time in the rates of return on both types of capital; generally these rates (with some exceptions) 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.

VIII. Catch-Up Scenarios and the Role of R&D Policy

The model parameters are used to sketch several scenarios of how and when the Korean manufacturing sector will catch up with that of Japan. Of particular interest in this regard is the probable effect of increased R&D expenditure on both, upgrading the production structure of Korean manufacturing, as well as catching up with Japan in terms of the level of labor productivity.
Further, we calculate the *time* it will take the manufacturing sector in Korea to catch up with that in Japan in terms of the *level* of labor productivity. The catch-up period will depend on how fast the level of labor productivity grows in Japan and Korea in the years to come. To compare the level of labor productivity in the manufacturing sectors of the two countries we establish a reference case in terms of the level of labor productivity for the Japanese sector, and compare the evolution of the Korean manufacturing level with this reference case over the period 1991-2001. The effect of increased R&D investment on labor productivity for the projection period is examined under several circumstances, particularly the case where the ratio of total R&D expenditure to GNP is increased to 5% by the year 2000, the announced objective of the Korean government.

The first step is to calculate the growth rates of labor productivity for the Japanese and Korean manufacturing sectors using the estimated parameters of our econometric model. The equations for calculating labor productivity growth for the two sectors are:

(a) Korean manufacturing:

\[
(\dot{Y}/L)^K = \beta_L^K \dot{L} + \gamma_M^K \dot{M} + \gamma_K^K \dot{K} + \gamma_R^K \dot{R} + \gamma_i^K
\]

(b) Japanese manufacturing:

\[
(\dot{Y}/L)^J = \beta_L^J \dot{L} + \gamma_M^J \dot{M} + \gamma_K^J \dot{K} + \gamma_R^J \dot{R} + \gamma_i^J
\]

where \((\dot{Y}/L)^K\) and \((\dot{Y}/L)^J\) are labor productivity growth rates in the Korean and Japanese manufacturing sectors; \(\beta_i^K = (\gamma_i^K - 1)\), \(\beta_i^J = (\gamma_i^J - 1)\), and \(\gamma_i\), \(i = L, M, K, R\) are the output elasticities of the inputs, and \(\gamma_i^K\) and \(\gamma_i^J\) are the growth rates of autonomous technical change. \(\dot{L}, \dot{M}, \dot{K},\) and \(\dot{R}\) are, respectively, the rates of growth of inputs—labor, materials, capital services and R&D capital assumed to prevail over the projection period 1990-2001. The gap between the productivity growth rates of the two sectors over the projection period is calculated using equation (22) below.
\[
[(\dot{Y}/L)_K - (\dot{Y}/L)_J] = (\beta_i^K L_K - \beta_i^J L_J) + (\gamma_i^K \dot{M}_K - \gamma_i^J \dot{M}_J) + (\gamma_i^K \dot{K}_K - \gamma_i^J \dot{K}_J) \\
+ (\gamma_i^K \dot{R}_K - \gamma_i^J \dot{R}_J) + (\gamma_i^K - \gamma_i^J)
\]

To calculate the time period during which the level of labor productivity of the Korean manufacturing sector may catch up with that of Japan, we use the formula

\[
T = \frac{\ln(Y/L)_0^J - \ln(Y/L)_0^K}{\ln(1 + r_K) - \ln(1 + r_J)}
\]

where \((Y/L)_0^J\) and \((Y/L)_0^K\) are, respectively, the levels of labor productivity in Japan and Korea in the base period, 1990, and \(r_K\) and \(r_J\) are the rates of growth of labor productivity generated in our different scenarios. The real gross output per man-hour is used as our measure of the labor productivity level. In calculating the catch-up period, the base year level of labor productivity is crucial. We choose the year 1990 as our base year for projection, a natural choice considering that our estimation period covers 1974-1990. In order to remove a cyclical factor and have a consistent benchmark value for projection, we take the simple mean of gross output per man-hour over 1988-90 for each sector as the base values. The specific benchmark values turn out to be 39.86 and 55.96 for Korea and Japan, respectively.\(^8\)

Using equation (21a) and (21b) we calculate the contribution of traditional inputs and technical change, TCH, to the difference in growth of labor productivity in the two sectors. The contribution of technical change (TCH) is defined as the sum of the contribution of R&D and pure or autonomous technical change. Using the parameter estimates of the model and the rates of growth of inputs over the sample period 1975-1990, as well as for the projection period 1990-2001, we construct the contribution of the sources of productivity growth for both the Korean and Japanese manufacturing sectors. Using equation (22), the difference in the growth of labor productivity between the two sectors is calculated as a result of the
differences in the contributions of the sources of their labor productivity growth. The sources of labor productivity growth differentials between the two sectors for the sample period 1975-90 and three sub-periods are shown in table (12). Several aspects of these results are quite interesting.

(1) Labor productivity in Korean manufacturing has been growing at a substantially higher rate than in Japanese manufacturing. This was particularly true in the 1980s; in 1986-90 the difference between the growth rates of labor productivity in the two sectors was over 8%, an extremely high rate.

(2) The growth of labor input has been much higher in Korean manufacturing than that experienced by the Japanese manufacturing sector, and thus contributed negatively to the closing of the growth rates of labor productivity. This effect was substantial in the early period (1975-80), but has declined in recent years.

(3) The high growth rate of materials in Korean manufacturing has been the main source of increased labor productivity growth in Korea relative to that of the Japanese manufacturing sector. Growth of materials has accounted for a substantial degree of the catch-up accomplished by Korean manufacturing.

Table 12: The Contribution of Different Sources to Differences in Productivity Growth Rates Between the Korean and Japanese Manufacturing Sectors 1975-1990

<table>
<thead>
<tr>
<th>(%)</th>
<th>Δ(Y/L)_{KJ}</th>
<th>ΔL</th>
<th>ΔM</th>
<th>ΔK</th>
<th>Technical change TCH</th>
<th>ΔR</th>
<th>ΔT</th>
</tr>
</thead>
<tbody>
<tr>
<td>1975-90</td>
<td>4.215</td>
<td>-4.232</td>
<td>7.351</td>
<td>1.526</td>
<td>-0.178</td>
<td>0.068</td>
<td></td>
</tr>
<tr>
<td>1986-90</td>
<td>8.467</td>
<td>-2.009</td>
<td>8.864</td>
<td>1.230</td>
<td>-0.093</td>
<td>-0.068</td>
<td></td>
</tr>
<tr>
<td>1981-85</td>
<td>3.676</td>
<td>-2.207</td>
<td>4.659</td>
<td>0.567</td>
<td>-0.242</td>
<td>-0.068</td>
<td></td>
</tr>
<tr>
<td>1975-80</td>
<td>1.121</td>
<td>-7.772</td>
<td>8.334</td>
<td>2.572</td>
<td>-0.194</td>
<td>0.299</td>
<td></td>
</tr>
</tbody>
</table>
4) The growth of R&D investment in the Korean manufacturing sector, particularly after 1981, has been spectacular, although it started from a very low level. Korea started investment in R&D much later than Japan, and R&D investment in Korean manufacturing industries in the early 1970s was rather modest. For this reason even in 1990 the cost share of R&D in total manufacturing is very small in Korea, while in Japan the share of R&D in this sector is almost four times larger. This in turn may explain why R&D capital's role in terms of contributions to growth of \( \dot{Y}/L \) in Korea is still rather small.

5) As shown in table (12), the rapid growth of R&D capital in Korean manufacturing has contributed over time to the narrowing of the gap between the labor productivity levels in the Korean and the Japanese manufacturing sectors. Still, a deficit remains in terms of the contribution of R&D to narrowing the gap in the labor productivity levels. For the sample period 1975-1990 the contribution of R&D capital is negative .178. The magnitude of R&D contribution, however, has moved substantially in favor of Korea. Since 1981, when the Korean manufacturing industries undertook substantial R&D investment, the contribution of R&D capital to closing the gap between the level of labor productivity of Korea to that of the Japanese total manufacturing sector declined from -.242 for the period 1981-85 to -.093, a decline of over 60%. Thus, aside from the high rate of return, noted earlier, on R&D investment that Korean manufacturing has enjoyed in this period, Korean industries have reaped a significant benefit from their R&D investment in narrowing the gap between the level of labor productivity of the Korean and Japanese aggregate manufacturing sector. This conclusion may not apply to all sub-industries in Korean
manufacturing. To assess the role of R&D capital in the competitive performance of the individual Korean manufacturing industries against their Japanese and other competitors in the world economy would require a careful study at a disaggregate industry level.

(6) Another interesting feature of our comparison is the contribution of autonomous technical change, TC, to closing the gap in the labor productivity levels of the two sectors. As shown in table (12), autonomous technical change's contribution is positive in the period 1975-1980, but becomes negative since 1981. This means that the production frontier shifted up more rapidly in Korean manufacturing than that of the Japanese in the late seventies. This is an interesting and somewhat unexpected result; it may reflect the latecomer advantage that Korea may have enjoyed in the early part of its industrialization. Korean industries were able in the 1970s to import considerable technology and capital from advanced countries. Technology import declined in the 1980s when Korean industries became significant players in international markets. Our model generates results that support this proportion. The estimated value of $\frac{\partial \ln VC}{\partial \ln K}$, our measure of cost saving due to autonomous technical change for the Japanese manufacturing sector, is very stable. For Korean manufacturing the contribution of technical change, TC, starts high and trends downward in 1974-1980, then stabilizes over the 1980s. In 1986-1990, the contribution of TC to labor productivity in both sectors is quite similar, but the advantage is still with the Japanese manufacturing sector.

The fact that autonomous technical change is not likely to contribute substantially to narrowing the gap between the Korean and Japanese manufacturing sectors means that
Korean industries must increase their own efforts for technical advance. Korea must achieve either higher growth of capital and materials to generate high growth rates of output and labor productivity, or increase its investment in R&D capital. However, supply constraints will likely lead to a rise in factor costs such as the increase in wage rates, which will inhibit a high growth rate of productivity. One way to overcome this problem is to invest further in R&D so that the technical change gap between the two manufacturing sectors is further narrowed substantially, allowing the Korean manufacturing sector to catch up with the level of productivity in Japan.

It is also important to note that the major role of R&D investment, however, is likely to be most significant in the transformation of the structure of production in particular manufacturing industries. This issue cannot be inferred from our aggregate results; specific industry cases need to be examined. Nevertheless, what our model suggests is that the rate of return after tax on R&D is quite high in Korea in comparison with those in the US and Japan, as well as in comparison with the return on physical capital in Korea. This suggests that there is considerable underinvestment in R&D in Korean manufacturing.

**Scenarios for Catch-Up**

To generate alternative scenarios for the evolution of the productivity growth rates for the two manufacturing sectors, and an assessment of alternative R&D investment expenditure policies that the Korean government and private enterprises may undertake, the following four steps are necessary: (a) specification of how input prices will evolve over the projection period; (b) a reasonable set of assumptions about average growth rates of inputs in the two sectors over this period; (c) a reference base to describe the evolution of productivity levels in the Japanese manufacturing sector. The options that might be pursued by the Korean manufacturing sector will be compared against the reference case; and (d) calculation of the
"required" R&D investment/output ratio at the manufacturing level that would be consistent with the R&D / GNP ratio of 5%, the announced government target in 2000.

(a) Input Prices Over the Period 1991-2001

We generate the input prices for the period 1991-2001 using the average annual growth rates, obtained from the recent United Nations Project Link in 1993. The average growth rates of prices and real GDP for the two countries for the period 1991-2000 are shown below.

Table 13: Average Annual Growth Rate for Factor Prices and GDP in 1991-2001* (%) | Korea | Japan |
<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>$W_L^{1'}$</td>
<td>10.62</td>
<td>2.89</td>
</tr>
<tr>
<td>$W_M^{2'}$</td>
<td>2.72</td>
<td>1.25</td>
</tr>
<tr>
<td>$W_K^{3'}$</td>
<td>3.26</td>
<td>0.14</td>
</tr>
<tr>
<td>$W_R^{2,3'}$</td>
<td>5.49</td>
<td>1.25</td>
</tr>
<tr>
<td>GDP deflator $^4'$</td>
<td>5.49</td>
<td>1.25</td>
</tr>
<tr>
<td>real GDP</td>
<td>7.5</td>
<td>3.0</td>
</tr>
</tbody>
</table>


There are, however, considerable trends and variations in the growth rates of the individual series. These yearly variations and trends of course affect the projected values of the level of

*Note:
1. % change of monthly wage rate in manufacturing sector for Korea; % change of nominal wage per capita for Japan.
2. We assume that the growth rates of $W_R$, the price deflator for R&D investment, are the same as the GDP deflator.
3. We assume that the real interest rate and depreciation rate will not change, but only the price deflator for investment will change.
4. We assume the GDP deflator will move same as GNP deflator.
labor productivity in the two sectors.

We have assumed the average growth rates for the period 1991-2001 to prevail for the period 2001-2010. Finally, in the absence of any detailed projection of prices at the sectoral levels, we have assumed that the growth rates of prices are the same as those for the aggregate Japanese and Korean economies shown above.

(b) The Growth of Inputs

We make two sets of assumptions about the growth of inputs: One, we assume that the average growth rates of traditional inputs L, M, and K experienced by the Korean manufacturing sector in 1981-1990 will prevail in the projection period of 1991-2001. The rate of growth of R&D capital, however, is assumed to vary according to the R&D policy and expenditure undertaken by Korean manufacturing. The alternative possibility is to assume much slower average growth rates of the traditional inputs for the Korean manufacturing sector over the projection period than those experienced during the 1981-1990 period. This assumption is based on the notion that Korea, because of supply limitation and increased price of inputs, is not likely to be able to sustain the historical growth rates of inputs experienced in the 1980s. This assumption is consistent with the view that as the Korean economy makes its transition from a "high growth" developing and newly industrializing economy to a lower growth and mature economy in which the rate of productivity becomes the critical source of economic growth.

(c) Baseline Projection: Japanese Output and Productivity of Growth

To establish a baseline, we need to estimate the level of labor productivity in the Japanese manufacturing sector over the projection period. For this purpose we assume that the inputs in the Japanese manufacturing sector will grow at their average annual rates for the period 1981-1990. The same procedures are taken in deriving new output elasticities as
for the Korean manufacturing sector.

In table 13 the growth rates of inputs used for projections and the resulting growth rates of output and labor productivity for the Japanese manufacturing sector for the period 1991-2001 are shown. Several interesting results are suggested by the figures shown in this table.

(1) The growth rate of gross output $\frac{\partial \ln VC}{\partial t}$ is slightly above 5%, which exceeds by about 2% points the growth of GDP forecasted for this period by Project Link. This may be expected because manufacturing industries may grow faster than other sectors of the economy.

(2) The contribution of the rate of technical change TCH rises by 16%. The contribution of the autonomous part of technical change remains fixed (by the assumption of the model) at .55.

(d) Required R&D Expenditure/Output Rates

To assess the impact of different R&D investment expenditure policy on growth of outputs and labor productivity over the projection period, we need to construct the corresponding growth rates of the net stock of R&D capital. We assume different growth rates of R&D capital stock, $g_R$, and assume that R&D capital stock grows according to the equation

$$R_{t+k} = R_t (1 + g_R)^k$$

over the next k periods. Using the perpetual inventory method, given $R_{t+k}$ series, and depreciation rate of $\delta_R$ (.15), we generate the net R&D investment series $I_{t+k}^R$ consistent with $g_R$. We then calculate the ratio of R&D investment to output in the manufacturing sector for the span of k periods. The growth rate of gross output ($g_y$) in the Korean manufacturing
sector is generated by the model given the course of prices and average growth of inputs and technology. Using the relation

\[(25) \quad Y_{t+k} = Y_t (1 + g_v)^k,\]

we construct a series for the level of gross output corresponding to different output growth rates, \(g_v\). The ratios of R&D expenditure to gross output in Korean manufacturing over the projection period, consistent with the corresponding growth of R&D capital, are obtained by dividing the ratio of \(I^n_{t+k}\) by the \(Y_{t+k}\) series.

To establish the required level of total R&D investment for the aggregate economy, we use the ratio of total manufacturing R&D to total R&D expenditure in 1990 as a weight. The share of the manufacturing sector in total R&D investment in Korea has been rising steadily since the early 1970's. In 1989, it reached a level of 66.9% from a mere 31.3% in 1979. We assume that this share will be 69% in 1996 and 70% in 2000, which seems to be a reasonable assumption considering that it was about 65% and 64% in 1989 for Japan and the US, respectively. After we generate the level of R&D investment in the total economy using this assumed share, we can compute total R&D investment over GDP ratio. The level of GDP over the projection period is obtained from the UN Project Link, as mentioned earlier, for the period 1991-2001.

To calculate the projected level of labor productivity we need, aside from calculating the growth rates of input prices and input quantities, the values of appropriate output elasticities. In principal we can use different values of these elasticities estimated at a particular year or at an average point of the sample. We have chosen the output elasticities calculated by our model for the year 1990, the end of our sample point as more realistic. The values of output elasticities used to calculate the baseline projection for the Japanese manufacturing is shown in table 14. The relevant output elasticities for the Korean
manufacturing sector used in all of the scenarios are \( \gamma_L = .146, \gamma_M = .777, \gamma_K = .191, \gamma_R = .028 \) and \( \gamma_t = .003 \). Note that the values of these elasticities are quite close for the Japanese manufacturing. The major difference is in the output elasticity of R&D capital which is about twice as large in Japan and in output elasticity of autonomous technical change which is about one-third higher in Japan than in Korea.

Given these assumptions, we have generated two possible scenarios.

**Scenario I: Historical Growth Rates**

We assume in this scenario that the average growth rates of the traditional inputs over the projection period 1991-2001 will be the same as those experienced over the period 1981-90. The growth rates of the traditional inputs in the Korean manufacturing sector used in this scenario were: \( \dot{L} = 3.14\%, \dot{M} = 11.72\%, \) and \( \dot{K} = 11.8\% \). Several growth rates for R&D capital ranging from 15% to 30% were used to generate the appropriate level of R&D capital and the implied R&D gross investment. The growth rates of 15% to 30%, as we have noted earlier, were experienced by the Korean manufacturing sector before. In fact, the growth rate of R&D capital during 1975-80 was above 30%, 24% over the period 1981-85, and 28% in 1986-90. The value \( g_R = 26.37\% \) corresponds to the actual average growth rate of R&D capital in Korean manufacturing over the period 1981-1990. The results of our projections corresponding to the assumed growth rates of R&D capital are shown in table 15.

The growth rates of output (\( \dot{Y} \)) and labor productivity (\( \dot{Y}/L \)) are quite high; this is basically a reflection of the high growth rates of the traditional inputs (\( L, M, K \)) assumed in this scenario. The contribution of the rate of technical change due to the increased growth of R&D capital rises as the growth rate of R&D capital (\( g_R \)) increases. The
contribution of the growth of R&D capital to output and labor productivity growth increases with higher values of $g_R$. For example, its contribution to growth of $\dot{Y}$ and $\langle \dot{Y}/L \rangle$ are about .047 and .063 respectively at $g_R = .20$; these contributions increase to .076 and .101 when the stock of R&D capital grows at 0.25.

The required R&D investment as a percent of gross output of the manufacturing sector, consistent with the assumed growth rates of R&D capital stock, $g_R$, is also shown in table 15. For 1996, the ratio will increase from .70 to 1.90, corresponding to 15 and 30 percent growth of R&D capital stock. The corresponding ratios in the year 2000 are .77 to 3.29. Note that in calculating this ratio we have used gross output which is much larger than value added or industry GDP. In terms of value added, this ratio would be about 10.0%. This figure is twice the R&D investment expenditure to manufacturing GDP ratio of 4.8% in 1990. We can calculate the required total R&D expenditure as a percentage of national GDP using the assumptions made about the ratio of total R&D in the manufacturing sector to that of the Korean economy and the growth rate of GDP projected by Project Link. A growth rate of R&D capital of 15% implies a total R&D to GDP ratio of about 2.35 in the year 2000; at growth rates of R&D capital of 25% at the manufacturing sector, total R&D/GDP ratio rises to about 6.6%.

Finally, using the relation (22), the growth rates of $\langle \dot{Y}/L \rangle$ shown in table 15 for the Korean manufacturing sector, and those shown in table 14 for the Japanese manufacturing sector, we estimate the time period in which the Korean manufacturing sector may catch up with that of Japan in terms of the level of labor productivity. The remarkable fact is that catch-up periods do not differ with different growth rates of R&D stock. The convergence will take place mainly around 1996-98 in all cases. The reason
is that growth rates of labor productivity (\(\ddot{Y}/L\)) vary little as the value of \(g_R\) increases. This in turn is due to the growth rates of the traditional inputs, which are by assumption the same in the experiments reported in table 15. That is, when the growth rate of traditional input is very high, the growth rate of R&D, though very rapid, will have relatively minor effect because the share of R&D in output is comparatively so small.

**Scenario II  Moderate Growth Rates of Inputs**

In this scenario we have assumed that the growth rates of traditional inputs over the projection period will be much lower than the historical growth rates experienced in 1981-1990. The average growth rates used in this scenario were assumed to be: \(L = 1.5\%\), \(M = 7\%\), and \(K = 9\%\). We assume the same growth rates for R&D capital as in Scenario I. A precise estimation of the growth rates of these inputs would require forecasts of the growth rates of labor, materials, and capital services at the total manufacturing level for the 1990s which are not available. However, there is evidence that employment growth in the manufacturing sector could slow down because of a substantial rise in wage rates and slow growth of population. Similarly, supply considerations and increases in prices of materials and capital services may restrict their growth rates.

The results of scenario II are presented in table 16. They differ greatly from the results reported in table 15. The growth rates of output and productivity are much smaller than in Scenario I. The smaller growth rates of \(Y\) and \(\dot{Y}/L\) reflect the slower growth of the traditional inputs. The contribution of TCH, reflecting mainly the contribution of R&D capital to growth of output and productivity, is much higher under this scenario. For example, assuming \(g_R = .25\), the contribution of technical change is about 18% to \((\ddot{Y})\) and

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22% to (Y/L). About 90% of these contributions are primarily due to the contribution of R&D capital. The ratio of R&D expenditures to gross output in the manufacturing sector is about 28% higher in 1996 and 48% in the year 2000 than the corresponding cases under Scenario I. These higher ratios are due to the slower growth rates of output projected in Scenario II. The ratio of total R&D to GDP for total economy, however, remains the same as in Scenario I because the growth rates of R&D capital and GDP are the same in the two scenarios.

The catch-up period in Scenario II is much longer than in Scenario I, reflecting the slower projected growth rates of labor productivity for the Korean manufacturing sector under Scenario II. The catch-up period is about four years longer at R&D capital growth rates of over 25% and gets much longer if growth rates of R&D capital are much lower than the rate. For example, at \( g_R = .15 \), the catch-up year under Scenario I is approximately 1998, but 2008 under Scenario II. Under Scenario II, when we compare the catch-up periods associated with different growth rates of R&D capital, we observe the effect of different growth of R&D capital on the length of the catch-up period. For example, when \( g_R = .25 \), given the growth rates of other inputs, the catch-up year is 2003, while at \( g_R = .15 \), the catch-up period is extended to the year 2008. That is, the catch-up period is shortened by five years if the R&D investment policy promotes growth of R&D capital stock of about 25%.

The importance of growth rate of R&D capital in the catch-up process can be seen from another scenario based on the growth rates of inputs projected recently by the Korean Development Institute (KDI). KDI estimates average growth rates of inputs for the period 1991-2001 of \( \dot{L} = 3.47\% \), \( \dot{M} = 6.17\% \) and \( \dot{K} = 8.46\% \), which are similar to those of scenario II. The
major exception is that we assume the growth rate of labor to be about 40% of that projected by KDI. Using the KDI assumption on input growth and $g_R = 20\%$, the growth rate of labor productivity for the Korean manufacturing sector will be about 4.25%. This growth rate of labor productivity will be less than that generated by the baseline projection for the Japanese manufacturing sector of 4.31%. Given the fact that the level of labor productivity is higher in Japan than that in Korea in the base year 1990, there is no possibility of complete convergence. However, if the growth rate of R&D capital in Korean manufacturing is pushed to $g_R = 30\%$ and assuming all the other inputs grow according to the average growth rates projected by KDI, the catch up process will be complete in 2007-08. This suggests that if the growth of labor is as high as projected by KDI, the Korean manufacturing sector must invest in R&D capital at rates much higher than 30% to catch up with the level of labor productivity of the Japanese manufacturing sector at anytime before the year 2008.

Given the results of our two scenarios, the question is which growth rate of R&D capital is sustainable. Once this rate is chosen we can calculate the required R&D investment to gross output ratio in Korean manufacturing, and the corresponding ratio of total R&D expenditure to GDP for the Korean economy. This choice is not easy, and depends on several considerations such as the anticipated growth of gross output in manufacturing and GDP, the proportion of total R&D expenditure devoted to manufacturing, the distribution of the R&D investment among the manufacturing industries, the evolution of future input prices and increases in the quantity and quality of the inputs. The structure of the production process may also change in response to R&D investment; new products and production processes will be developed as a consequence of investment in R&D. The magnitude of autonomous technical change, which we have assumed to remain unchanged in our simulations, may likewise change in response to the growth of prices, inputs, and R&D investment. Also, the rate of autonomous technical change for Korean
manufacturing may turn out to be much higher in the future than our estimates because of human capital formation, organizational changes, learning by doing, etc.

Nonetheless, recognizing these considerations, we can still use our simulation result to consider the consequences of the government policy to increase total R&D expenditure/GDP ratio to 5% in the year 2000. We shall concentrate on the results of Scenario II, which seem to be more likely to occur. Looking at the column with the R&D/GDP ratio in table 16, the growth rate of R&D capital stock consistent with a 5% R&D/GDP ratio is about 0.22. This rate is lower than the \( g_R = 26.37\% \) which the Korean manufacturing sector experienced in the period 1981-1990. With this growth rate the share of R&D in total cost of this sector in the year 2000 will be approximately 6.2%, which will be much lower than the projected Japanese share of about 9% in the same year. The 22% growth rate of R&D investment in Korea is lower than historically experienced; it may very well be sustainable and consistent with the ratio of R&D/GDP of 5% in the year 2000, as targeted by the Korean government. However, two important qualifications are in order.

(1) The structures of R&D expenditures in Korea and Japan are quite different. In 1990, Japan spends about 12% of R&D expenditure on equipment and structures for R&D facilities; 38% of R&D funds are spent on materials, and 51% on scientists and technicians. In Korea, inputs for R&D activities are approximately as follows: equipment and structures, 43%; materials, 25%; and scientists and technicians, 28%. These shares suggest that Korea may have developed sufficient research facilities, but now may have to shift resources to hire more scientific and technical personnel. This may not be very easy to do in the short-term if the educational and training institutions have difficulty producing the required scientific skills. In the short run, the cost of R&D personnel will increase, slowing the rate of growth of R&D capital.

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(2) The results reported here pertain to the entire total manufacturing sector of each of the economies. To design a successful R&D policy, it is essential to know the distribution of total R&D in different industries within the manufacturing sector, and compare performance of specific industries in different countries. For example, a study by Nadiri and Prucha (1990) comparing two high R&D-intensive industries, the electrical machinery indicates that R&D capital contributes greatly to the productivity growth. Similarly, since the distribution of R&D expenditures varies greatly as noted earlier, within the Korean manufacturing sector, a systematic study will indicate a much more significant role played by R&D at the sub-industry level. The degree of R&D intensity and the impact of R&D investment on the structure of production and costs vary considerably among different industries, and therefore the rates of return to R&D investment often vary among industries. The policy challenge, therefore, is not only to increase total R&D expenditure to reach a particular target over a period of time, but to allocate optimally a given R&D expenditure among different industries. To allocate a given R&D investment expenditure among several industries will require a careful assessment of the role R&D plays in different industries and to estimate the likely private and social rates of return to private and publicly-funded R&D investment in different industries.

IX. Conclusion

The basic conclusion that our analysis suggests is that Korean industries have benefited greatly from their R&D investment. The rate of return on R&D investment in the manufacturing sector has been very high compared to that in the Japanese and US sectors. R&D investment has also been a major contributor to narrowing the gap between levels of labor productivity in the Korean and Japanese manufacturing sectors. The Korean manufacturing sector could overtake the Japanese sector in terms of levels of productivity in the next four to five years if it can sustain
the high growth rate of traditional input experienced in the 1980s. Such high rates of growth of inputs, however, are not likely to be sustainable in light of the slow growth of population (projected to be about 1%), rising wage rate, and the slow pace of autonomous technological progress. In such circumstances the growth of R&D expenditures becomes very important. As the results of Scenario II indicate, high R&D by the Korean manufacturing sector can offset to a great extent the technological gap behind that of the Japanese sector, and could shorten considerably the catch-up period when Korea faces lower growth of traditional inputs. These results will, of course, alter considerably if the pace of technological progress or input accumulation in the Japanese manufacturing sector increases in the coming years.

A reasonable strategy for the Korean manufacturing sector is to keep a moderately high input growth, particularly that of capital accumulation, and a high R&D expenditure policy, particularly if the Japanese manufacturing sector experiences high growth rates. To expedite the growth rate of output and productivity, transform the technological structure of its industries, and shorten the catch-up period for achieving the same level of labor productivity in Japan during this decade will require sustained support and refinement of this policy. The declared aim of achieving a total R&D expenditure/GDP ratio of 5% for the economy is desirable. However, the bottlenecks, particularly in the quality and number of scientists and technicians, may make such an achievement more challenging.
NOTES

The author would like to thank Seongjun Kim for his excellent research assistance, and Marilyn Harris for her help in preparing this manuscript. Support from the C.V. Starr Center for Applied Economics of New York University is also gratefully acknowledged.

1. Let \( n_v = \partial \ln \text{VC}/\partial \ln y \) and \( n_y = \partial \ln \text{SC}/\partial \ln y \) denote the output elasticity of variable and short-run (total) costs, respectively. Differentiating (2) with respect to output, and letting \( z \) vary arbitrarily, we obtain

\[
\text{SC}_y = F_y + f_y z \dot{y} + r \dot{z} \dot{y}
\]

To allow for inoptimal choice of \( z \), let \( F_z = r + d \) where \( d = (d_1, \ldots, d_e) \) denotes the deviations of the shadow prices from the market rental prices of \( z \). Using this notation and converting (6) to elasticities we obtain

\[
n_v = (1 + \pi)^{-1} \left[ n_v - \pi y n_{yy} \right]
\]

where \( \pi = (1 + rz'/\text{VC}) \), \( \pi_y = dz'/\text{VC} \) and \( n_{yy} = \partial \ln z/\partial \ln y \). Therefore, the short-run (total) cost elasticity reflects the variable cost elasticity, the divergence of fixed inputs from their static equilibrium levels, and the response of those inputs to changes in the level of output. If static equilibrium holds, \( z = z^* \) and \( d = 0 \), short- and long-run costs coincide, and the long-run cost elasticity \( n = \partial \ln \text{C}/\partial \ln y \) becomes

\[
n_v = (1 + \pi^*)^{-1} n_v^*
\]

where \( \pi^* \) and \( n_v^* \) are evaluated at \( z = z^* \).

2. Caves, Christensen and Swanson (CCS) show that the degree of returns to scale, RTS, can be expressed as \( \text{RTS} = (1 - \partial \ln \text{VC}/\partial \ln z) \). At \( z = z^* \) this reduces to equation (8) (where \( \text{RTS} = n_v^{-1} \)), but in general it implies that the degree of long run scale economies can be retrieved from the restricted cost function at arbitrary levels of \( z \). The equation derived by CCS is correct. The problem with their analysis is that RTS is not the correct measure of scale economies in general. The concepts of RTS is base on equiproportional increases in all inputs, including \( z \). As Hanoch (1975) showed, the correct concept of scale economies is \( n_v^{-1} \), measured along the expansion path. The two concepts are the same only if the production structure is homothetic, in which case the expansion path is linear and equiproportional expansion of all inputs corresponds to long-run cost-minimizing behavior. That is, the envelope conditions are assumed implicitly to hold, and \( z = z^* \). Therefore, the only case when RTS is the correct of scale economies corresponds to the case where \( z = z^* \). If the technology is not homothetic, the CCS measure of RTS is equivalent to the reciprocal of the short run cost elasticity. To show this, suppose that all inputs are increased equiproportional but not along the expansion path. This is the equivalent in (7) to assuming that \( n_{yy} = n_v' \), since if all inputs grow at the same rate then (short run) costs must also grow at that rate. Then (7) reduces to \( n_v = (1 + \pi + \pi_{yy})^{-1} n_v \). Since \( \pi + \pi_{yy} = \partial \ln \text{VC}/\partial \ln z \), \( n_v = (1 - \partial \ln \text{VC}/\partial \ln z)^{-1} n_v \). Then the CCS result is simply \( \text{RTS} = n_v^{-1} \). In other words, the CCS result should be interpreted as a special case of (7), pertaining to the short-run cost elasticity. As indicated before, in order for it to relate to long-run scale economies, the assumption \( z = z^* \) must be made. That is, equation (8) holds only at \( z = z^* \), and influences based on (8) are invalid if \( z \neq z^* \). This finding contrasts with Caves, Christensen, and Swanson (1981), who claim to show that the long-run scale economies can be retrieved at any arbitrary level of \( z \).
3. We made some corrections on Korean R&D investment data for 1974 and 1975. According to the official data published by MOST, R&D investment by manufacturing sector in current price in 1974 and 1975 are 2.61 and 0.25 billion won respectively while those of all industry are 33.9 and 42.7 bil. won. Our new figures are 7.54 and 9.50 bil. won, which is derived under the assumption that the share of manufacturing sector in R&D expenditures in 1974 and 1975 is same as that of 1973. The new R&D expenditure series show much more reasonable trend.

4. Kwack told us that even though depreciation rate for capital stock was estimated as 1.91% during 1968 - 77 and 5.21% during 1977 - 87 by polynomial benchmark method, which used investment series and national wealth survey data in 1968, 1977 and 1987, there is very high possibility of underestimation of depreciation rate. It is because that the investment and benchmark values for capital stock are not completely consistent with each other, and it is widely accepted that the investment data are underevaluated. Kwon and Yuhn (1990) used 12 % depreciation rate which they got from BOK, Financial Statements Analysis.

5. 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 (Hulten (1973)). Path independence is therefore an essential element of any acceptable Divisia index.

The conventional Divisia index of $\hat{F}$ is the cost-share weighted average of rates of growth of inputs:

$$\hat{F} = \sum_i \left( \frac{P_i}{C} \right) \dot{X}_i , \quad \sum P_i X_i = C,$$

where $P_i$ and $X_i$ are the $i$th factor’s price and quantity, and $C$ is total cost. Hulten (1973) has shown that (14) is path independent if and only if $F$ is linearly homogeneous, i.e., if the production function exhibits constant returns to scale. To preserve path independence when $F$ is not linearly homogeneous, we must use the "quasi-Divisia" index (Hulten (1973)):

$$\hat{F} = \sum_i \left( \frac{P_i}{PQ} \right) \dot{X}_i ,$$

where PQ is the value of output. This is a weighted sum (not average) of the rates of growth of the factor inputs where the weights are value (not cost) shares.

6. The parameter estimates used to calculate the net rate of return is given by

$$\gamma_i = \frac{1}{P_i K_i} \left[ (\hat{S}_i + m_{ii} AKBK_i + m_{ij} AKBK_j) \hat{C}^Y \right]$$

$i = K, R$

Where $\hat{C}^Y, \hat{S}_i$ are respectively the estimate values of variable cost, estimate share of physical and R&D capital in variable cost; $m_{ii}$ and $m_{ij}$ are the own- and cross-adjustment cost coefficients and AKBK, and AKBKj are the ratio defined as $\Delta K_{i,-1} \frac{K_{t-1}}{VC_{t-1}}$ representing the magnitude of the adjustment costs for each of the two quasi-fixed inputs, K and R.

7. See Bernstein and Nadiri (1988) for further discussion.
8. The output, Y, is expressed in 1982 constant $US, and 1982 PPP exchange rates are used to convert each national currency into US dollars.
BIBLIOGRAPHY


OECD, *Main Economic Indicators*, various issues.


Table 1. Growth of Output and Inputs and Input Shares in the Total Manufacturing Sector of the United States, Japan and Korea

<table>
<thead>
<tr>
<th></th>
<th>Output</th>
<th>Labor</th>
<th>Materials</th>
<th>Capital</th>
<th>R&amp;D</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>US</td>
<td>Japan</td>
<td>Korea</td>
<td>US</td>
<td>Japan</td>
</tr>
<tr>
<td>1975-80</td>
<td>1.0</td>
<td>3.5</td>
<td>13.4</td>
<td>-0.2</td>
<td>-0.6</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1981-85</td>
<td>1.6</td>
<td>4.0</td>
<td>10.1</td>
<td>-1.2</td>
<td>1.3</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1986-90</td>
<td>3.3</td>
<td>4.5</td>
<td>15.2</td>
<td>-0.2</td>
<td>0.3</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1975-90</td>
<td>1.9</td>
<td>4.0</td>
<td>12.9</td>
<td>-0.5</td>
<td>0.3</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1981-90</td>
<td>2.5</td>
<td>4.3</td>
<td>12.7</td>
<td>-0.7</td>
<td>0.8</td>
</tr>
<tr>
<td></td>
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<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

*Average annual rates of growth
Table 2. Input Shares in the Total Manufacturing Sector of the United States, Japan and Korea*

<table>
<thead>
<tr>
<th></th>
<th>Labor</th>
<th></th>
<th>Materials</th>
<th></th>
<th>Capital</th>
<th></th>
<th>R &amp; D</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
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<td>Japan</td>
<td>Korea</td>
<td>US</td>
<td>Japan</td>
<td>Korea</td>
<td>US</td>
<td>Japan</td>
</tr>
<tr>
<td>1975-80</td>
<td>15.7</td>
<td>14.8</td>
<td>11.1</td>
<td>64.7</td>
<td>67.4</td>
<td>72.7</td>
<td>13.1</td>
<td>14.9</td>
</tr>
<tr>
<td>1981-85</td>
<td>14.3</td>
<td>14.1</td>
<td>9.7</td>
<td>61.6</td>
<td>67.0</td>
<td>71.0</td>
<td>16.2</td>
<td>15.4</td>
</tr>
<tr>
<td>1986-90</td>
<td>14.1</td>
<td>14.6</td>
<td>11.2</td>
<td>64.2</td>
<td>63.6</td>
<td>70.1</td>
<td>13.5</td>
<td>17.2</td>
</tr>
<tr>
<td>1975-90</td>
<td>14.8</td>
<td>14.5</td>
<td>10.7</td>
<td>63.6</td>
<td>66.1</td>
<td>71.4</td>
<td>14.2</td>
<td>15.8</td>
</tr>
<tr>
<td>1981-90</td>
<td>14.2</td>
<td>14.3</td>
<td>10.4</td>
<td>62.9</td>
<td>65.3</td>
<td>70.6</td>
<td>14.9</td>
<td>16.3</td>
</tr>
</tbody>
</table>

*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 (in percentage)*

<table>
<thead>
<tr>
<th>Type of Productivity</th>
<th>Total Factor</th>
<th>Labor</th>
<th>Materials</th>
<th>Capital</th>
<th>R&amp;D</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>US</td>
<td>Japan</td>
<td>Korea</td>
<td>US</td>
<td>Japan</td>
</tr>
<tr>
<td>1975-80</td>
<td>0.08</td>
<td>0.99</td>
<td>0.35</td>
<td>1.25</td>
<td>4.07</td>
</tr>
<tr>
<td>1981-85</td>
<td>0.75</td>
<td>0.57</td>
<td>1.89</td>
<td>2.85</td>
<td>4.20</td>
</tr>
<tr>
<td>1986-90</td>
<td>0.79</td>
<td>0.44</td>
<td>1.72</td>
<td>3.58</td>
<td>3.44</td>
</tr>
<tr>
<td>1975-90</td>
<td>0.51</td>
<td>0.69</td>
<td>1.26</td>
<td>2.48</td>
<td>3.68</td>
</tr>
<tr>
<td>1981-90</td>
<td>0.77</td>
<td>0.51</td>
<td>1.80</td>
<td>3.22</td>
<td>3.44</td>
</tr>
</tbody>
</table>

*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 5. The Parameter Estimates: Physical Capital and R&D Capital Quasi-fixed.

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Estimates</th>
<th>Parameters</th>
<th>Estimates</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\alpha_0$</td>
<td>1.0540 (0.0681)</td>
<td>$\beta_{y1}$</td>
<td>0.0555 (0.0059)</td>
</tr>
<tr>
<td>$\alpha_y$</td>
<td>-0.1436 (0.0090)</td>
<td>$\beta_{yy}$</td>
<td>-0.0109 (0.0300)</td>
</tr>
<tr>
<td>$\alpha_{y2}$</td>
<td>-0.0192 (0.0026)</td>
<td>$\beta_{rr}$</td>
<td>-0.0143 (0.0043)</td>
</tr>
<tr>
<td>$\alpha_{y3}$</td>
<td>-0.0822 (0.0058)</td>
<td>$\beta_{rr}$</td>
<td>-0.0004 (0.0002)</td>
</tr>
<tr>
<td>$\beta_0$</td>
<td>-5.5305 (1.7486)</td>
<td>$\beta_{y2}$</td>
<td>-0.0422 (0.0088)</td>
</tr>
<tr>
<td>$\beta_{02}$</td>
<td>3.8089 (1.3259)</td>
<td>$\beta_{k1}$</td>
<td>0.0515 (0.0063)</td>
</tr>
<tr>
<td>$\beta_{03}$</td>
<td>5.1231 (1.6393)</td>
<td>$\beta_{1r}$</td>
<td>-0.0041 (0.0033)</td>
</tr>
<tr>
<td>$\beta_1$</td>
<td>0.2267 (0.0538)</td>
<td>$\beta_{ky}$</td>
<td>0.0488 (0.0179)</td>
</tr>
<tr>
<td>$\beta_{y2}$</td>
<td>-0.0070 (0.0048)</td>
<td>$\beta_{1y}$</td>
<td>0.0709 (0.0106)</td>
</tr>
<tr>
<td>$\beta_{y3}$</td>
<td>-0.0711 (0.0146)</td>
<td>$\beta_{y2y}$</td>
<td>-0.0361 (0.0109)</td>
</tr>
<tr>
<td>$\beta_{y}$</td>
<td>0.4441 (0.1908)</td>
<td>$\beta_{y3}$</td>
<td>-0.0610 (0.0112)</td>
</tr>
<tr>
<td>$\beta_{y2}$</td>
<td>0.2932 (0.0618)</td>
<td>$\beta_{k1}$</td>
<td>-0.0041 (0.0041)</td>
</tr>
<tr>
<td>$\beta_{y3}$</td>
<td>0.5025 (0.0872)</td>
<td>$\beta_{k2}$</td>
<td>0.0504 (0.0137)</td>
</tr>
<tr>
<td>$\beta_k$</td>
<td>2.7159 (0.4273)</td>
<td>$\beta_{k3}$</td>
<td>0.0691 (0.0153)</td>
</tr>
<tr>
<td>$\beta_{k2}$</td>
<td>-1.4886 (0.3043)</td>
<td>$\beta_{1r}$</td>
<td>-0.0028 (0.0003)</td>
</tr>
<tr>
<td>$\beta_{k3}$</td>
<td>-2.4116 (0.4078)</td>
<td>$\beta_{rr}$</td>
<td>-0.0006 (0.0012)</td>
</tr>
<tr>
<td>$\beta_r$</td>
<td>-0.2509 (0.1433)</td>
<td>$\beta_{rt}$</td>
<td>0.0099 (0.0016)</td>
</tr>
<tr>
<td>$\beta_{r2}$</td>
<td>0.0067 (0.1067)</td>
<td>$\beta_{rr}$</td>
<td>-0.0012 (0.0006)</td>
</tr>
<tr>
<td>$\beta_{r3}$</td>
<td>0.1052 (0.1548)</td>
<td>$\mu_{kk}$</td>
<td>0.0002 (0.0006)</td>
</tr>
<tr>
<td>$\beta_{r}$</td>
<td>-0.0532 (0.0141)</td>
<td>$\mu_{kk2}$</td>
<td>0.0003 (0.0003)</td>
</tr>
<tr>
<td>$\beta_{r2}$</td>
<td>0.0057 (0.0026)</td>
<td>$\mu_{kk3}$</td>
<td>0.0042 (0.0008)</td>
</tr>
<tr>
<td>$\beta_{r3}$</td>
<td>0.0172 (0.0079)</td>
<td>$\mu_{kr}$</td>
<td>0.0002 (0.00007)</td>
</tr>
<tr>
<td>$\beta_{kk}$</td>
<td>-0.4744 (0.0548)</td>
<td>$\mu_{rr}$</td>
<td>0.0014 (0.0006)</td>
</tr>
<tr>
<td>$\beta_{k2}$</td>
<td>0.1452 (0.0431)</td>
<td>$\mu_{rr2}$</td>
<td>0.0030 (0.0022)</td>
</tr>
<tr>
<td>$\beta_{kk3}$</td>
<td>0.2663 (0.0544)</td>
<td>$\mu_{rr3}$</td>
<td>0.0249 (0.0940)</td>
</tr>
</tbody>
</table>

* Estimated standard errors are in parentheses. The subscripts $y$, $l$, $k$, $r$, and $t$ refer to output, labor, physical capital, r&d capital, and time, respectively. Also the subscripts 2 and 3 denote the country dummy variables, 2 for Japan and 3 for Korea respectively. $\alpha$'s are the parameters from the inverse demand function, $\beta$'s from the translog variable-cost-function, and $\mu$'s are the adjustment cost parameters.
Table 6. Price, Cost and Variable Input Elasticities and Estimated Scale and Markups in the Total Manufacturing Sectors of United States, Japan and Korea (1990 values).*

<table>
<thead>
<tr>
<th></th>
<th>Elasticities</th>
<th>U.S.</th>
<th>Japan</th>
<th>Korea</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>-0.142 (0.022)</td>
<td>-0.163 (0.010)</td>
<td>-0.226 (0.014)</td>
</tr>
<tr>
<td>Price and Variable Cost Elasticities</td>
<td></td>
<td>1.099 (0.015)</td>
<td>1.103 (0.014)</td>
<td>1.084 (0.018)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>-0.003 (0.002)</td>
<td>-0.004 (0.002)</td>
<td>-0.003 (0.003)</td>
</tr>
<tr>
<td>Own Price Elasticities of Variable Inputs</td>
<td></td>
<td>-0.501 (0.035)</td>
<td>-0.507 (0.034)</td>
<td>-0.491 (0.037)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>-0.101 (0.007)</td>
<td>-0.107 (0.007)</td>
<td>-0.092 (0.007)</td>
</tr>
<tr>
<td>Scale and Markup</td>
<td></td>
<td>1.146 (0.018)</td>
<td>1.137 (0.020)</td>
<td>1.054 (0.023)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>16.8% (0.012)</td>
<td>19.4% (0.014)</td>
<td>29.2% (0.023)</td>
</tr>
</tbody>
</table>

* Asymptotic standard errors are in parentheses. The elasticities and the scale and markup measures are defined as follows:

\[
\begin{align*}
\varepsilon_{PY} &= \frac{\partial \ln P_Y}{\partial \ln Y} \\
\varepsilon_{CY} &= \frac{\partial \ln VC}{\partial \ln Y} \\
\varepsilon_{CT} &= \frac{\partial \ln VC}{\partial t} \\
\varepsilon_{LL} &= \frac{\partial \ln L}{\partial \ln W_L} \\
\varepsilon_{MM} &= \frac{\partial \ln M}{\partial \ln W_M} \\
\text{SCALE} &= \frac{1 - (\varepsilon_{CK} + \varepsilon_{CR})}{\varepsilon_{CY}} \\
\text{MARKUP} &= \frac{(P_Y - MC)}{P_Y}
\end{align*}
\]

where \(\varepsilon_{CK}\) and \(\varepsilon_{CR}\) are the variable cost elasticities w.r.t. capital and r&d, respectively and VC and MC are variable cost and marginal cost.
Table 7a. Short-Run Fixed Output, Cost and Input Elasticities with respect to Capital and R & D in the Total Manufacturing Sectors of United States, Japan and Korea (1990 values).

<table>
<thead>
<tr>
<th>Elasticities w.r.t. Capital</th>
<th>U.S.</th>
<th>Japan</th>
<th>Korea</th>
</tr>
</thead>
<tbody>
<tr>
<td>( \varepsilon_{LX} )</td>
<td>0.139 (0.037)</td>
<td>0.076 (0.037)</td>
<td>0.195 (0.047)</td>
</tr>
<tr>
<td>( \varepsilon_{MK} )</td>
<td>-0.231 (0.011)</td>
<td>-0.282 (0.015)</td>
<td>-0.192 (0.012)</td>
</tr>
<tr>
<td>( \varepsilon_{CK} )</td>
<td>-0.169 (0.007)</td>
<td>-0.219 (0.012)</td>
<td>-0.131 (0.013)</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Elasticities w.r.t. R &amp; D</th>
<th>U.S.</th>
<th>Japan</th>
<th>Korea</th>
</tr>
</thead>
<tbody>
<tr>
<td>( \varepsilon_{LR} )</td>
<td>-0.116 (0.021)</td>
<td>-0.059 (0.019)</td>
<td>-0.038 (0.024)</td>
</tr>
<tr>
<td>( \varepsilon_{MR} )</td>
<td>-0.086 (0.005)</td>
<td>-0.030 (0.007)</td>
<td>-0.007 (0.004)</td>
</tr>
<tr>
<td>( \varepsilon_{CR} )</td>
<td>-0.091 (0.004)</td>
<td>-0.035 (0.006)</td>
<td>-0.012 (0.005)</td>
</tr>
</tbody>
</table>

* The asymptotic standard errors are in parentheses.
Table 7b. Short-Run Variable Output, Cost and Input Elasticities with respect to Capital and R&D in the Total Manufacturing Sectors of United States, Japan and Korea (1990 values).*

<table>
<thead>
<tr>
<th>Elasticities</th>
<th>U.S.</th>
<th>Japan</th>
<th>Korea</th>
</tr>
</thead>
<tbody>
<tr>
<td>A. Elasticities w.r.t. Capital</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>( \eta_{YK} )</td>
<td>0.535 (0.068)</td>
<td>0.683 (0.094)</td>
<td>0.287 (0.083)</td>
</tr>
<tr>
<td>( \eta_{LK} )</td>
<td>0.592 (0.074)</td>
<td>0.664 (0.091)</td>
<td>0.429 (0.063)</td>
</tr>
<tr>
<td>( \eta_{MK} )</td>
<td>0.384 (0.075)</td>
<td>0.507 (0.100)</td>
<td>0.133 (0.085)</td>
</tr>
<tr>
<td>( \eta_{CK} )</td>
<td>0.419 (0.072)</td>
<td>0.534 (0.096)</td>
<td>0.180 (0.079)</td>
</tr>
<tr>
<td>B. Elasticities w.r.t. R &amp; D</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>( \eta_{YR} )</td>
<td>0.115 (0.045)</td>
<td>0.015 (0.043)</td>
<td>0.009 (0.028)</td>
</tr>
<tr>
<td>( \eta_{LR} )</td>
<td>-0.018 (0.041)</td>
<td>-0.045 (0.040)</td>
<td>-0.030 (0.026)</td>
</tr>
<tr>
<td>( \eta_{MR} )</td>
<td>0.046 (0.050)</td>
<td>-0.012 (0.046)</td>
<td>0.004 (0.029)</td>
</tr>
<tr>
<td>( \eta_{CR} )</td>
<td>0.035 (0.048)</td>
<td>-0.018 (0.044)</td>
<td>-0.002 (0.027)</td>
</tr>
</tbody>
</table>

* The asymptotic standard errors are in parentheses.
Table 8. Sources of Output Growth for Manufacturing Sector, Average Annual Rates of Growth (in percentage).

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>United States</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1975 - 80</td>
<td>1.09</td>
<td>-0.03</td>
<td>0.62</td>
<td>0.34</td>
<td>0.01</td>
<td>0.81</td>
<td>-0.66</td>
</tr>
<tr>
<td>1981 - 85</td>
<td>1.61</td>
<td>-0.23</td>
<td>0.58</td>
<td>0.22</td>
<td>0.13</td>
<td>0.52</td>
<td>0.38</td>
</tr>
<tr>
<td>1986 - 90</td>
<td>3.33</td>
<td>-0.04</td>
<td>2.52</td>
<td>0.14</td>
<td>0.23</td>
<td>0.26</td>
<td>0.22</td>
</tr>
<tr>
<td>1981 - 90</td>
<td>2.47</td>
<td>-0.13</td>
<td>1.55</td>
<td>0.18</td>
<td>0.18</td>
<td>0.39</td>
<td>0.30</td>
</tr>
<tr>
<td>1975 - 90</td>
<td>1.95</td>
<td>-0.09</td>
<td>1.20</td>
<td>0.24</td>
<td>0.12</td>
<td>0.55</td>
<td>-0.06</td>
</tr>
<tr>
<td><strong>Japan</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1975 - 80</td>
<td>3.47</td>
<td>-0.11</td>
<td>2.32</td>
<td>0.30</td>
<td>0.12</td>
<td>0.75</td>
<td>0.08</td>
</tr>
<tr>
<td>1981 - 85</td>
<td>3.98</td>
<td>0.23</td>
<td>1.91</td>
<td>0.52</td>
<td>0.18</td>
<td>0.46</td>
<td>0.68</td>
</tr>
<tr>
<td>1986 - 90</td>
<td>4.55</td>
<td>0.06</td>
<td>4.73</td>
<td>0.68</td>
<td>0.24</td>
<td>0.25</td>
<td>-1.42</td>
</tr>
<tr>
<td>1981 - 90</td>
<td>4.27</td>
<td>0.15</td>
<td>3.32</td>
<td>0.60</td>
<td>0.21</td>
<td>0.36</td>
<td>-0.37</td>
</tr>
<tr>
<td>1975 - 90</td>
<td>3.97</td>
<td>0.05</td>
<td>2.95</td>
<td>0.49</td>
<td>0.18</td>
<td>0.50</td>
<td>-0.20</td>
</tr>
<tr>
<td><strong>Korea</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1975 - 80</td>
<td>13.39</td>
<td>0.99</td>
<td>10.47</td>
<td>2.53</td>
<td>0.02</td>
<td>0.46</td>
<td>-1.09</td>
</tr>
<tr>
<td>1981 - 85</td>
<td>10.09</td>
<td>0.43</td>
<td>7.21</td>
<td>1.19</td>
<td>0.11</td>
<td>0.31</td>
<td>0.85</td>
</tr>
<tr>
<td>1986 - 90</td>
<td>15.23</td>
<td>0.26</td>
<td>12.03</td>
<td>1.97</td>
<td>0.26</td>
<td>0.19</td>
<td>0.51</td>
</tr>
<tr>
<td>1981 - 90</td>
<td>12.66</td>
<td>0.34</td>
<td>9.62</td>
<td>1.58</td>
<td>0.18</td>
<td>0.25</td>
<td>0.02</td>
</tr>
<tr>
<td>1975 - 90</td>
<td>12.93</td>
<td>0.59</td>
<td>9.94</td>
<td>1.94</td>
<td>0.12</td>
<td>0.33</td>
<td>0.68</td>
</tr>
</tbody>
</table>

a/ Growth rate of inputs weighted by its output elasticity.
<table>
<thead>
<tr>
<th></th>
<th>Labor</th>
<th>Capital</th>
<th>R&amp;D</th>
<th>TC</th>
<th>Residual</th>
</tr>
</thead>
<tbody>
<tr>
<td>US</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1975-80</td>
<td>2.48</td>
<td>1.54</td>
<td>0.49</td>
<td>0.24</td>
<td>-0.05</td>
</tr>
<tr>
<td>1976-80</td>
<td>1.25</td>
<td>0.71</td>
<td>0.01</td>
<td>0.34</td>
<td>0.28</td>
</tr>
<tr>
<td>1978-80</td>
<td>2.86</td>
<td>1.49</td>
<td>0.56</td>
<td>0.02</td>
<td>0.32</td>
</tr>
<tr>
<td>1981-85</td>
<td>3.58</td>
<td>0.42</td>
<td>0.34</td>
<td>0.30</td>
<td>0.35</td>
</tr>
<tr>
<td>1986-90</td>
<td>3.84</td>
<td>0.41</td>
<td>0.45</td>
<td>0.05</td>
<td>-0.11</td>
</tr>
<tr>
<td>Japan</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1975-80</td>
<td>3.68</td>
<td>2.22</td>
<td>0.85</td>
<td>0.38</td>
<td>-0.12</td>
</tr>
<tr>
<td>1976-80</td>
<td>4.07</td>
<td>0.68</td>
<td>0.68</td>
<td>0.36</td>
<td>0.34</td>
</tr>
<tr>
<td>1978-80</td>
<td>2.69</td>
<td>1.36</td>
<td>0.26</td>
<td>0.23</td>
<td>-0.56</td>
</tr>
<tr>
<td>1981-85</td>
<td>4.20</td>
<td>2.70</td>
<td>0.72</td>
<td>0.39</td>
<td>0.41</td>
</tr>
<tr>
<td>1986-90</td>
<td>4.30</td>
<td>2.87</td>
<td>0.41</td>
<td>0.41</td>
<td>-0.01</td>
</tr>
</tbody>
</table>

Table 9. Sources of Labor Productivity Growth for Manufacturing Sector, Average Annual Rates of Growth (in percentage)
Table 10. Decomposition of the Traditional Measure of Total Factor Productivity Growth for the Total Manufacturing Sectors of the United States, Japan and Korea (in percentages)

<table>
<thead>
<tr>
<th>Period</th>
<th>United States</th>
<th>Japan</th>
<th>Korea</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>TFP</td>
<td>R &amp; D effect</td>
<td>Technical change</td>
</tr>
<tr>
<td>1975-80</td>
<td>0.73</td>
<td>0.30</td>
<td>0.16</td>
</tr>
<tr>
<td>1975-80</td>
<td>0.16</td>
<td>0.24</td>
<td>0.12</td>
</tr>
<tr>
<td>1981-90</td>
<td>1.07</td>
<td>0.24</td>
<td>0.33</td>
</tr>
<tr>
<td>1975-90</td>
<td>1.14</td>
<td>0.34</td>
<td>0.23</td>
</tr>
<tr>
<td>1975-90</td>
<td>1.31</td>
<td>0.32</td>
<td>0.19</td>
</tr>
<tr>
<td>1981-90</td>
<td>1.04</td>
<td>0.35</td>
<td>0.25</td>
</tr>
<tr>
<td>1975-90</td>
<td>3.15</td>
<td>0.40</td>
<td>0.11</td>
</tr>
<tr>
<td>1975-90</td>
<td>2.69</td>
<td>0.56</td>
<td>-0.02</td>
</tr>
<tr>
<td>1981-90</td>
<td>3.43</td>
<td>0.31</td>
<td>0.19</td>
</tr>
</tbody>
</table>

* The traditional TFP measure in the second column 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 11. 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).

<table>
<thead>
<tr>
<th>Period</th>
<th>Capital</th>
<th></th>
<th></th>
<th></th>
<th>R &amp; D</th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>U.S.</td>
<td>Japan</td>
<td>Korea</td>
<td>U.S.</td>
<td>Japan</td>
<td>Korea</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1980-90</td>
<td>10.63</td>
<td>7.69</td>
<td>17.84</td>
<td>12.39</td>
<td>11.73</td>
<td>19.42</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1980</td>
<td>11.30</td>
<td>9.27</td>
<td>17.55</td>
<td>14.16</td>
<td>12.01</td>
<td>31.46</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1985</td>
<td>11.14</td>
<td>7.96</td>
<td>15.06</td>
<td>11.56</td>
<td>12.31</td>
<td>18.94</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1990</td>
<td>9.63</td>
<td>9.33</td>
<td>22.78</td>
<td>11.11</td>
<td>15.60</td>
<td>23.88</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Table 11: Decomposition of Total Factor Productivity Growth in the US, Japanese, and Korean Total Manufacturing Industries (in percentages)

<table>
<thead>
<tr>
<th></th>
<th>US</th>
<th>Japan</th>
<th>Korea</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total Factor Productivity</td>
<td>0.77</td>
<td>1.23</td>
<td>3.32</td>
</tr>
<tr>
<td>Scale Effect</td>
<td>0.28</td>
<td>0.65</td>
<td>2.92</td>
</tr>
<tr>
<td>Temporary Equilibrium Effect</td>
<td>0.03</td>
<td>0.04</td>
<td>-0.03</td>
</tr>
<tr>
<td>Mark-Up Effect</td>
<td>0.02</td>
<td>0.18</td>
<td>1.91</td>
</tr>
<tr>
<td>R&amp;D Effect</td>
<td>0.16</td>
<td>0.21</td>
<td>0.09</td>
</tr>
<tr>
<td>Technical Change</td>
<td>0.30</td>
<td>0.32</td>
<td>0.34</td>
</tr>
<tr>
<td>Unexplained Residual</td>
<td>-0.04</td>
<td>-0.08</td>
<td>-0.16</td>
</tr>
</tbody>
</table>
Table 14: The Baseline Projections for the Japanese Manufacturing Sector, 1991-2000, mean values for the 1991-2001 period

<table>
<thead>
<tr>
<th></th>
<th>L</th>
<th>M</th>
<th>K</th>
<th>R</th>
<th>t</th>
<th>( \hat{Y} )</th>
<th>( \hat{Y}/L )</th>
<th>Contributed by</th>
<th>TCH</th>
<th>( \hat{R} )</th>
<th>t</th>
</tr>
</thead>
<tbody>
<tr>
<td>output elasticity</td>
<td>.140</td>
<td>.755</td>
<td>.219</td>
<td>.072</td>
<td>.004</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>growth rate (%)</td>
<td>0.82</td>
<td>3.51</td>
<td>6.24</td>
<td>8.92</td>
<td>-</td>
<td>5.13</td>
<td>4.31</td>
<td></td>
<td>1.00</td>
<td>0.64</td>
<td>0.36</td>
</tr>
</tbody>
</table>

*mean values for 1991-2001 period*
Table 15: Scenario I: Historical Growth Rates for L, M and K (Percent)
Korean Total Manufacturing Sector

<table>
<thead>
<tr>
<th>$g_r$</th>
<th>$\dot{Y}$</th>
<th>$\dot{Y}/L$</th>
<th>Contributed by</th>
<th>Required R&amp;D</th>
<th>Investment Ratios</th>
<th>Catch-up period</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>TCH $\dot{R}$ $t$</td>
<td>$R &amp; D$ Exp.*</td>
<td>Total R&amp;D Exp.**</td>
<td>GDP</td>
</tr>
<tr>
<td>30.00</td>
<td>13.24</td>
<td>10.10</td>
<td>1.84 1.54 0.30</td>
<td>1.90 3.29</td>
<td>5.04 10.62</td>
<td>1996-97</td>
</tr>
<tr>
<td>26.37</td>
<td>12.92</td>
<td>9.78</td>
<td>1.41 1.11 0.30</td>
<td>1.53 2.39</td>
<td>4.03 7.57</td>
<td>1996-97</td>
</tr>
<tr>
<td>25.00</td>
<td>12.83</td>
<td>9.69</td>
<td>1.28 0.98 0.30</td>
<td>1.40 2.11</td>
<td>3.69 6.64</td>
<td>1996-97</td>
</tr>
<tr>
<td>20.00</td>
<td>12.56</td>
<td>9.42</td>
<td>0.89 0.59 0.30</td>
<td>1.01 1.30</td>
<td>2.63 4.02</td>
<td>1997-98</td>
</tr>
<tr>
<td>15.00</td>
<td>12.39</td>
<td>9.25</td>
<td>0.64 0.41 0.30</td>
<td>0.70 0.77</td>
<td>1.82 2.35</td>
<td>1997-98</td>
</tr>
</tbody>
</table>

* The ratio is the manufacturing sector.
** The ratio refers to the aggregate economy.
Table 16: Scenario II: Moderate Growth Rates for L, M and K (Percent)
Korean Total Manufacturing Sector

<table>
<thead>
<tr>
<th>$g_R$</th>
<th>$\dot{\gamma}$</th>
<th>$\bar{\gamma} / L$</th>
<th>Contributed by</th>
<th>Required R&amp;D</th>
<th>Investment Ratios</th>
<th>Catch-up period</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>TCH $R$ $t$</td>
<td>R &amp; D Exp.*</td>
<td>Total R&amp;D Exp.**</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Gross Output</td>
<td>GDP</td>
<td></td>
</tr>
<tr>
<td>30.00</td>
<td>9.19</td>
<td>7.69</td>
<td>2.29 1.49 0.30</td>
<td>2.41 4.82</td>
<td>5.25 11.05</td>
<td>2001-02</td>
</tr>
<tr>
<td>26.37</td>
<td>8.73</td>
<td>7.23</td>
<td>1.73 1.43 0.30</td>
<td>1.94 3.53</td>
<td>4.19 7.88</td>
<td>2002-03</td>
</tr>
<tr>
<td>25.00</td>
<td>8.58</td>
<td>7.08</td>
<td>1.56 1.26 0.30</td>
<td>1.78 3.12</td>
<td>3.84 6.91</td>
<td>2002-03</td>
</tr>
<tr>
<td>20.00</td>
<td>8.17</td>
<td>6.67</td>
<td>1.06 0.76 0.30</td>
<td>1.28 1.94</td>
<td>2.74 4.19</td>
<td>2004-05</td>
</tr>
<tr>
<td>15.00</td>
<td>7.91</td>
<td>6.41</td>
<td>0.73 0.43 0.30</td>
<td>0.90 1.16</td>
<td>1.90 2.45</td>
<td>2007-08</td>
</tr>
</tbody>
</table>

* The ratio is the manufacturing sector.
** The ratio refers to the aggregate economy.