The Role of R&D in Explaining Total Factor Productivity Growth in Japan, South Korea, and Taiwan*

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Abstract

We explain total factor productivity growth (TFPG) residuals for Japan, South Korea and Taiwan, by expenditures on basic, applied and experimental research in each of the three countries. We find that, overall, there is evidence that R&D expenditures in these countries had a positive impact on TFPG. This suggests that growth in these countries, contrary to a recent assertion by Krugman (1994), is not simply explained by input accumulation.

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"The newly industrializing countries of Asia, like the Soviet Union of the 1950s, have achieved rapid growth in large part through an astonishing mobilization of resources."

1 INTRODUCTION

The quote above from Paul Krugman (1994, p. 70) highlights a controversy about the sources of East Asian growth that has not been fully resolved. Krugman goes on to assert that "Once one accounts for the role of rapidly growing inputs in these countries' growth, one finds little left to explain" (p. 70). This is somewhat of an extreme position, of course, and Young's (1995) careful growth accounting work indicates that, except for Singapore, there is evidence of total factor productivity growth (TFPG) in the other three East Asian "tigers": Hong Kong, South Korea and Taiwan. Young's own conclusion, though, is that this TFPG is quite ordinary. Singh and Trieu (1996), however, perform a similar growth accounting exercise for Japan, Korea and Taiwan. Their results for the latter two countries are quite similar to Young's, but they suggest that TFPG has been higher in Korea and Taiwan than one might have expected for countries at their level of development.

Strictly speaking, calculations of TFPG leave it as an unexplained residual, possibly as a result of undermeasurement of the physical inputs. At the same time, TFPG is often thought of as reflecting technological progress, which in turn is a linchpin of economic growth. If this is correct, then TFPG should, in turn, be explainable by measures of inputs into the process of technological change. The most obvious such measure is R&D expenditures. Thus, we have the following plausible causal chain: R&D investment --> technological innovation --> productivity increase --> economic growth. In Singh and Trieu (1996), we examined the last link in this chain for Japan, Korea and Taiwan. In the current study, we look for evidence of the first two links[1], by examining the impact of R&D expenditures on TFPG in these three countries.

We find some evidence that R&D expenditures had a positive impact on TFPG. Thus, our results shed some light on the controversy raised by Krugman. In particular, they weaken the argument that growth in Korea and Taiwan is just the result of input accumulation, and is therefore in danger of quickly petering out. The results of our quantitative analysis fit well with case studies that emphasize the importance that all three countries in our sample have given to R&D, and with previous empirical work on Japan, which has found that some kinds of R&D in Japan have been very productive.

Our methodology follows a considerable literature: much earlier work on the link between TFPG and R&D expenditures was motivated by the experience of the United States

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[1] Thus we do not attempt a decomposition of the entire process: this is not really feasible given our data. On the complexities of the process summarized in the simple chain above, see Rosenberg (1990). Teubal (1996) analyzes R&D and technology policy in newly industrializing economies as a complex learning process.

and other OECD countries. Productivity growth rates declined substantially around 1973 in most of these countries. Research was directed toward explaining both the previous high productivity growth rates before 1973 and the decline afterwards. One explanation for the decline in productivity growth rates was thought to be declining R&D expenditures, and some evidence was found for this.[2]

Mansfield (1980) extended previous work by disaggregating R&D expenditures, to examine whether basic research, as contrasted with applied research and development, made a significant contribution to an industry's or firm's rate of technological innovation and productivity change. His results for the United States indicated a statistically significant and direct relationship between the amount of basic research carried out by an industry or firm and its rate of increase of total factor productivity, when its expenditures on applied R&D were held constant. Thus, we follow Mansfield in working with R&D expenditures disaggregated into basic research, applied research and experimental development.

The rest of the paper is organized as follows: Section 2 briefly describes previous quantitative analyses and case studies of the links between productivity growth and R&D expenditures for the three countries in our study. We summarize the differences in our approach from previous studies, to identify our contribution. Section 3 outlines the analytical framework and the methodology for estimating the contribution of R&D expenditures to productivity growth, which closely follows earlier studies by Griliches (1973), and Mansfield

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[2] At an aggregate level for example, Griliches (1973, 1980), Mansfield (1974, 1980) and Terleckyj (1974, 1980) found industrial research and development had significant effects on the rate of productivity growth. See also Link (1987), Maddison (1987), Jorgenson (1988) and Kokkelenberg and Nguyen (1991).

(1980). Section 4 briefly discusses the variables used, their definition, and data generation. We include a summary description of the results of our study (Singh and Trieu, 1996) on the sources of economic growth in Japan, Korea, and Taiwan, which provided the TFP data used in this paper. Section 5 presents the estimation results and their basic interpretation. Section 6 concludes with a discussion of the lessons of our study, in the light of other work on East Asian growth.

2 RELATED LITERATURE

The literature on R&D and productivity for the three countries in our study can be put into two categories, econometric work and case studies, with the latter being by far the larger segment. We review work in each of these categories in turn..

Econometric Studies

The most work has been done on Japan. Mansfield (1988a,b) uses firm level data, and compares Japanese and United States experience. He finds evidence that applied R&D in Japan has yielded a higher rate of return than in the United States. His econometric results provide no indication that basic research has been particularly effective in Japan. Mansfield also stresses the role of foreign technology, and the distinction between process and product R&D, noting that Japanese firms in his sample spend relatively more on process improvements.

Griliches and Mairesse (1990) also use firm level data. They find that, although significant, the contribution of the R&D intensity to the explanation of the variance in productivity growth is rather small. Nor can R&D account for the mean difference in growth rates between the two countries. Nevertheless, the estimated coefficients imply that R&D contributed between 0.4% and 0.6% per year to productivity growth in both countries, which "is not a small matter after all" (p. 330). Griliches and Mairesse also find that the estimated effect of growth in the capital-labor ratio on firm productivity in manufacturing appears to be twice as large in Japan as in the United States.

Yoshitomi (1992) examines correlations at the industry level in Japanese manufacturing, which suggest that the higher the R&D expenditure, the higher is the growth rate of total factor productivity. He also examines other effects of R&D, finding a positive influence of R&D spending on business investment.

Mansfield (1990) reviews some of the problems with econometric studies of the productivity of Japanese R&D, including issues of causality and data quality. He also emphasizes that R&D alone does not explain productivity, noting the importance of investment in retooling and updating facilities.

For South Korea, Kim (1986) investigates the impact of indigenous R&D and technology transfer on productivity growth in Korea. He finds a strong positive effect of total R&D expenditure on productivity growth in Korea for the period 1976-82. The basic analytical framework employed is similar to the studies of Japan discussed above, a marginal product model derived from an aggregate production function, which provides an economic rationale for estimating the rate of return from investment in R&D and disembodied technology import. For this earlier period, Kim finds no positive productivity impacts of basic research at the industry level. He also finds a positive impact of technology imports on productivity growth, but concludes that indigenous R&D was more important than the transfer of foreign technology in this period (though the two are complementary).

For Taiwan, Wang (1994) does not look at the link between R&D and productivity, but examines the factors influencing the decision to engage in cooperative research activity. He finds that firms that are more active in R&D are also more willing to allocate their R&D resources to cooperative arrangements.

Zhao (1992) examines the empirical relationship between indigenous technological capability and imported technology in Japan, South Korea and Taiwan (as well as China and India). He argues that technological capability has two dimensions: knowledge generation, as measured by R&D expenditure and national patents; and knowledge application, as measured by value added and technology export. His regression results indicate that imported technology leads to increases in R&D: this complementarity result being consistent with that of Kim (1986).

Case Studies

The importance of technology has been highlighted in numerous analyses of the experience of Japan, South Korea and Taiwan. For example, a study by the British Chamber of Commerce in Japan (1987) states that "The Japanese are very probably the most committed nation in the world to research and development" (p. 1). This study provides surveys of R&D in several key industries, and notes the importance both of self-funded industrial R&D and of the Japanese government's own research in its institutes and laboratories, which is directed towards industrial needs. Two of the study's contributors, paralleling the econometric results of Mansfield, conclude:

> Despite the effects of relative economic hardship upon research budgets in general, it is important to note that Japanese companies are not moving money away from the applied research that will help guarantee their markets over the next five to ten years. While there are as yet no totally convincing signs that Japan will begin to contribute to basic research to an extent commensurate with the size of its economy, the efficiency of the research system as we have seen it will ensure that Japan's companies remain at the leading edge of the current technologies of the day. (p. 72)

Kodama (1995) provides a historical perspective on Japan's transformation of manufacturing after World War II[3]. He emphasizes that in the period from the 1950s through the mid-1970s, a fairly high percentage of all Japanese R&D funds was spent on digesting the imported technology.

> From 1975 to 1985, Japan focused on developing technology to fuel the country's economic growth. As new technologies such as integrated circuits, liquid crystal display, and carbon fiber, were developed, capital investments were made in manufacturing to take advantage of them. This in turn led to economic growth, which allowed more R&D and kept the cycle going. (p. 4)

Kodama goes on to note that, since the mid-1980s, R&D investment has overtaken capital investment as an aggregate in the Japanese economy.

For South Korea, Choi (1988) and Lee (1988) both stress the importance of the Korean government's formulation of policies and strategies for the development of science and technology with many innovative support measures, resulting in the creation of a "national R&D system" . The three-pronged approach that was adopted emphasized manpower development, accelerated introduction of foreign advanced technologies, and

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[3] A brief, but even broader historical summary is provided by Rosenberg (1990).

stimulation of domestic R&D activities. These papers provide a detailed description of the institutional framework for R&D in Korea. Recent institutional developments in Korea are described in Shin and Kim (1994).

Wade (1990), in his well-known study of Taiwan, describes in detail the push provided by the government to their country's mastery of semiconductor and computer technologies. Wade also emphasizes the similarities in the development styles of Japan, Korea and Taiwan. He notes that the East Asian four (Korea and Taiwan plus Hong Kong and Singapore) are "stretching their industrial structures as they expand into more advanced sectors, using technology to remain competitive in light manufactures" (p. 347).

Ranis (1990) provides an overview of the experience of Japan, Korea and Taiwan, and provides long run data on patent applications in Japan. In particular, he suggests that, for all three countries, TFP has moved closely with domestic patents, " an indication of the importance of indigenous technology change as captured by domestic R&D or its proxy" (p. 169).

Zhao (1992) also notes that government R&D efforts were mobilized in Japan, Korea and Taiwan to support activities in assessing, acquiring and improving imported foreign technology. He notes the development of private R&D also. In Korea, in 1975, government R&D expenditure took up 80 percent of the total national R&D. By 1987 the ratio was reversed: industrial sectors financed 80 percent of the national R&D. In Taiwan, an important item on the agenda for new technological development was the establishment of Hsinchu Science Park. One major objective of the park was to serve as a focal point where leading local science and engineering institutions and high technology industries could be linked, and bring together local R&D activities and imported technology. An increased amount of R&D expenditures went into technology-intensive sectors. As noted above, Zhao's analysis focuses on the complementarity between indigenous and foreign sources of technological progress in these countries[4].

Relationship to Our Analysis

While some of the above studies simultaneously examine the three countries in our sample, they do not do so in the context of formal econometrics. While the case studies document the importance given to R&D in these countries, they do not always focus on the implications for growth, through a link between R&D spending and total factor productivity growth. In many cases, they do not distinguish between types of R&D spending. In all these respects, our empirical analysis makes a fresh contribution. Finally, our work updates previous studies, which is particularly useful in the context of the cautionary note of Krugman (1994) regarding the prospects for future growth in these three East Asian economies.

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[4] We may also note Ranis's (1990) observation on this point: "openness to the inflow of new ideas from the advanced countries, embodied in capital movements, or disembodied, gave the initial stimulus; but most of the credit thereafter belongs to domestic adaptations".

3 THE MODEL

The model used here was employed in earlier studies for OECD countries, by Griliches (1973, 1980), Terleckyj (1974, 1980), and Mansfield (1980)[5]. These studies found that aggregate R&D expenditure was directly related to the rate of productivity growth. Mansfield (1980) attempted to disaggregate R&D, in particular, to determine whether an industry's or firm's rate of productivity change was related to the amount of basic research it performed, when other relevant variables (such as its rate of expenditure on applied R&D) were held constant. Here we follow Mansfield in the disaggregation of R&D, but examine the link between R&D and productivity at the economywide, rather than the firm or industry level.

In a particular economy, the aggregate production function, using the Cobb-Douglas form, can be written as:

$$Q_t = Ae^{\lambda . t} R_{tb}^{\alpha_1} R_{ta}^{\alpha_2} R_{td}^{\alpha_3} L_t^{\beta_1} K_t^{\beta_2} u_t \quad \textbf{(1)}$$

where Q_t is the output in year t, R_{tb} is the stock of basic R&D capital, R_{ta} is the stock of applied R&D capital, R_{td} is the stock of experimental development R&D capital, L_t is the labor input, K_t is the stock of capital input in year t, and the sum of β_1 and β_2 equals 1 if there are constant returns to scale to labor and capital.

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[5] Thus we do not explicitly model the R&D process, as might be done in an endogenous growth model: see Jones (1995), for example. It is not clear if this would change our methodology substantially.

The approach we use here is to work with estimates of total factor productivity growth derived from growth accounting. This involves subtracting from output growth the amount which can be attributed to growth in the physical inputs, capital and labor. Let ρ stand for the annual rate of change of total factor productivity (TFP growth or TFPG). By manipulating equation (1) we obtain the following relationship:

$$\rho_t = \lambda + \alpha_1\left(\frac{dR_{tb}/dt}{R_{tb}}\right) + \alpha_2\left(\frac{dR_{ta}/dt}{R_{ta}}\right) + \alpha_3\left(\frac{dR_{td}/dt}{R_{td}}\right) \quad (2)$$

Since the coefficients are the corresponding output elasticities, we have:

$$\alpha_1\left(\frac{dR_{tb}\ /\ dt}{R_{tb}}\right) = (\partial Q_t\ /\ \partial R_{tb})\ .\ \left(\frac{dR_{tb}\ /\ dt}{Q_t}\right)$$
$$\alpha_2\left(\frac{dR_{ta}\ /\ dt}{R_{ta}}\right) = (\partial Q_t\ /\ \partial R_{ta})\ .\ \left(\frac{dR_{ta}\ /\ dt}{Q_t}\right)$$
$$\alpha_3\left(\frac{dR_{td}\ /\ dt}{R_{td}}\right) = (\partial Q_t\ /\ \partial R_{td})\ .\ \left(\frac{dR_{td}\ /\ dt}{Q_t}\right)$$

Hence, substituting these in, we obtain:

$$\rho_t = \lambda + \phi_0\left(\frac{dR_{tb}\ /\ dt}{Q_t}\right) + \phi_1\left(\frac{dR_{ta}\ /\ dt}{Q_t}\right) + \phi_2\left(\frac{dR_{td}\ /\ dt}{Q_t}\right) \quad (3)$$

where:

$$\phi_0 = \partial Q_t\ /\ \partial R_{tb}$$
$$\phi_1 = \partial Q_t\ /\ \partial R_{ta}$$
$$\phi_2 = \partial Q_t\ /\ \partial R_{td}.$$

In this form, we assume that the marginal products of R&D expenditures are approximately constant. We assume, with Mansfield and other authors, that a country's expenditure on R&D during year t is approximately equal to that year's change in the country's stock of R&D

capital. For this assumption to hold, the depreciation of the R&D capital must be small enough to be ignored.[6] Thus, equation (3) becomes:

$$\rho_t = \lambda + \phi_0\left(\frac{B_t}{Q_t}\right) + \phi_1\left(\frac{A_t}{Q_t}\right) + \phi_2\left(\frac{E_t}{Q_t}\right) + z_t \qquad \textbf{(4)}$$

where B_t is a country's expenditure on basic research in year t, A_t is a country's expenditure on applied R&D in year t, and E_t is a country's expenditure on experimental development R&D in year t, and z_t is a random error term. Equation (4) yields the separate effects of basic, applied, and experimental development R&D on total factor productivity growth, and is the form we use for estimation.

One important modification we make in practice to the estimated equations is to allow for lags in the explanatory variables where possible. The effects of R&D often occur with a lag, and the lag for basic research is generally thought to be much longer than for applied R&D. Because so little is known about the length of these lags, previous work along the lines followed here has sometimes ignored them; but this is less satisfactory once we separate basic research from applied R&D. While the length of our data set does not permit a full lag specification, lagged effects turn out to be important.

An alternative approach to estimating equation (4) is to work directly with the production function. For example, by differencing the logarithms of the production function, we have:

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[6] See Mansfield (1980), p.864. We also tested the assumption of no depreciation in the context of an alternative specification, equation (5), where we constructed a measure of R&D stocks. We found that assuming no depreciation had more explanatory power than an alternative assumption of 10% depreciation. See Trieu (1995) for further details.

$$\Delta lnQ_t = \lambda + \alpha_1 \Delta lnR_{tb} + \alpha_2 \Delta lnR_{ta} + \alpha_3 \Delta lnR_{td} + \beta_L \Delta lnL_t + \beta_K \Delta lnK_t + \epsilon_t \quad (5)$$

where, in the case that labor and capital are disaggregated:

$$\Delta lnL_t = \sum_{j=1}^{N} \bar{\theta}_{lj} \Delta lnl_{tj} \qquad \text{and} \qquad \Delta lnK_t = \sum_{i=1}^{N} \bar{\theta}_{ki} \Delta lnk_{ti} \ ,$$

or by following the sequence of steps that led to equation (4), we have

$$\Delta lnQ_t = \lambda + \phi_0(\frac{X_t}{Q_t}) + \phi_1(\frac{A_t}{Q_t}) + \phi_2(\frac{E_t}{Q_t}) + \beta_L \Delta lnL_t + \beta_K \Delta lnK_t + \epsilon_t \quad (6)$$

Growth accounting calculations typically assume constant returns to scale with respect to the physical inputs, labor and capital. By imposing the restriction $\beta_L + \beta_K = 1$, from the last two terms of equation (6), we have:

$$\Delta lnQ_t - \Delta lnK_t = \lambda + \phi_0(\frac{X_t}{Q_t}) + \phi_1(\frac{A_t}{Q_t}) + \phi_2(\frac{E_t}{Q_t}) + \beta_L(\Delta lnL_t - \Delta lnK_t) + \epsilon_t \ . \quad (7)$$

Equations (5)-(7) are estimated in Trieu (1995). The results obtained with the three variants of this alternative approach are broadly consistent with the results presented in this paper, as we indicate in more detail in section 5.

4 VARIABLES AND DATA

The data sources for this study are listed in the Appendix. Some data is derived from our previous paper, Singh and Trieu (1996), as we describe in more detail below.

Dependent Variable

TFPG is the dependent variable in this study. The procedures for estimation of TFPG are discussed in detail in Singh and Trieu (1996), where the data sources used are also listed. We used data from a variety of national sources, including national income statistics and labor statistics in particular. Essentially, we use the standard growth accounting methodology of Jorgenson, Gollop and Fraumeni (1987), as applied by Young (1992) to Hong Kong and Singapore. The results of this growth accounting exercise are summarized in Tables 1A and 1B. We used two approaches, following Young (1992), with aggregate measures of labor and capital, and indexes constructed from disaggregated categories of the inputs. Table 1B summarizes the calculations based on the "differentiated" inputs. One of the main conclusions of our earlier study was that TFPG has been important in all three economies. We also concluded that TFPG in Korea and Taiwan was greater than in comparable developing countries. Yet, since TFPG estimates can be criticized as simply reflecting our ignorance, it is important to try to explain the TFP residuals from the growth accounting exercise. Since TFPG is thought to be closely related to technological progress, it is particularly useful to explain it by measures of inputs into the process of technological change, e.g., R&D expenditures.

Independent Variables

There are three categories of inputs: total R&D expenditure, capital and labor. However, equation (4) only directly requires data on R&D, since data on capital and labor inputs were used to construct the dependent variable, TFPG. Total R&D expenditure disaggregates into sub-input categories. For each country, total R&D expenditure is divided into three categories: basic research (BR), applied research (AR), and experimental development (ED). In this study, data for disaggregated R&D expenditure, Japan covered the period 1966-91, Korea covered the period 1982-90 (although the total R&D expenditure data was available since 1974, the disaggregated R&D expenditure data was only available since 1982), and Taiwan covered the period 1978-90. The description of these three categories of R&D[7] are defined as follows:

Basic research is defined as original investigation for the advancement of scientific knowledge ... which do(es) not have immediate commercial objective.

Applied research is undertaken in order to determine possible uses of basic research with a specific practical aim or objective, or to explore new form of application different from existing method.

Experimental development is the use of results gained from basic and applied research, or practical experience, that is directed to the introduction of new materials, equipment, products, systems and processes, as well as to the improvement of those already introduced.

Disaggregated R&D expenditures for each country are available in current prices. We deflated these data with the general (or all cities) consumer price index of their own countries. The deflated data are presented in Tables 2-4 for the three countries. The growth rates of these deflated BR, AR, and ED expenditures in Japan during the period 1965-91 were, respectively, 4.56, 6.95, and 9.69 percent (Tables 1 and 2). Note that basic research

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[7] These characterizations are taken from the Japanese Department of Science and Technology (1985). The categories for Korea and Taiwan appear to be similar, all of them being derived from the categorization of the United States.

expenditures grew more slowly than output, while AR and ED had somewhat higher growth rates than real output. In 1965, the three disaggregated R&D expenditures started at similar amounts (see Table 2). However, at the end of 1991, the amount of AR had risen to twice the amount of BR, and ED had risen to over twice the amount of AR. During the period, the average annual growth rate of basic, applied, and experimental development R&D expenditures in Korea amounted to 21.72, 21.11, and 19.25 percent, respectively (Tables 1 and 3). Finally, the growth rates of BR, AR, and ED R&D expenditures during the period 1978-90 in Taiwan were 22.18, 20.26, and 16.44 percent, respectively (Tables 1 and 4). Thus all the categories of research expenditures grew faster than real output in Korea and in Taiwan.

There are no data on the ratio of each country's expenditure on basic research, applied research, and experimental development to its value added. We calculated these ratios for each country by dividing each country's expenditure on basic research (BR), applied research (AR), and experimental development (ED) by its output. Using these data, we estimated the regressions for equation (4), as shown in Tables 5 and 6..

5 ESTIMATION RESULTS AND INTERPRETATION

Our results in investigating the role of R&D to TFP growth and output growth in Japan, Korea, and Taiwan, are summarized in Tables 5 and 6, for the estimates of TFPG based on aggregate and differentiated labor and capital respectively. For each country and each case of input measurement, we tried several different lag specifications. We present a selection of the results, based on the reasonableness of the estimates and the overall fit. We report the same specifications in Tables 5 and 6, to allow comparison across the two cases of input measurement. We consider each country's results in turn, and then summarize our findings.

Japan

For Japan, the first regression in Table 5 indicates that applied research (AR), as a proportion of output, has contributed significantly to TFPG, whereas basic research (BR) expenditure was not related to TFPG. This estimation finds a negative effect of experimental development (ED) expenditures on TFPG. It should be borne in mind that the estimated coefficient magnitudes are of economic interest. To get an idea of the effects predicted by the estimated equation, note that the ratio ARE in 1991 was about 0.0068, or 0.68%. An increase in this ratio by 0.001, i.e., close to a 15% increase in the ratio of applied research expenditures to output, is predicted to lead to an increase in TFPG of about 0.043, or 4.3%. This is rather high, compared to the average TFPG for the period of estimation, which was about 2.9%. This is, to some extent, a consequence of the assumption that the effects of R&D are linear. The hypothetical increase of 0.001 would be a considerably larger percentage increase at an earlier point in the sample, since the ratio was growing over time. An increase of 0.001 in the ratio of experimental development expenditures to output is predicted to *decrease* TFPG by 0.013.

When we added a one year lag for BR and ED in the second regression of Table 5, AR continued to display a significant effect on TFPG, and BR also contributed significantly to TFPG, initially with a negative effect, and then with a positive effect after one year. The ratio EDE was no longer statistically significant in explaining TFPG. The magnitudes of the coefficients are similar to those in the first equation. Intuitively, these findings suggest a relationship between the amount of BR and AR expenditures and the Japanese economy's rates of productivity increase during 1966-1991. The results for applied research are broadly consistent with Mansfield's earlier results for Japan using firm level data. The results for basic research are consistent to the extent that the overall effect, within-year plus with a year's lag, is small, since the two coefficients are opposite in sign and close in magnitude. Note that the results do not find any indication of a positive relationship between the proportion of output spent on experimental development and TFPG.

One might expect that once changes in the quality of inputs are controlled for, as is done to some extent with the differentiated input case in Table 6, that R&D expenditures would matter less in explaining TFPG. However, this is not the case. The same two specifications for Japan in Table 6, with differentiated inputs used to construct the TFPG series, show a considerable stability of the coefficients. Again, the predicted impacts are somewhat on the high side, but they do support the kind of case study and other empirical evidence that has suggested an important role for applied R&D in Japan's growth.

Korea

The first regression for Korea in Table 5 indicates that basic research, as a proportion of output, has had a large positive impact on TFPG, whereas TFPG was negatively affected by applied research and experimental development expenditures. However, none of the coefficients are statistically significant, since there is only one degree of freedom in the regression. This is due to the addition of an AR(2) error process, to correct for serial correlation indicated in the regression without the autoregressive terms. Since an alternative to assuming serial correlation in the error is a respecification of the lag structure, we did this in the second reported regression. When lags of one and two are added for basic research, BRE seems to have a significant positive effect on TFPG with a one year lag. Again, the magnitude of the coefficient is somewhat high, and the problem of degrees of freedom must be noted once again. However, the results are suggestive that basic research may have mattered positively for Korean TFPG: in particular, the magnitudes of the positive coefficients outweigh the magnitudes of negative coefficients.

As in the case of Japan, the results for Korea for the case where TFPG is calculated based on differentiated inputs are quite similar to the results based on aggregate labor and capital. The difference now is that the coefficients are estimated somewhat more precisely in the results of Table 6 for Korea. The overall impact seems to suggest, as in the case of the estimates based on aggregate inputs, that there was a positive effect of R&D expenditure on TFPG.

Taiwan

For Taiwan , in the case of aggregate inputs (Table 5), none of the categories of disaggregated R&D expenditures were statistically significant in the specification without lags. However, when lags were added, the coefficient of BRE was positive and significant at a lag of one or two years, and at the 10 percent level of significance, as may be seen from the three alternative specifications reported. In each lag specification, the coefficient of the contemporaneous value of BRE was negative, but statistically insignificant, and smaller in magnitude than the coefficient of the lagged value. In all three lagged specifications, the coefficient of ARE was negative and marginally significant, while the coefficients of EDE were statistically insignificant.

The corresponding results for Taiwan when differentiated inputs were used in the construction of the TFPG measure were quite similar to the results for aggregate inputs. The results, reported in Table 6, indicate a somewhat stronger positive impact of basic research, and negative impact of applied research. The estimates are somewhat more precise, in terms of standard errors. As in the case of Korea, the positive coefficients are greater in magnitude than the negative coefficients, suggesting an overall positive impact of R&D expenditures on TFPG.

Alternative Specifications

As we noted in section 3, an alternative approach to estimating the effect of R&D expenditures on TFPG is to directly include them in a production function estimation along with capital and labor input measures. We performed these estimations for each of equations (5)-(7). For equation (5), we constructed measures of R&D capital stocks, as required by the specification. The results were broadly similar, and we do not report them in any detail here. In each case, the coefficient of applied research tended to be positive for Japan, while the coefficient of basic research (sometimes with a lag), tended to be positive for Korea and Taiwan. The coefficients for other categories of R&D tended to be negative, but smaller in magnitude. Thus the predicted impacts of R&D expenditure on growth were robust to these alternative specifications. We should note that the estimated coefficients of labor and capital were not well-estimated in these cases. While the hypothesis of constant returns to scale to the two physical inputs could not be rejected, the point estimates were imprecise, and sometimes economically implausible. Thus we view the growth accounting approach as more satisfactory.

Discussion

Our results for the three countries may be subjected to several criticisms. While there has been much work on Japan, and our results seem to match previous ones quite well, our results for Korea and Taiwan are weaker for several reasons. First, we have much shorter data series for these two countries. Second, the estimated positive impact of basic research in these lower-income countries may seem counter-intuitive[8]. While we cannot overcome the

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[8] For example, Lim and Song (1996) undertake a factor analysis of "Basic Scientific Research Capability" (BSRC), and conclude that Korea and Taiwan come out rather low compared to OECD countries on their index of BSRC. On the other hand, their measure simply is an input index, and does not claim to measure the productivity effects of whatever capability exists in these countries. That is the differing emphasis of our analysis.

data problem, we believe the explanation must lie in the fact that, while the categories of research expenditures are ostensibly uniform across the three countries, Korea and Taiwan have been more similar over this period, in relying more on government-funded R&D. Furthermore, there may simply be differences in how R&D expenditures are classified in practice. A related point is that the impact of different categories of R&D expenditure is not really linear and separable, as we have assumed in our specification. We chose our estimating equation to parallel previous work in this area, but our results suggest that an alternative specification which incorporates complementarities in the different types of R&D would be worth exploring.

Having noted these shortcomings, it is important to stress the positive nature of our results. It is particularly striking that estimated TFPG, which has sometimes been dismissed as merely a measure of our ignorance, can be well explained by R&D expenditures. Furthermore, this relatively good fit is obtained with a dependent variable which is a growth rate, and independent variables that are ratios: we are presumably not just picking up common trends in our regressions. Also of note are the economically significant magnitudes of the positive effects. While the linear specification may lead to an overstatement of the impact of R&D on TFPG, we believe our results do suggest that the policies of all three countries with respect to R&D have translated into higher efficiency and higher growth.

6. CONCLUSIONS AND IMPLICATIONS

This study is of interest in that it seems to be the first attempt to econometrically investigate the effects of disaggregated R&D investment expenditures on productivity growth for Japan, Korea, and Taiwan at the national level. Also, with the results of this paper indicating that certain types of R&D are important for explaining TFPG, there is a suggestion that the TFPG estimates for these countries are not merely residuals, but rather that TFPG is capturing technological progress in some way. Together with the fact that TFPG has been substantial in the three countries, as argued in Singh and Trieu (1996), our results in this paper suggest that Krugman's position in his 1994 article, as described in the introduction, is somewhat questionable.

Of course, this study alone cannot resolve the controversy. However, our results support some of the responses to Krugman (Letters to the Editor, 1995), which stressed technological change as well as trade and government policies. Clearly, as the World Bank's (1993) well-known study implies, East Asian growth did not have a single, simple cause[9]. But that study put relatively less emphasis on technological change *per se*. Here we suggest that, whatever other "right" policies were pursued with respect to macroeconomic stability,

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[9] Rosenberg (1990), after examining the relative failure of R&D in India, puts this well: "History suggests that countries that have managed to grow rapidly have done so by doing many things right, not just one or two things. With respect to such policies, it appears that potential payoffs may be very high, but only if science and technology are perceived as complements to effective economic policies, not as substitutes." (p. 151) This quote also suggests why Krugman's comparison of East Asian newly industrializing economies with the Soviet Union may be misleading.

trade and industrial policy, the net result in Japan, Korea and Taiwan may have been the kind of growth that can persist, rather than growth that is quickly subject to diminishing returns[10].

A final cautionary note is in order, and that is the diversity of the policies and experience of the different East Asian countries. We have deliberately chosen the three countries that have been closest in many respects (though with great differences still among them). Unlike Krugman, we do not extrapolate from our sample to the experience of other East and Southeast Asian countries, which may not yet have paid the same attention to acquiring technological capabilities of the same order as Japan, Korea and Taiwan[11]. Yet the experience of those three countries may still provide a guidepost for others.

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[10] Teubal (1996) also stresses the importance of the general "promotion of R&D and capabilities *per se* and not only as part of infant industry promotion" in Japan and Korea (p. 460, footnote 22).

[11] These issues are spelled out by Wade (1994), for example.

Table 1A: Summary Growth of Real Output, TFPG, and Disaggregated R&D Expenditures Growth Rates of Japan, Korea, and Taiwan (Aggregate Capital and Labor)

Country	Year	Growth of Real Output[1]	Proportion of Percentage Growth Accounted by[2]			% Growth of Disaggregated R&D Expenditures		
			Capital	Labor	TFPG	BRE	ARE	EDE
Japan	1965-91	5.45	29.99	16.86	53.15	4.56	6.95	9.69
Korea	1965-90	8.78	48.98	23.50	27.52			
	1982-90	9.43	31.62	22.00	46.38	21.72	21.11	19.25
Taiwan	1963-91	8.69	25.52	27.17	47.31			
	1978-90	7.43	32.97	25.03	42.00	22.18	20.26	16.44

Notes:

[1] Average annual growth rates of output of Japan (at 1985 constant prices and in billion yen), Korea (at 1985 constant prices and in billion won), and Taiwan (at 1986 constant prices and in million of NT$), respectively.

[2] In Japan during the period 1965-91, capital, labor, and TFP contributed 1.63, 0.92, and 2.89 percent, respectively of the 5.44 percent in real output growth. In Korea during the period 1965-90,capital, labor, and TFP contributed 4.30, 2.06, and 2.42 percent, respectively of the 8.78 percent in real output growth. During the period 1982-90, capital, labor, and TFP contributed 2.98, 2.08, and 4.37, respectively of the 9.43 percent real output growth. In Taiwan during the period 1963-91, capital, labor, and TFP contributed 2.22, 2.36, and 4.11 percent, respectively of the 8.69 percent in real output growth. During the period 1978-90, capital, labor, and TFP contributed 2.54, 1.86, and 3.12 percent, respectively of the 7.43 percent in real output growth.

Table 1B: Growth of Real Output, TFPG, and Disaggregate R&D Expenditures Growth Rates of Japan, Korea, and Taiwan (Differentiated Capital and Labor)

Country	Year	Growth of Real Output[1]	Proportion of Percentage Growth Accounted by[2]			Growth of Disaggregate R&D Expenditures (%)		
			Capital	Labor	TFPG	BRE	ARE	EDE
Japan	1965-91	5.45	30.41	26.06	43.53	4.56	6.95	9.69
Korea	1965-90	8.78	49.55	24.37	26.08			
	1982-90	9.43	32.80	24.53	42.67	21.72	21.11	19.25
Taiwan	1968-90	8.48	40.35	29.56	30.09			
	1978-90	7.43	35.18	38.05	26.77	22.18	20.26	16.44

Notes:

[1] Average annual growth rates of output of Japan (at 1985 constant prices and in billion yen), Korea (at 1985 constant prices and in billion won), and Taiwan (at 1986 constant prices and in million of NT$), respectively.

[2] In Japan during the period 1965-91,capital, labor, and TFP contributed 1.65, 1.42, and 2.37 percent, respectively of the 5.44 percent in real output growth. In Korea during the period 1965-90, capital, labor, and TFP contributed 4.35, 2.14, and 2.29 percent, respectively of the 8.78 percent in real output growth. During the period 1982-90, capital, labor, and TFP contributed 3.09, 2.31, and 4.03 percent, respectively of the 9.43 percent in real output growth. In Taiwan during the period 1968-90, capital, labor, and TFP contributed, 3.42, 2.51, and 2.55 percent, respectively of the 8.48 percent in real output growth. During the period 1978-90, capital, labor, and TFP contributed 2.61, 2.83, and 1.99 percent, respectively of the 7.43 percent in real output growth.

Table 2: R&D Expenditures in Japan, 1965-1991

R&D Expenditures							Output	
Year	BRE	Δln(BRE)	ARE	Δln(ARE)	EDE	Δln(EDE)	Q	Δln(Q)
65	449.96		462.74		573.46		100729.5	
66	483.00	0.0708	470.10	0.0158	669.8	0.1553	111400.6	0.1007
67	550.37	0.1306	561.30	0.1773	833.9	0.2192	123439.2	0.1026
68	623.87	0.1254	666.65	0.1720	1050.9	0.2312	139130.7	0.1197
69	655.07	0.0488	744.81	0.1109	1291.8	0.2063	156257.0	0.1161
70	746.45	0.1306	884.67	0.1721	1572.0	0.1963	171661.4	0.0940
71	815.35	0.0883	879.81	-0.0055	1711.2	0.0849	178891.0	0.0413
72	845.60	0.0364	963.62	0.0910	1955.8	0.1336	193698.5	0.0795
73	826.33	-0.0231	998.69	0.0357	2113.2	0.0774	208470.0	0.0735
74	762.28	-0.0807	981.87	-0.0170	2163.9	0.0237	207182.7	-0.0062
75	773.56	0.0147	1068.2	0.0843	2449.2	0.1239	213107.8	0.0282
76	690.48	-0.1136	1028.5	-0.0378	2452.7	0.0014	222084.4	0.0413
77	685.22	-0.0077	1059.9	0.0301	2484.4	0.0129	232550.0	0.0460
78	743.04	0.0810	1125.2	0.0598	2617.7	0.0522	243873.1	0.0475
79	753.86	0.0145	1260.2	0.1133	2857.8	0.0878	257371.9	0.0539
80	754.89	0.0014	1319.7	0.0461	3118.1	0.0872	266722.1	0.0357
81	790.77	0.0464	1462.8	0.1030	3430.6	0.0955	276268.2	0.0352
82	866.86	0.0919	1592.8	0.0851	3698.7	0.0752	285002.3	0.0311
83	935.03	0.0757	1699.8	0.0650	4048.8	0.0904	292701.5	0.0267
84	978.53	0.0455	1815.3	0.0658	4424.3	0.0887	305187.1	0.0418
85	1030.6	0.0518	2001.8	0.0978	4985.9	0.1195	320397.2	0.0486
86	1095.2	0.0608	2016.7	0.0074	5149.0	0.0322	328816.3	0.0259
87	1240.2	0.1244	2149.6	0.0638	5453.7	0.0575	342315.2	0.0402
88	1269.0	0.0229	2311.9	0.0728	5971.5	0.0907	363567.1	0.0602
89	1340.0	0.0545	2493.6	0.0757	6597.3	0.0997	380709.4	0.0461
90	1411.4	0.0519	2716.0	0.0854	7081.5	0.0708	399043.1	0.0470
91	1471.9	0.0420	2816.1	0.0362	7130.5	0.0069	415196.2	0.0397
A % Growth:		0.0456		0.0695		0.0969		0.0545

Notes:
1. Disaggregated R&D and output in Japan are measured at 1985 constant prices and in billion of yen.
2. BRE,ARE, EDE: basic, applied, and experimental development R&D; Q: real output
3. Differences of natural logs, denoted Δln, are growth rates
4. A% Growth: average annual % growth of disaggregated R&D and output.

Table 3: R&D Expenditures in South Korea, 1982-1990

Disaggregated R&D Expenditures							Output	
Year	BRE	Δln(BRE)	ARE	Δln(ARE)	EDE	Δln(EDE)	Q	Δln(Q)
82	69.55		109.41		316.91		61820.9	
83	118.40	0.5320	188.04	0.5416	345.29	0.0858	69101.0	0.1113
84	145.18	0.2040	245.21	0.2655	464.01	0.2955	75606.4	0.0900
85	194.70	0.2934	337.10	0.3183	623.36	0.2952	80846.9	0.0670
86	246.55	0.2361	395.92	0.1608	839.32	0.2975	90867.8	0.1168
87	294.88	0.1790	347.63	-0.1301	1130.8	0.2981	101804.	0.1136
88	322.13	0.0884	410.14	0.1654	1337.8	0.1680	113492.	0.1087
89	337.39	0.0463	410.58	0.0011	1508.2	0.1199	120477.	0.0597
90	395.42	0.1587	592.21	0.3663	1478.2	-0.0201	131503.	0.0876
A % Growth:		0.2172		0.2111		0.1925		0.0943

Notes:
1. Disaggregated R&D expenditures and output in Korea are measured at 1985 constant prices and in billion won. Other notation is as in Table 1.

Table 4: R&D Expenditures in Taiwan, 1978-1990

	Disaggregate R&D Expenditures						Output	
Time	BRE	Δln(BRE)	ARE	Δln(ARE)	EDE	Δln(EDE)	Q	Δln(Q)
78	447.88		2038.6		4872.5		1592166	
79	598.32	0.2896	2952.4	0.3704	7033.1	0.3670	1722309	0.0786
80	1090.9	0.6006	8045.1	1.0025	3752.3	-0.6283	1848060	0.0705
81	1166.4	0.0669	8326.0	0.0343	7725.0	0.7221	1961950	0.0598
82	1774.7	0.4197	9923.6	0.1755	5481.9	-0.3430	2031623	0.0349
83	2335.9	0.2748	5369.4	-0.6142	11594.	0.7491	2203233	0.0811
84	3189.9	0.3116	7270.5	0.3031	12104.	0.0430	2436766	0.1007
85	3697.9	0.1478	8427.0	0.1476	13451.	0.1055	2557447	0.0483
86	3809.0	0.0296	11747.	0.3322	13146.	-0.0229	2855180	0.1101
87	3799.2	-0.0026	12107.	0.0302	20683.	0.4532	3207383	0.1163
88	5316.8	0.3360	20421.	0.5228	17321.	-0.1774	3442826	0.0708
89	5434.6	0.0219	18648.	-0.0908	27459.	0.4608	3703420	0.0729
90	6414.3	0.1657	23186.	0.2178	35307.	0.2437	3883646	0.0475
A % Growth:		0.2218		0.2026		0.1644		0.0743

Notes:
1. Disaggregate R&D expenditures and output in Taiwan are at 1986 constant prices and in million of NT$. Other notation is as for Table 1.

Table 5: Results of Regressions to Explain Total Factor Productivity Growth in Japan, South Korea, and Taiwan (Aggregate Estimates)

Country	Constant	lag	Independent Variable			R^2	DW	# of Obs
			BRE	ARE	EDE			
Japan	-0.022		-4.129	42.683	-13.461	0.55	1.74	26
	(-0.63)		(-0.40)	(2.30)**	(-2.76)**			
AR(1)	-0.061		-52.715	57.089	-7.122	0.62	1.78	25
	(-1.17)		(-2.28)**	(2.25)**	(0.597)			
		1	45.241		-9.004			
			(2.41)**		(-1.11)			
Korea	0.092		207.717	-72.030	-33.176	0.72	3.17	7
AR(2)	(0.32)		(3.27)	(-3.10)	(-2.27)			
	-0.027		-19.997	-8.332	-42.367	0.99	2.45	7
	(-1.01)		(-0.86)	(-1.00)	(-4.98)			
		1	284.568					
			(11.67)*					
		2	-57.083					
			(-3.00)					
Taiwan	0.048		24.818	-10.870	1.112	0.27	1.74	13
	(2.04)*		(0.90)	(-1.70)	(0.20)			
	0.037		-67.987	-9.791	4.800	0.59	2.20	12
	(1.52)		(-1.26)	(-1.56)	(-0.88)			
		1	90.961		10.268			
			(1.99)*		(1.22)			
	0.077		-53.851	-15.334	-1.996	0.67	2.57	11
	(2.20)*		(-1.03)	(-1.90)	(-0.34)			
		1			5.197			
					(0.49)			
		2	77.415					
			(2.16)*					
	0.070		-36.835	-12.807	-3.531	0.65	2.59	11
	(1.78)		(0.87)	(-1.99)*	(-0.56)			
		2	79.415		1.409			
			(2.14)*		(0.18)			

Notes: 1. Estimated from equation (4), $\rho_t=\lambda+\phi_0(X_t/Q_t)+\phi_1(A_t/Q_t)+\phi_2(E_t/Q_t)+z_t$.

2. BRE, ARE, and EDE are the ratios of basic, applied and experimental development R&D expenditures over GNP.

3. The number in parentheses below each regression coefficient is its t-value.

4. Levels of significance: * significant at the 10-percent level; ** significant at the 5-percent level; *** significant at the 1-percent level.

Table 6: Results of Regressions to Explain Total Factor Productivity Growth in Japan, South Korea, and Taiwan (Differentiated Estimates)

Country	Constant	lag	Independent Variable			R^2	DW	# of Obs
			BRE	ARE	EDE			
Japan	-0.032 (-0.90)		-4.822 (-0.46)	46.039 (2.42)**	-14.338 (-2.87)***	0.56	1.75	26
AR(1)	-0.071 (-1.25)		-58.276 (-2.52)**	56.836 (2.53)**	-7.906 (-0.75)	0.64	1.86	26
		1	51.525 (3.02)***		-7.859 (-0.90)			
Korea AR(1)	0.097 (8.07)***		199.471 (6.27)***	-69.587 (-6.38)***	-32.428 (-6.99)***	0.94	3.26	8
	-0.051 (-4.40)		-7.227 (-0.71)	-4.941 (-1.35)	-35.401 (-9.42)*	0.99	2.45	7
		1	256.941 (23.87)**					
		2	-69.122 (-8.23)*					
Taiwan	0.038 (1.59)		-57.910 (-1.08)	-13.124 (-2.11)*	-5.262 (-0.97)	0.68	2.29	12
		1	98.125 (2.17)*		7.390 (0.89)			
	0.082 (2.48)*		-43.991 (-0.89)	-19.201 (-2.51)*	-2.270 (-0.41)	0.76	2.93	11
		1			1.933 (0.19)			
		2	84.811 (2.50)*					
	0.079 (2.15)*		-37.457 (-0.95)	-18.251 (-3.05)**	-2.927 (-0.50)	0.76	2.95	11
		2	85.234 (2.47)*		0.759 (0.11)			

Notes: As for Table 5.

Appendix : Data Sources

1. Japan (output and R&D expenditures are at 1985 constant prices and in billion yen):
disaggregated R&D expenditures (basic research, applied research, and experimental development)

1965-1971 : Indicators of Science & Technology, Department of Science and Technology, Japan, 1973, p.22.

1972-1975 : Aggregate data, “total research expenses used”, Historical Statistics of Japan, Japan Statistical Association, 1987, V.5, p.293.

1972-1975 : Differentiated data, by basic research, applied research, and experimental development R&D expenditures, estimated by interpolation.

1976-1979 : Indicators of Science & Technology, 1982, pp. 36-37, and 1993, pp. 30-31, respectively.

1980-1991 : Indicators of Science & Technology, 1993, pp. 30-31

Q (GDP) : Japan's real GDP : Annual Report on National Accounts, Economic Planning Agency, various issues. Economic Statistic Annual, various issues.

CPI in Japan: Economic Statistics Annual, Statistical Department, The Bank of Japan, various issues.

2. Korea (output and R&D expenditures are at 1985 constant prices and in billion won)
R&D expenditures for Korea (at current prices):

1982-1990 : Korea Statistical Yearbook, The Korean Statistical Association, various issues.

Q : Korea's GDP

1982-85 (1985=100) : Economic Statistics Yearbook, 1989, p. 287.

1986-90 (1985=100) : Korea Statistical Yearbook, 1991, pp. 470-71.

CPI : 1982-90 (1985=100) : Korea Statistical Yearbook, 1991, pp. 426-427.

3. Taiwan (output and R&D data are at 1986 constant prices and in million of NT$)
Disaggregated R&D expenditures (basic research, applied research, and experimental development) in Taiwan.

1978-1990 : Statistical Yearbook of the Republic of China, 1988, p. 255 & 1992, p.102.

Q (GDP) : Taiwan's Real GDP.

1978-90 (1986=100) : National Income in Taiwan Area of the ROC, DGBAS, Republic of China, 1991, pp. 72-75.

CPI : 1978-90 : Statistical Yearbook of the Republic of China, 1992, p. 296.11

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