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Nancy Birdsall and Changyong Rhee*

***** Abstract ****

Using the UNESCO data for R&D expenditures and personnel, this paper documents international differences in R&D activities and assesses empirically the link between R&D and economic growth, and the determinants of R&D differentials. Within our group of OECD countries, R&D activity and economic growth are correlated for one of our two proxies. Contrary to the findings of Romer [1989] and Lichtenberg [1992], however, they are not correlated across all, including developing countries. Moreover, even for OECD countries, it is likely that economic growth affects R&D activity rather than vice versa. First, there is no evidence for OECD countries that R&D activity at the beginning of the period 1970-85 contributed to growth during the period as a whole. Second, our analysis of the determinants of R&D activities shows a robust link between these activities and the level of income, suggesting that R&D activities become important only after a country reaches a certain stage of development. For developing countries, our results are consistent with the widespread view, first proposed by Gerschenkron, that countries that are behind grow by catching up technologically, not be advancing the technological frontier.

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I. Introduction

R&D (research and development) activity is generally acknowledged as a likely source of economic growth, given it is a critical input to technological progress, and given evidence from firm and industry level studies of healthy rates of private and social returns (Mansfield [1977], Jaffe [1986]). Yet except for Romer[1989] and Lichtenberg [1992], we know of virtually no other cross-country studies of economic growth that incorporate country-level data on R&D activity -- despite a recent resurgence in the growth literature, incorporating an increasing array of economic, social and political variables.[1]

The paucity of studies reflects in part the relatively poor state of country-level R&D data that is sufficiently comparable for international comparisons. For this paper, we developed such data by undertaking country-by-contry adjustments to information made available by UNESCO on R&D expenditures and personnel at the country level.[2] On the basis of our adjusted data, we assess empirically the link between R&D activity and economic growth, and we analyze the determinants of R&D differentials across countries. We find that growth in R&D activity and economic growth are positively correlated, but only across OECD countries (contrary to the findings in Romer [1989] and Lichtenberg [1992]). And even among OECD countries there is no evidence that R&D activity causes economic growth. Our cross country analysis does show a robust empirical link between R&D activities and the *level* (not growth rate) of income, suggesting that R&D activities become prominent only after a country reaches a certain stage of development.

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[1] See, for example, Easterly (1993), Levine and Renelt (1992), and Barro (1991).

[2] Our adjustments were made on the basis of details on definitions and exclusions that are included in the footnotes to the published UNESCO data.

We believe our findings are fully consistent with the view that growth in developing countries is largely a matter of technological catch-up, as first proposed by Gerschenkron, i.e. based on learning from and adapting technologies developed elsewhere rather than on advancing the technological frontier.[3] This probably requires extensive investments in education and training, including in engineering, but not extensive R&D activity.

The paper is organized as follows. Section II describes our data. Section III sets out cross country analysis of the growth-R&D link, and Section IV sets out our analysis of R&D differentials across countries. Section V concludes.

II. Data

The first international attempt to standardize the definition of R&D and the measurement of R&D inputs was made by OECD member countries at a conference in Frascati, Italy, in 1963. The resulting "Frascati Manual" has provided the basis for OECD's collecting and publishing R&D data on a regular basis. Since 1969, UNESCO has published standardized R&D statistics for some developing countries, based on the Frascati concepts. We use the published UNESCO sources, plus a supplementary UNESCO tape, for our country R&D data.[4]

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[3] Page and Pack (1993) distinguish between technological catch-up and increases in "technical efficiency" and show that the most successful economies of East Asia have grown primarily on the basis of the former. Their finding is consistent with the view of Romer (1989) that growth is affected by the transfer of ideas, and the empirical finding of Kim and Lau (1993) that there has been little or no increase in TFP growth in East Asia, when TFP growth is defined narrowly as increases in technical efficiency.

[4] We are grateful to Mr. Morton M. Brown of the statistical office in the UNESCO, Paris for providing a supplementary tape.

We use measures of R&D inputs, rather than outputs. Within a country the difficulty of measuring R&D inputs is well known. The concept itself is hard to define; according to the OECD definition, the main criterion to distinguish R&D inputs from related scientific activities is "the presence in R&D of an appreciable element of *novelty*" (Frascati Manual [1981]). There are no adequate measures of R&D output.[5] Much of R&D output is in the form of newly improved commodities whose quality-adjusted price indices are rarely available. A significant portion of R&D output is produced in industries such as health, defense, and space, where externalities are large and are difficult to measure and capture statistically.

To measure R&D inputs, we construct a stock variable and a flow variable:

(i) Personnel: As a proxy for the accumulated stock of R&D capital, we use the number of scientists and engineers employed in R&D activities.

(ii) Expenditures: As a proxy for the change in R&D stock, we use gross domestic expenditure on R&D. Following common practice, we ignore the depreciation and lagged effects of past R&D investments.[6]

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[5] There is no internationally agreed system of output measurement. Two indicators, the number of patent applications and the technical balance of payments, are available for OECD member countries for a limited sample period.

[6] In the UNESCO yearbooks, these measures are broken down by specialization (natural science, social science, etc.), sector of performance (private industries, universities, the governments), source of funds (government funds, productive enterprise and special funds, etc.), and type of R&D activity (fundamental research, applied research, etc.). The more specific the measure, the larger are the differences in definitions across countries and the shorter are available sample periods.

Even for the basic R&D input proxies, some national specifications vary from the international norms set out in the Frascati Manual. Details of differences between national and international specifications are set out in footnotes of the UNESCO Statistical Yearbook and the supplementary tape. On the basis of individual footnotes[7], we exclude countries (or observations) if their specification is too different from the international norm. For example, we exclude the expenditure and manpower data for Greece and the manpower data for Norway since they do not include R&D activities in private productive sectors. We exclude Fiji, French Polynesia and Tonga since their data relate to one research institute only.

At the same time, to avoid excluding too many countries, we permit some variation in the R&D input definitions. The most severe example of this is the manpower variable for several countries, including Japan, which is based on the number of physical persons, rather than the international standard of full time equivalent persons. The R&D personnel for Japan are as a result estimated to be overstated by about 30 percent, according to other studies.[8]

Our data set consists of manpower and expenditure data for 21 OECD countries and 19 developing countries, whose sample periods differ widely across countries. Table 1 shows the sample averages and the growth rates of our R&D input proxies for each country. The first two columns list the average and the annual growth rates of R&D expenditures as a percentage of GDP between 1970 and 1985. The third column shows the average of the number of scientists and engineers (employed in R&D activities) per million population

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[7] The proportion of footnoted observations is large, indicating the primitive state of international standardization of R&D measurement.

[8] OECD, Proposed Standard Practice for Surveys of Research and Experimental Development: "Frascati Manual 1980", Paris, 1981.

between 1970 and 1975, and the fourth column shows annual growth rates between 1970 and 1985. The last two columns are for the number of scientists and engineers not normalized by population.[9]

Following the OECD convention, Table 1 puts OECD countries into three groups (major, medium, and small R&D performer) on the basis of the amount of R&D expenditures. The groups based on R&D expenditures are not necessarily the same as the groups based on R&D expenditures as a percentage of GDP. Table 2 breaks down R&D expenditures by source of funds and by type of R&D activities. The first two columns in Table 2 report the average ratios of government funded R&D to the sum of government and privately funded R&D expenditures.[10] The last two columns report the average ratios of basic R&D expenditures to the sum of basic and applied (including experimental) R&D expenditures. Data for these refined categories are available for a smaller set of countries.

Some characteristics emerge from Tables 1 and 2. First, R&D activities in developing countries are negligible. The average R&D expenditure as a percentage of GDP between 1970 and 1985 is only 0.36 percent for developing countries, just 25 percent of the average for OECD countries of 1.42 percent. Between 1970 and 1975, the average number of scientists and engineers employed in R&D activities is 172 per million population for

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[9] In calculating sample averages and annual growth rates, the number of observations included differs across countries, and we use our discretion to minimize bias due to the differences in sample periods. We tried to avoid the concentration of samples around certain periods; if the values for 1985 are not available, either 1984 or 1986 figures are used.

[10] The source of funds code in the UNESCO data set includes other categories such as foreign funds and other funds. Since their proportion is usually minimal and we are not sure whether they should be treated as part of privately-funded expenditures, we exclude them in calculating the ratios in Table 2.

developing countries, just 14 percent of the average for OECD countries of 1,248 per million population. Moreover, given that the developing countries in our sample are almost certainly those with more R&D activity than those not in the sample, the average R&D activity for all developing countries is almost certainly lower than in our sample.

Second, manpower proxies indicate that both the average growth rates and the variance of R&D activities is higher in developing countries than in the OECD countries. Between 1970 and 1985, the average growth rates of the number of scientists and engineers per million population are 3.84 percent for 18 OECD countries and 6.04 percent for 11 developing countries. Standard deviations are 1.97 and 4.86, respectively. During that period, the growth rates of R&D expenditures as a percentage of GDP are not very different between OECD countries and developing countries. They are 2.27 percent for 18 OECD countries and 2.42 percent for 11 developing countries. The standard deviations are 1.96 and 5.29, respectively. Among developing countries, the average R&D expenditures as a percentage of GDP of India and Korea are similar in size to those for low income OECD countries such as Spain, Portugal, and Iceland. The growth rates of the former are greater.

Thirdly, though high R&D investment is often regarded as a major factor explaining Japan's high economic growth, Table 1 indicates that Japan's R&D activities, in terms of R&D expenditures or the growth rates of manpower indices, do not seem exceptional by OECD standards. (Japan's manpower indices are overestimated as noted above.) Surprisingly, even Japan's ratio of applied R&D is not higher than the OECD average. Its ratio of government funded R&D is lower.

Though not reported in Table 1, the time series of our data shows that R&D expenditures have grown as rapidly as or more rapidly than GDP in the majority of countries; the R&D elasticity with respect to GDP seems to be greater than 1. For OECD countries, this series data also reveal that R&D expenditures started to accelerate from the late 1970s, after faltering in the middle of the decade.

III. R&D and Economic Growth

To analyze the relationship between R&D activities and economic growth, we use a simple cross-country regression model as in Dowrick and Nguyen [1989]:

$$(1)\quad q_i = a_0 + a_1k_i + a_2R_i + a_3l_i - a_4 \ln Y_{i0}^* + \varepsilon_i ,$$

where q_i, k_i, R_i, and l_i are the average annual growth rates of real GDP, capital stock, R&D capital stock, and employment, respectively, of country i. Y_{i0}^* denotes *initial* per capita GDP of country i relative to a technological leader, the United States, in our analysis. The term is included to capture the convergence effect, including the likelihood of total factor productivity catch-up effects. The reduced form (1) can be easily derived by introducing R&D capital stock in Dowrick and Nguyen's [1989] production function. Equation (1) can be rewritten to incorporate the investment-GDP ratio by adopting the common practice of proxying capital stock growth by the average share of investment in output (I/Q)[11]:

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[11] This approximation is exact if capital-output ratios are constant across countries and over time. With the same logic, if R&D capital-output ratios are constant, we can proxy R in equation (2) by the average R&D expenditures as a percentage of GDP.

(2) $q_i = a_0 + a_1(I/Q)_i + a_2R_i + a_3l_i - a_4 \ln Y_{i0}^* + \varepsilon_i$.

Table 3 presents the OLS regression results for equation (2). Definitions and sources of variables are summarized in the appendix. For R_i, we use three measures: the growth rates of the number of scientists and engineers employed in R&D activities per million population (GSCP7085), the growth rates of the number of scientists and engineers not denominated by population (GSCI7085), and the average R&D expenditures as a percentage of GDP (RND1_Y). Since our R&D proxies are available only after 1970, the data are the sample averages or the growth rates between 1970 and 1985. LNDIFF70 is the log of the gap in GDP per capita in the year 1970.

The first three columns of Table 3 report the regression results for the full sample. The next four columns report the results for OECD countries and developing countries. Consistent with the results in previous studies (Abramovitz [1986], Baumol and Wolff [1988], Barro [1991]), we find that high investment rates are strongly associated with high GDP growth, and there is evidence for catch-up in levels of total factor productivity.

As for the growth-R&D nexus, our results are mixed. The average growth rates of the number of scientists and engineers, whether denominated by population or not (GSCP7085, GSCI7085), are significant in explaining GDP growth rates for the full sample and OECD countries, but not for the developing countries. If we take this evidence at face value, it suggests that R&D activities become important only after a country reaches a certain degree of economic development.

However, the average R&D expenditure as a percentage of GDP (RND1_Y) is insignificant in explaining economic growth even for OECD countries. Breaking R&D expenditures into sub-fields does not alter the result. Table 4 reports regression results when government funded and privately funded expenditures enter the regressions separately.[12] They do not provide evidence for a significant return from privately funded or government funded R&D investment.

How can our mixed result be best interpreted? One might argue that the expenditure variable is a better proxy since manpower indices could be proxying the changes in human capital instead of R&D capital. To check the validity of this argument, we include proxies for human capital accumulation used in Barro [1991], the primary and the secondary school enrollment rates, in the equation (2). The second column in Table 4 shows that both the secondary enrollment rates and GSCP7085 are significant in explaining GDP growth.[13] The magnitude and significance of the coefficient of GSCP7085 do not change after the inclusion of the enrollment rates. Our measure of the number of scientists and engineers employed on R&D activities is thus probably not simply playing the role of (less educated) human capital. Of course our proxies may represent highly educated human capital, but it would be hard to distinguish the inputs of highly educated human capital from R&D capital anyway.

Moreover, there is a positive case for choosing GSCP7085 or GSCI7085 over RND1_Y.

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[12] Because of the limited number of non-OECD country observations, we report the results for OECD countries only. Neither are applied and fundamental R&D investments significant in growth equations, which is not shown since it covers only 9 countries.

[13] Differently from Barro [1991], the fact that the primary school enrollment rates are insignificant in our regression is because our samples are mostly OECD countries and the sample periods of the regressions is from 1970.

As mentioned in Section II, since our selection criterion allows a certain degree of arbitrariness in national specifications of R&D measurement, international comparison of the *levels* of our proxies could be misleading. However, if national specifications have been time-invariant, comparing the *growth rates* of our proxies would be less problematic. This argument suggests that GSCP7085 or GSCI7085 are better proxies than RND1_Y.[14]

At the same time, the results in Table 3 cannot be interpreted as demonstrating a causal relationship from R&D activities to economic growth. The positive partial correlation between GSCP7085 and economic growth may be due to simultaneous equation bias: Growth of R&D capital stock could simply follow economic growth. In order to control for this possible endogeneity, we estimated the relationship between initial R&D activities at the beginning of the sample period and subsequent economic growth, shown in Table 5.

Following Barro [1991] and other cross country studies, we regressed the growth rates of real GDP per capita between 1970 and 1985 on initial level of real GDP (GDP70), initial primary and secondary school enrollment rates (PRIM, SEC), and the ratio of government spending to GDP (GOV), together with a proxy for initial R&D capital stock,[15] the average number of scientists and engineers per million population between 1970 and 1975 (SCI_P). We use the average value between 1970 and 1975 because some of our sample countries do

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[14] We think this problem is more than a measurement error problem. First, international comparability of RND1-Y is less problematic among *OECD countries*, but we still have the same problem for OECD countries only. Second, the partial correlation between RND1-Y and GSCP7085 (GSCI7085) is negative. The correlation coefficient between them are -0.48, -0.38, and +0.46 for the full sample, for OECD countries, and for developing countries, respectively. It suggests that both variables cannot be used as a proxy for the change of R&D capital stock. Section IV further discusses this negative finding.

[15] As shown in Mankiw, Romer, and Weil [1992], this specification can represent the transitional dynamics of a neoclassical growth model with human and R&D capital.

not have the data for the year 1970. Using average values has the additional advantage of avoiding a systematic bias in estimating the dependent variable and the initial values of independent variables from a common base year.

The result in column 1, Table 5 shows that SCI_P is not significant in explaining the per capita GDP growth rate. In order to check whether this result is due to a different specification from those in Table 3, the second column includes the average investment-GDP ratio and GSCP7085 in the regression. We confirm the previous result that the average investment ratio and GSCP7085 are significant explanatory variables, but still the initial R&D stock, SCI_P, is insignificant. The third column reports the same conclusion for the OECD countries only.[16]

The last three columns in Table 5 test parameter stability over time. Given a possible lag in the effect of R&D on economic growth, the fourth column regresses per capita GDP growth rates between 1975 and 1985 on the same set of independent variables, whose initial values are for the year 1970. Also, from previous cross country studies of growth, we know that the fit of the regression is much better if the sample periods are extended back to the 1960s. The fifth regression extends the sample period; the dependent variable is the GDP growth rate for the period 1960 to 1985, and the initial values for independent variables (except SCI_P) are the figures in the year 1960. Note that the estimated coefficient

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[16] Barro and Lee [1993] report a similar finding for the data set including over 100 countries. They find that the initial values of educational attainment at higher (rather than secondary) level are insignificant for economic growth, even for OECD countries, and conclude that "human capital in the form of higher education would be unimportant for most countries, which tend to adopt leading technologies rather than invent fundamentally new things" [p.14-15]. The difference between their highly educated human capital stock variable and ours is that ours includes only those employed in R&D activities.

of SCI_P could be biased upward since SCI_P is the average value in the middle of the sample period. In both cases, however, SCI_P is not correlated with economic growth. The results for OECD countries and developing countries are not different (not reported in Table 5).[17]

The finding that our proxies for initial R&D activities are not correlated with economic growth contrasts sharply with Romer [1989] and Lichtenberg [1992] who use the same UNESCO data set. Romer [1989] finds a positive correlation between the initial number of scientists and engineers employed in R&D activities and subsequent economic growth. Lichtenberg [1992] finds that the ratio of privately funded R&D expenditures to GNP is highly correlated with economic growth in a sample of 59 countries, though government funded R&D expenditures are not.

We believe their results should be treated cautiously because of probable data problems and possible resulting selection bias. Lichtenberg [1992] includes many developing countries that have just one annual observation on the R&D expenditure/GNP ratio, and uses the one observation as an average for the whole sample period. Available data for other countries are often too concentrated around certain periods to represent an average value for the period 1970 and 1985. Both authors include countries whose specifications diverge considerably from the international norms explained in Section II.

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[17] Our findings in Table 5 are not sensitive to White's heteroskedastic error correction, inclusion of other proxies for political stability and market distortions used in Barro [1991], and the choice of R&D proxies. Using the number of scientists and engineers (not denominated by population) or average R&D expenditure in percentage of GDP between 1970 and 1975, without a good theoretical reason, as a proxy for initial R&D capital does not alter the conclusions.

The combination of results from Tables 3 and 5 suggests that the positive contemporaneous correlation between our proxies for R&D activities and economic growth (Table 3) is capturing the positive effect of economic growth on R&D activities -- the reverse of the expected causation. Higher initial R&D activities do not necessarily lead to subsequent economic growth (Table 5).

Is this result contradictory to numerous micro-studies, which document high returns to R&D expenditures at the firm or industry level? (Griliches [1984], Jaffe [1986], Mansfield [1977]) At face value, our results suggest that high private returns to R&D expenditures in micro-studies do not reflect high social returns. They may result from enhanced monopoly power of a firm at the cost of its competitors. Alternatively, it may be that evidence of high returns from micro studies of firms and industries in highly developed countries, mostly the United States, does reflect social gains, but such gains to R&D activities become important only after a country or a firm advances to a technologically leading group.[18]

IV. Determinants of R&D Expenditures

This section analyzes what variables are important in explaining international differences in R&D expenditures as a percentage of GDP. The issue itself is interesting. In addition, this analysis provides an indirect test of the quality of our data. If large measurement errors or differences in national specifications are a major reason for our previous finding, it is less

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[18] The other explanation may be the poor quality of the R&D proxies. International standardization in measuring R&D activities is still in the experimental stage. The UNESCO data, even with adjustments, may not provide an adequate basis for study of the effects of R&D on growth compared, for example, to other data, such as those on education enrollments, that routinely used in studies of growth.

likely that we will find meaningful determinants of our R&D proxies.

In Table 6, the dependent variable in the first two regressions is average R&D expenditures as a percentage of GDP between 1970 and 1985 (RND1_Y). The results show that the initial level of per capita GDP (GDP70) and the initial number of scientists and engineer in R&D activities per million population (SCI_P) are major factors explaining cross country differentials in R&D expenditures. We find that GDP70 or SCI_P alone can explain 61 percent or 75 percent of the cross country variation. It is interesting to note that the average share of physical investment in GDP is not a significant factor once the initial level of GDP is controlled, though it is significant without GDP70. Other variables such as export share, government expenditure share, and proxies for initial human capital are not significant in explaining the variation of RND1_Y, and their inclusion does not alter the results. The results for the OECD countries are similar.

The finding that the R&D expenditure share is strongly related to the level of income and the level of initial R&D stock is not surprising. A country with higher per capita GDP (larger physical capital stock) should have a lower marginal productivity of physical investment, and therefore, a larger incentive to invest in R&D, which can alleviate the diminishing marginal productivity of physical capital. In contrast, the positive effect of initial R&D stock suggests that the marginal productivity of R&D capital is not diminishing, i.e., there are constant or increasing returns to R&D investment. This is consistent with the view that huge fixed costs are involved in R&D investment.

The third and the fourth columns report the results when privately funded and government funded R&D expenditures to GDP ratios are used as dependent variables, respectively. They show qualitatively the same results with those for total R&D expenditures. The finding is not surprising, considering the high correlation coefficient (0.70) between privately funded and government funded R&D expenditures to GDP ratios.[19]

The last two columns in Table 6 show typical regression results when the dependent variable is the growth rates of the number of scientists and engineers per million population (GSCP7085). As expected from our previous regressions in Table 3 and 5, the per capita GDP growth rate is a significant determinant of GSCP7085. In fact, we find other variables we used in this paper are not robustly related to GSCP7085 using Levine and Renelt's [1992] approach to assessing robustness. Note that GSCP7085 is negatively related to the initial level of income, GDP70, which is a major determinant of R&D expenditures. Ex post, this finding illustrates the reason for the negative correlation between our manpower and expenditure proxies for R&D activities (see footnote 13). We believe that R&D activities are income-elastic and led by high income countries, consistent with the results in columns 1-4. Therefore, at least for the OECD countries, expenditure data appears to provide a better proxy for growth in R&D activities than manpower data. At the same time, the finding in columns 5 and 6 confirms our earlier supposition of reverse causality, i.e., growth of income induces growth of R&D manpower indices in all countries.

VI. Conclusions

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[19] The correlation coefficient between fundamental R&D and applied R&D expenditures to GDP rations is 0.89.

Using the UNESCO data for R&D expenditures and personnel, this paper documents international differences in R&D activities and assesses empirically the link between R&D and economic growth, and the determinants of R&D differentials. Within our group of OECD countries, R&D activity and economic growth are correlated for one of our two proxies. Contrary to the findings of Romer [1989] and Lichtenberg [1992], however, they are not correlated across all, including developing countries. Moreover, even for OECD countries, it is likely that economic growth affects R&D activity rather than vice versa. First, there is no evidence for OECD countries that R&D activity at the beginning of the period 1970-85 contributed to subsequent growth during the period. Second, our analysis of the determinants of R&D activities shows a robust link between these activities and the level of income, suggesting that R&D activities become important only after a country reaches a certain stage of development. For developing countries, our results are consistent with the widespread view, first proposed by Gerschenkron, that countries that are behind grow by catching up technologically, not by advancing the technological frontier.

Appendix: Definitions of Variables in Table 1-6

AVG_EX70: Average ratio of exports to GDP for the years 1960-85; from World Bank BESD.

AVGI7085: Average ratio of public plus private investment over GDP for the years 1970-85; from Barro [1991].

GOV7085: average ratio of real government "consumption" expenditure to real GDP for the years 1960-85; from Barro [1991]

GRND1_Y: government funded expenditures on R&D as a percentage of GDP; average for the years 1970-85; calculated from UNESCO data set.

GR7085: growth rates of GDP per capita, in 1980 $US, for the years 1970-85; from World Bank BESD.

GDP70: GDP per capita in 1980 $US, for the year 1970; from World Bank BESD.

GPOP7085: growth rates of population for the years 1970-85; from World Bank BESD.

GRSCP7085: growth rates of the number of R&D scientists and engineers per million population for the years 1970-85; calculated from UNESCO data set.

GRSCI7085: growth rates of the number of R&D scientists and engineers for the years 1970-85; calculated from UNESCO data set.

LNDIFF70: log difference between GDP70 of each country relative to U.S. GDP70.

PRND1_Y: privately funded expenditures on R&D as a percentage of GDP; average for the years 1970-85; calculated from UNESCO data set.

PRIM: primary school enrollment rate; from Barro [1991]

RND_Y: Expenditure on R&D as a percent of GDP; average during the period 1970-75; calculated from UNESCO data set.

RND1_Y: same as above for the years 1970-85.

SCI_P: average number of R&D scientists and engineers per million population for the years 1970-75; calculated from UNESCO data set.

SEC: secondary school enrollment rate; from Barro [1991]

TGDP7085: growth rates of GDP, in 1980 $US, for the years 1970-85; from World Bank BESD.

References

Abramovitz, Moses, "Catching Up, Forging Ahead, and Falling Behind," Journal of Economic History, XLVI (June 1986), 385-406

Barro, Robert, " Economic Growth in a Cross Section of Countries," Quarterly Journal of Economics, CVI (1991), 407-43

Barro, Robert and Jongwha Lee, "Sources of Economic Growth," mimeo, Harvard University, April 1993.

Baumol, William and Edward Wolff, "Productivity, Growth, Convergence, and Welfare: Reply," American Economic Review 78, December 1988, 1155-59.

Dowrick, Steven, and Duc-Tho Nguyen, "OECD Comparative Growth," American Economic Review, LXXIX (December 1989), 1010-30.

Easterly, William, "Explaining Miracles: Growth Regressions Meet the Gang of Four," presented at the NBER's Fourth Annual East Asian Seminar on Economics, San Francisco, June 17-19, 1993.

Griliches, Zvi, R&D, Patents and Productivity, Chicago: University of Chicago Press, 1984.

Jaffe, Adam B., "Technological Opportunity and Spillovers of R&D: Evidence from Firms' Patent, Profits, and Market Value," American Economic Review 76, (December 1986), 984-1001.

Kim, Jong-Il, and Lawrence Lau, "Sources of Economic Growth of the Newly-Industrialized Countries on the Pacific Rim," presented at the "Conference on the Economic Development of the Republic of China and the Pacific Rim in 1990 and Beyond," Taiwan, China, 1993.

Levine, Ross, and David Renelt, "A Sensitivity Analysis of Cross-Country Growth Regressions," American Economic Review 1(4) (September, 1992), 942-963.

Lichtenberg, Frank R., "R&D Investment and International Productivity Differences," NBER Working Paper #4161, September 1992.

Mankiw, Gregory, David Romer, and David Weil, "A Contribution to the Empirics of Economic Growth," Quarterly Journal of Economics 107, (May 1992), 407-38.

Mansfield, Edwin, The Production and Application of New Industrial Technology, New York: N.W. Norton, 1977.

OECD, Proposed Standard Practice for Surveys of Research and Experimental Development: "Frascati Manual 1980", Paris, 1981.

Page, John and Howard Pack, "Accumulation, Exports, and Growth in the High Performing Asian Economies," presented at the Carnegie-Rochester Conference on Public Policy, 1993.

Romer, Paul, "What Determines the Rate of Growth and Technological Change?," working paper #279, The World Bank, September 1989.

UNESCO. *Statistical Yearbook, Paris, 1963-present.

TABLE 1: R&D INPUTS

	[1] Expenditure in % of GDP		[2] Researchers per mill. population		[3] Number of Researchers	
	(1) avg(%) (1970-85)	(2) growth(%) (1970-85)	(3) avg (1970-75)	(4) growth(%) (1970-85)	(5) Avg (1970-75)	(6) growth (1970-85)
OECD Countries						
Major R&D Performer						
U.S.	2.44	0.79	2523.6	1.30	531516	2.27
Japan	2.16	2.70	3230.9	3.06	349323	4.04
Germany	2.29	2.32	1550.2	4.96	95379	3.73
France	1.89	1.33	1207.5	3.14	62678	3.69
U.K.	2.15	0.71	1400.3	n.a.	78193	n.a.
Medium R&D Performer						
Italy	0.84	1.85	605.3	4.45	33054	4.83
Canada	1.15	0.66	1006.1	3.00	22073	4.11
Netherlands	1.97	0.07	1730.1	1.92	23117	2.62
Sweden	2.01	4.89	1497.9	5.24	12207	5.46
Switzerland	2.28	2.74	1481.5	3.64	9496	3.76
Australia	1.05	-0.66	1838.6	0.05	24600	1.43
Belgium	1.48	1.15	1328.9	1.55	12925	1.81
Small R&D performer						
Austria	0.99	4.93	617.4	4.67	4640	4.78
Norway	1.33	2.57	n.a.	n.a.	n.a.	n.a.
Denmark	1.05	1.75	959.8	3.97	4804	4.21
Finland	1.08	3.96	1247.6	6.30	5828	6.72
New Zealand	n.a.	n.a.	852.7	n.a.	2549	n.a.
Ireland	0.75	0.41	687.2	3.75	2129	5.00
Spain	0.35	6.13	219.3	5.93	7570	6.80
Portugal	0.35	1.16	223.7	3.93	2050	4.77
Iceland	0.61	5.94	756.8	8.29	161	9.34
LDCs						
Argentina	0.38	3.23	289.7	1.84	7300	3.38
Ecuador	n.a.	n.a.	92.1	n.a.	569	n.a.
Egypt	n.a.	n.a.	299.4	2.62	10665	5.17
Ghana	n.a.	n.a.	359.9	n.a.	3260	n.a.
Guatemala	0.24	8.78	47.6	n.a.	269	n.a.
India	0.51	5.95	76.2	7.64	44412	7.50
Iran	n.a.	n.a.	128.9	-3.01	3829	0.40
Jordan	0.32	-3.64	78.9	3.95	207	6.65

	[1] Expenditure in % of GDP		[2] Researchers per mill. population		[3] Number of Researchers	
	(1) avg(%) (1970-85)	(2) growth(%) (1970-85)	(3) avg (1970-75)	(4) growth(%) (1970-85)	(5) Avg (1970-75)	(6) growth (1970-85)
Korea	0.57	8.79	192.4	11.74	6533	13.31
Mauritius	0.40	-6.53	127.7	6.86	107	8.20
Mexico	0.32	6.33	98.8	7.70	5417	10.67
Nigeria	n.a.	n.a.	35.0	n.a.	2066	n.a.
Peru	0.34	-3.07	131.4	11.00	1885	13.52
Philippines	0.19	0.23	n.a.	n.a.	n.a.	n.a.
Singapore	n.a.	n.a.	228.2	13.01	502	14.38
Sri Lanka	0.17	0.34	n.a.	n.a.	n.a.	n.a.
Sudan	n.a.	n.a.	153.3	n.a.	2311	n.a.
Trinidad & Tobacco	0.53	6.21	n.a.	n.a.	n.a.	n.a.
Uruguay	n.a.	n.a.	419.7	3.09	1150	2.74
Total Avg	1.04	2.32	770.13	4.68	38188	5.70
OECD Avg	1.41	2.27	1248.27	3.84	64214	4.41
LDC Avg	0.36	2.42	172.45	6.04	5655	7.81

TABLE 2: SOURCE AND TYPE OF R&D EXPENDITURES

	Gov't Funded R&D(1)		Fundamental R&D(2)	
	[1] Avg (1970-75)	[2] Avg (1970-85)	[3] Avg (1970-85)	[4] Avg (1970-85)
OECD Countries				
Major R&D performer				
U.S	0.567	0.536	0.136	0.132
Japan	0.292	0.276	0.360	0.235
Germany	0.484	0.447	0.285	0.237
France	0.598	0.576	0.207	n.a
U.K.	0.540	0.520	0.119	n.a.
Medium R&D performer				
Italy	0.461	0.466	0.216	0.186
Canada	0.643	0.577	0.225	n.a.
Netherland	0.456	0.483	n.a.	n.a.
Sweden	0.427	0.405	0.178	0.191
Switerland	n.a.	n.a.	n.a.	n.a.
Austarlia	0.622	0.720	n.a.	n.a.
Belgium	0.390	0.354	0.232	n.a.
Small R&D performer				
Austria	0.302	0.395	n.a.	n.a.
Norway	0.642	0.606	0.235	0.203
Denmark	0.537	0.467	0.231	n.a.
Finland	0.435	0.439	n.a.	n.a.
New Zealand	n.a.	n.a.	n.a.	n.a.
Ireland	0.569	0.570	0.119	0.130
Spain	0.501	0.478	0.204	0.181
Portugal	0.719	0.697	0.156	0.166
LDCS				
Argentina	0.917	0.915	0.263	0.261
Korea	0.776	0.522	0.191	0.200
Mauritius	0.504	0.576	0.093	n.a.
Mexico	0.871	0.896	0.234	0.182
Sri Lanka	0.590	n.a.	0.041	n.a.
Sudan	0.970	n.a.	n.a.	n.a.
Uruguay	0.787	n.a.	0.129	n.a.
OECD Avg	0.510	0.500	0.207	0.184

**(1) The ratio of government fundend R&D to the sum of government and privately funded R&D.
(2) The ratio of fundamental R&D to the sum of fundamental, applied, and experimental R&D.

TABLE 3: R&D and Economic Growth (I)

Dependent variable: TGDP7085

Indep. variables	(1) ALL	(2) ALL	(3) ALL	(4) OECD	(5) OECD	(6) LDCS	(7) LDCS
Constant	-0.022 (-2.14)	-0.022 (-2.16)	-0.001 (-0.12)	-0.0007 (-0.103)	0.011 (1.307)	-0.054 (-1.80)	-0.030 (-0.53)
AVGI7085	0.153 (3.84)	0.148 (3.87)	0.133 (3.22)	0.052 (1.99)	0.075 (2.62)	0.236 (2.57)	0.161 (0.92)
GPOP7085	0.461 (1.36)	0.273 (0.87)	0.126 (0.33)	1.343 (4.21)	0.846 (2.35)	0.487 (0.64)	0.175 (0.14)
LNDIFF70	-0.008 (-2.46)	-0.008 (-2.66)	-0.007 (-2.46)	-0.004 (-1.62)	-0.0022 (0.55)	-0.015 (-1.96)	-0.010 (-1.39)
GSCP7085	0.0016 (2.07)			0.0017 (2.41)		0.0012 (0.79)	
GSCI7085		0.0018 (2.49)					
RND1_Y			-0.004 (-0.95)		-0.0049 (-1.76)		0.0414 (0.66)
R^2	0.67	0.69	0.47	0.75	0.66	0.74	0.43
D.W.	1.56	1.60	1.34	1.87	2.09	1.65	1.18
# of obs.	28	28	30	18	20	10	10

[*] Figures in parenthesis are t-statistics.

[*] For the definitions of variables, see appendix.

Table 4: R&D and Economic Growth

Dependent variable: TGDP7085

Independent Variables	*(1)* *OECD*	*(2)* *OECD*
Constant	0.0077 (0.965)	-0.0091 (-0.646)
AVGI7085	0.0792 (2.982)	0.0433 (1.743)
GPOP7085	0.5783 (1.703)	1.2389 (4.056)
LNDIFF70	-0.0039 (-1.083)	-0.0063 (-2.22)
Gov't funded R&D	-0.0008 (-0.142)	
Privately Funded R&D	-0.0034 (-0.740)	
GSCP7085		0.0197 (2.93)
SEC		0.0197 (1.97)
PRIM		-0.004 (-0.367)
R^2	0.0683	0.819
D.W.	1.63	1.305
# of observation	18	18

Table 5: Growth & Initial R&D Capital

Dependent Variable/ Independent variable	(1) GR7085 All	(2) GR7085 All	(3) GR7085 OECD	(4) GR7585 All	(5) GR6085 All
Constant	-0.0093 (-0.46)	-0.0241 (-0.80)	0.0147 (1.020)	-0.026 (-1.060)	-0.0049 (-0.413)
Initial GDP	-0.0048 (-2.26)	-0.002 (1.54)	-0.0021 (-2.61)	-0.0059 (-2.26)	-0.0074 (-3.967)
SEC	0.0544 (1.992)	0.032 (1.44)	0.0215 (1.88)	0.056 (1.66)	0.0424 (2.133)
PRIM	0.0305 (1.429)	-0.0065 (-0.272)	0.0093 (0.847)	0.0373 (1.438)	0.0447 (3.898)
GOV	-0.0467 (-0.759)	0.0310 (0.506)	-0.0299 (-1.211)	-0.0022 (-0.029)	-0.0430 (-0.935)
SCI_P	-0.000 (-0.200)	0.000 (0.034)	0.000 (0.202)	0.000 (0.405)	0.000 (0.254)
AVGI7085		0.1257 (2.496)			
GSCP7085		0.0027 (2.810)			
R^2	0.363	0.601	0.485	0.327	0.530
D.W.	1.48	1.29	2.02	1.72	1.67
#of obs.	36	29	20	36	36

Table 6: Determinants of R&D Expenditures

Dependent variable/ Independent Variable	(1) RND1_Y All	(2) RND1_Y ALL	(3) PRND1_Y ALL	(4) GRND1_Y ALL	(5) GSCP7085 ALL	(6) GSCP7085 ALL
Constant	-0.439 (-0.88)	0.145 (0.36)	-0.755 (-1.42)	-0.014 (-0.04)	10.36 (3.00)	8.871 (2.37)
GDP70	0.228 (5.31)	0.097 (2.26)	0.129 (3.06)	0.120 (4.49)	-0.335 (-1.33)	-0.105 (-0.31)
GR7085	8.625 (1.08)	3.908 (0.62)	8.152 (1.12)	1.695 (0.36)	94.52 (2.35)	101.71 (2.50)
AVGI7085	0.163 (0.08)	-2.545 (-1.65)	1.301 (0.77)	-0.624 (-0.58)	-14.72 (-1.24)	-8.982 (-0.68)
AVG_EX70	-0.854 (-1.03)	0.748 (0.92)	0.104 (0.10)	0.243 (0.39)	1.766 (0.29)	-0.039 (0.00)
GOV7085	2.007 (1.00)	1.434 (0.95)	0.529 (0.24)	0.132 (0.09)	-19.64 (-1.63)	-18.028 (-1.49)
SCI_P		0.0006 (4.72)				-0.001 (-1.02)
R^2	0.65	0.84	0.48	0.63	0.38	0.42
D.W.	1.92	2.00	2.08	1.60	1.85	1.84
# of obs.	29	25	21	21	26	26