Science, Technology and Economic Growth: Toward a Theory

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Introduction

A large number of nations in the world, hosting a big share of humanity, remain poor and many of their people continue to suffer from ignorance, illiteracy, hunger, malnutrition, disease, high mortality rates and short human life expectancy. Can economic theory satisfactorily explain the continuing poverty of these nations? Can it provide useful guidelines for the poor countries to break out of their cycles of poverty?

The Philippines had desired to attain economic growth for a long time. Since gaining independence in 1946, its economic history had been characterized by "cycles of booms and busts." Can these "cycles" be satisfactorily explained? Studies conducted in the 1970's revealed that while, in general, high educational attainment had a strong causal effect on economic growth among other nations, this did not seem to be true to the Philippines. What unique features had Philippine education to explain its inability to contribute to economic growth?

However, since 1993 the Philippines has started to experience moderate economic growth, which is generally attributed to the new economic policies of deregulating the economy, inviting foreign investors and allowing free market forces to operate. Will the Philippines sustain its economic growth and successfully "pole-vault into the 21st century"? Or will it suffer from its old disease of an eventual "bust"?

A. *Statement of Purpose*

This paper aims to verify the notion that the adoption of modern technology is

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the primary source of success by Western Europe, the USA, Japan, and the four Asian "Newly Industrializing Countries" ("NIC's" or "Dragon Economies") in achieving industrialization and economic growth. In our effort to explain the success or failure of nations in the adoption of modern technology, we theorize that a nation's science and technology capability (STC) determines its ability to adopt modern technology, industrialize and eventually achieve economic growth and development.

Using two measures of science and technology capability (STC), namely, (1) the number of research and developmment (R&D) scientists and engineers per million population (SE/MP) and (2) the gross expenditure on research and development as a percentage of the gross national product (GERD/GNP), we tested the hypothesis that STC is the principal determinant of economic growth and development, the end product of which, economic success (ES), is measured by (3) per capita gross national product in US dollars (PCGNP).

In order to further test the relationship between science and technology capability (STC) and economic success (ES), separate time-series data from Japan, South Korea and Taiwan were also analyzed.

Finding the results of the regression analyses of the worldwide data, including those of the three sets of time-series data from Japan, South Korea and Taiwan, to be highly supportive of the hypothesis, we proceeded to make recommendations on how a developing country, like the Philippines, may attain industrialization and economic growth.

B. *The Role of Technology*

The success of the Industrial Revolution in transforming the economies of Europe starting in the middle of the 18th century established the role of technology in industrialization and economic development. The rapid industrialization of the USA, which eventually became the largest economy in the world, and the success of Japan's industrialization strategy in equalizing with Europe and the USA, particularly following its defeat in World War II, bolstered further the crucial role of technology in economic growth.

The more recent development saga of the so-called four Asian "NIC's", namely, South Korea, Singapore, Taiwan, and Hongkong, is truly phenomenal in that they achieved in only 25 years what it took European countries 250 years to accomplish. Again, common among the strategies of these "NIC's" is the adoption of modern technology in the production of high-value-added products aimed primarily at the export markets.

The Nobel laureate, Robert M. Solow (1957), noted that more than the billions in dollars of capital investment, it was technological progress which accounted for over 80 percent of the growth in output per labor hour in the USA from 1909 to 1949. Subsequent studies by Edward Denison (1974, 1980) confirmed that over 76 percent of the growth in output per labor hour in USA from 1929 to 1969 was also the result of technological progress. In the case of Japan, the adoption of new technologies enabled the country to almost triple its output per labor hour from 1960 to 1973 (Durnbusch & Fisher, 1985).

Theoretical Framework

A. Some Pre-Conditions of Economic Growth

It must be understood that there are certain minimal conditions which must be satisfied before a country becomes ready to undergo economic growth and development. These conditions make the environment conducive to the efficient operation of the factors of production in the economy.

(1) *Peace and order* refers to a condition where violence and criminality are kept to a minimum so that they do not impede or discourage economic activity. In the absence of peace, investors become afraid to engage in business activities, denying the economy a chance to expand and grow. Peace and order also refers to the absence of war, revolution, insurrection, rebellion or armed conflict.

(2) *Political stability* refers to a situation whereby the system of governance, particularly in the selection of political leaders, who are vested with the authority to decide and implement policies, is regular and predictable and changes in leadership are not attained by violence. It also means that general policies are consistent and stable and that they do not just drastically get changed or reversed upon change of political leaders. The predictability of economic policies is a minimum requirement for investors to make their resources available for the production of goods and services.

(3) *Free market economy* refers to a condition whereby the government allows free and open competition to exist in the market. A free market eliminates monopolists, welcomes outside investors, and keeps government regulations to a minimum. Free competition encourages investment from both local and foreign sources. Lack of free competition inhibits the entrance of new players in the market.

(4) *Physical infrastructure* refers to minimum requirements in roads, railways, bridges, seaports, airports, and other means of transportation and communication in order for business and industry to grow and thrive. Lack of infrastructure hampers production, distribution, storage and other economic ac-

tivities.

(5) *Factors of production* refer to minimum requirements in resources like land, labor and capital which a nation deploys for the production of goods and services to attain economic growth and development. However, it has been demonstrated that a nation does not need enormous amounts of the factors of production if it can invite foreign capital and labor and adopt modern technology to improve its economic efficiency.

(6) *Slow population growth* refers to a situation where the rate of growth in population is slower than the rate of growth in the economy so that positive absolute economic growth becomes possible and sustainable in the long run. A high population growth rate hinders economic development because a small gain in the economy can be offset by a bigger increase in population.

(7) *Human resource capability* refers to the general capacity of the population, as measured by its level of formal and informal training and education. A highly literate and educated population is expected to be more productive than a generally illiterate and uneducated population.

(8) *High savings and investment rates* refer to the percentage of nationa income saved and invested in the production of more goods and services. Higher savings mean higher investments, which translate to higher incomes, to even more savings and eventually to even more investments.

(9) *Minimal level of corruption* refers to a condition whereby the implementation of economic policies and the conduct of business activities are not subverted by either extortion by those enforcing government regulations or bribery by their clients. Corruption does not only defeat true market competition but it also increases the cost of doing business, thereby decreasing real business efficiency.

B. A Model of Economic Success

Classical economic theory emphasizes the role of production factors (e.g. land, labor and capital) in the expansion of the economy as a nation attains economic growth and development. However, the role of technical progress has been found to account for a great portion of economic growth (Solow, 1957; Denison, 1974; Dornbusch & Fisher, 1985). The adoption of modern technology is therefore crucial to the growth and development of a nation's economy because it provides newer methods of production which produce bigger outputs and better quality products at cheaper cost. The more modern a technology is, the more efficient and cost-effective it becomes in producing goods and services. More importantly, the adoption of new technology leads to the creation of improved, innovative or newly designed products which result in bigger revenues.

In order therefore for a country to develop economically and remain competitive, it must adopt modern technology. The adoption of modern technology through the purchase of imported machinery, however, has its drawbacks, namely: (1) imported machinery is usually expensive, (2) exporting countries normally do not sell their advance machinery to prevent the importing countries from becoming serious competitors, and (3) imported machinery often need technicians, parts, servicing, repairs or modifications which are not readily available in importing countries.

The successful adoption of modern technology therefore requires that a country ultimately develops its own technological capability. It must initially monitor worldwide technological discoveries and applications, study and innovate them and eventually create, invent or design new products and services. Such a technological capability requires that a large sector of the population becomes familiar with not only modern technology itself, but also with the whole gamut of the fundamental sciences that feed technology with increasing understanding of the underlying relationships among various natural phenomena.

The ability of a nation therefore to design high- technology, high-value-added products and services is dependent upon its science and technology capability (STC), as reflected by the number and quality of its scientists and engineers doing R & D work and the level of its investments in R & D efforts. The scientists and engineers conduct R & D work and in the process design new high-value-added products which help increase the nation's income.

Considering that the adoption of modern technology can account for a big portion of the increase in the economic output of developed nations, and considering further that the scarcity of the factors of production has not prevented nations like Singapore, Hongkong and South Korea from growing economically, a model is hereby proposed which emphasizes the importance of science and technology capability (STC) in the creation of economic success. The model is thus written as follows:

$$ES = f(STC)$$

where "ES" means "Economic Success," "STC" means "Science and Technology Capability," and "f" means "function of."

Economic Success (ES) is measured by per capita gross national product (PCGNP) in US dollars, while Science and Technology Capability (STC) is measured by (1) the number of R & D scientists and engineers per million population (SE/MP) and (2) the gross expenditures in research and development as a percentage of gross national product (GERD/GNP).

Analyses and Discussions of Results

Scientists and engineers are persons who completed at least tertiary level education in any field of science and engineering and who are engaged in professional work on research and development (R & D) activities, including researchers, administrators and other high-level personnel who direct the execution of R & D activities. R & D activities refer to any creative systematic activity undertaken to increase the stock of knowledge and the use of this knowledge to devise new applications, including fundamental research (experimental or theoretical without any immediate applications in mind), applied research (aimed at practical applications as in agriculture, medicine, industrial chemistry, etc.), and experimental development work toward new devices, products or processes. Science and engineering refer to the natural or fundamental sciences (physics, chemistry, biology and mathematics), engineering and technology, medical science, agricultural science and social science and humanities. R & D expenditures refer to intramural current expenditure, including labor (salaries and allowances), material (supplies and materials, miscellaneous), tangible fixed assets (building, equipment and fixtures), and other costs of operation. R & D expenditures include those expended within the national territory and overseas but owned by persons or entities from the same country.

Data on the number of R & D scientists and engineers per million population (SE/MP) and on the gross expenditures on research and development as a percentage of gross national product (GERD/GNP) were taken from the UNESCO *Statistical Yearbook* (1995) and the UNESCO *World Science Report* (1996). These data have a range from 1980 to 1992, but the average year they were taken was 1989. Per capita gross national product (PCGNP) were taken from the *World Development Report* (1996) by the Oxford University Press for the World Bank representing data as of 1994. There is therefore an average time lag of five (5) years from the time the data on both the number of scientists and engineers and the national R & D expenses were reckoned and the time the data on per capita income were recorded because it was assumed that science and technology capability (STC) takes some time to mature and become effective in increasing national incomes.

Data on the above three variables were taken on ninety-one (91) countries world-wide from all continents of the world and Oceania. Some of them are rich and industrialized, while the others are either developing, industrializing or poor (see Table 1).

Considering that all the data are of interval characteristics, regression analy-

Table 1. PCGNP, SE/MP, and GERD/GNP among 91 Countries of the World

No.	Country	1994 PCGNP (US$)	SE/MP	GERD/ GNP
1	Switzerland	37930	2409	1.8
2	Japan	34630	5163	3.0
3	Denmark	27970	2343	1.8
4	Norway	26390	3159	1.9
5	United States	25880	3874	2.9
6	Germany	25580	2713	2.8
7	Iceland	24630	3067	1.1
8	Austria	24630	1146	1.4
9	Sweden	23530	3081	2.9
10	France	23420	2267	2.4
11	Belgium	22870	1856	1.7
12	Singapore	22500	2305	1.27
13	Netherlands	22010	2656	1.9
14	Canada	19510	2347	1.6
15	Kuwait	19420	824	0.9
16	Italy	19300	1310	1.3
17	Finland	18850	2283	2.1
18	United Kingdom	18350	2334	2.1
19	Australia	18000	2115	1.4
20	Israel	14530	4836	2.1
21	Brunei Darussalam	14240	91	0.1
22	Ireland	13530	1737	0.9
23	Spain	13440	1060	0.9
24	New Zealand	13350	1555	0.9
25	Qatar	12820	746	0.0
26	Cyprus	10260	205	0.2
27	Portugal	9320	599	0.6
28	Korea, Republic	8260	1343	2.1
29	Argentina	8110	352	0.3
30	Greece	7700	54	0.3
31	Slovenia	7040	2993	1.5
32	Seychelles	6680	261	1.3
33	Urugay	4660	586	-
34	Mexico	4180	226	0.2
35	Gabon	3880	192	0.0
36	Hungary	3840	1200	1.1
37	Trinidad & Tobago	3740	240	0.8
38	Chile	3520	364	0.7
39	Malaysia	3480	327	0.1
40	Czekoslovakia	3200	3247	1.8
41	Mauritius	3150	180	0.4
42	South Africa	3040	319	1.0
43	Brazil	2970	390	0.4
44	Venezuela	2760	279	0.5
45	Russian Federation	2650	5930	1.6
46	Croatia	2560	1977	-
47	Turkey	2500	225	0.8

No.	Country	1994 PCGNP (US$)	SE/MP	GERD/ GNP
48	Thailand	2410	173	0.2
49	Poland	2410	854	0.9
50	Costa Rica	2400	534	0.3
51	Latvia	2320	3287	0.3
52	Fiji	2250	50	0.2
53	Belarus	2160	2200	0.8
54	Peru	2110	274	0.2
55	Ukraine	1910	6730	-
56	Tunisia	1790	389	0.3
57	Colombia	1670	39	0.1
58	Paraguay	1580	249	0.03
59	Jamaica	1540	8	0.0
60	Jordan	1440	119	0.3
61	El Salvador	1360	27	0.0
62	Lithuania	1350	1278	-
63	Ecuador	1290	169	0.1
64	Romania	1270	1220	0.7
65	Bulgaria	1250	4240	1.7
66	Guatemala	1200	99	0.2
67	Uzbekistan	960	1760	-
68	Philippines	950	90	0.1
69	Indonesia	880	161	0.2
70	Macedonia (FYR)	820	1258	-
71	Bolivia	770	250	1.7
72	Egypt	720	436	1.0
73	Sri Lanka	640	173	0.2
74	Congo	620	456	0.0
75	Senegal	600	342	-
76	Honduras	600	138	-
77	China	530	1128	0.5
78	Guyana	530	115	0.2
79	Guinea	520	264	-
80	Pakistan	430	58	0.9
81	Central African Rep	370	76	0.2
82	Benin	370	177	0.7
83	Nicaragua	340	207	-
84	India	320	145	0.8
85	Nigeria	280	14	0.1
86	Guinea-Bissau	240	263	-
87	Vietnam	200	334	0.4
88	Nepal	200	22	-
89	Madagascar	200	22	0.5
90	Burundi	160	32	0.3
91	Rwanda	80	12	0.5

Sources: UNESCO. *Statistical Yearbook* (1995)
UNESCO. *World Science Report* (1996)
World Bank. *World Development Report* (1996)

ses were performed, using per capita gross national product (PCGNP) in US dollars as the dependent variable, while (1) the number of scientists and engineers per million population (SE/MP) and (2) the gross expenditure on research and development as a percentage of gross national product (GERD/GNP), respectively, are treated as separate measures of the independent variable.

Since the two measures of the independent variable are highly correlated, no partial correlation or stepwise regression involving them was performed. Instead, a separate regression analysis was run for each measure of the independent variable with the dependent variable.

Time-series data from Japan, South Korea and Taiwan were taken from the *Historical Statistics of Japan* (1987), the *Japan Statistical Yearbooks* (1979-1996), the *Korea Statistical Yearbooks* (1962-1996), and the *China Statistical Yearbooks* (1970-1995), respectively.

A. Scientists and Engineers and Per Capita Income

In the performance of regression analyses, two models were initially used. In the first model, a constant or intercept was required to represent the contributions of other factors to the prediction of the dependent variable. However, in all the regression analyses performed on the worldwide data, the model with a constant or intercept invariably explained a smaller percentage of the variance in the dependent variable as compared with the second model which forced the regression line to pass through the point of origin (zero), thereby removing the constant or intercept. In view of this observation, the second model, without a constant or intercept, and which produced a better prediction of the dependent variable, was used as the basis of the report in this study.

The regression analysis of the data on all ninety-one (91) nations shows that for every increase in one (1) unit value in the number of scientists and engineers per million population, a corresponding increase of $4.56 occurs in the per capita GNP of the nations. Furthermore, the values of the independent variable (number of R & D scientists and engineers per million population) explain 49 percent of the variance in the dependent variable (per capita income in US dollars), which suggests a fairly good prediction of the latter by the former. Moreover, the finding is deemed very significant at the .00001 level, which means that there is only one chance in one hundred thousand that the configuration observed in the data would occur if in fact the two variables are unrelated.

While the results suggest that the relationship between the two variables are indeed strong and positive, a re-examination of some countries is in order. Sixteen former and present Communist countries, namely Slovenia, Hungary, Czechoslovakia, Russia, Croatia, Poland, Latvia, Belarus, Ukraine, Lithuania, Romania, Bulgaria, Uzbekistan, Macedonia, China and Vietnam, were not expected to use their scientists or engineers primarily to earn income. Furthermore, oil producing countries, like Brunei, Kuwait and Qatar did not need scientists or engineers to pump their oil. Moreover, Switzerland is a small country, which is blessed with a strong focus on few but interrelated high technology, export-oriented, high value-added products, a highly disciplined citizenry and officialdom, and rich financial centers, all special characteristics that make the country perform more efficiently and earn more income compared with the other nations. Finally, Israel is a small country faced with war against all its neighbors and therefore it cannot expect to effectively receive the full economic benefits of its scientists and engineers. Because the above twenty-one (21) nations are believed to have special characteristics that interfere with the usual relationship between science and technology capability and economic success, they have been removed from a subsequent analysis.

With only seventy (70) countries representing all continents of the world, the results of the regression analysis show that every increase in one (1) unit value in the number of scientists and engineers per million population (SE/MP) corresponds to an increase of $8.44 in per capita gross national product or income. The accuracy of the prediction is extremely high, measured by the 91 percent of the variance in the dependent variable explained by the independent variable. Moreover, the significance level (P=.00001) suggests that the chance that such a finding in the data would occur if in fact there was no relationship between the two variables is one out of one hundred thousand. An examination of the strong relationship between the two variables is provided by scattergram (Figure 1).

B. R & D Expenditure and Per Capita Income

The regression analysis on the data from seventy-nine (79) nations (twelve nations with missing values were excluded) shows that for every increase of one (1) percent of gross national product spent on research and development (GERD/GNP), there occurs a corresponding increase of $9,136.85 in per capita gross national product or income of the nations. Furthermore, the accuracy of the prediction is quite high, considering that 72% of the variance in PCGNP is explained by the values in GERD/GNP. Moreover, there is only one (1) chance in one hundred thousand (100,000) that the results as obtained would occur if in fact the variables were unrelated.

Considering that in the previous analysis of the relationship between per capita income and the number of R & D scientists and engineers per million people, twenty-one (21) nations were excluded because it was observed that there were factors other than the scientists and engineers which were influencing per capita income in these countries, it was also decided that the same countries

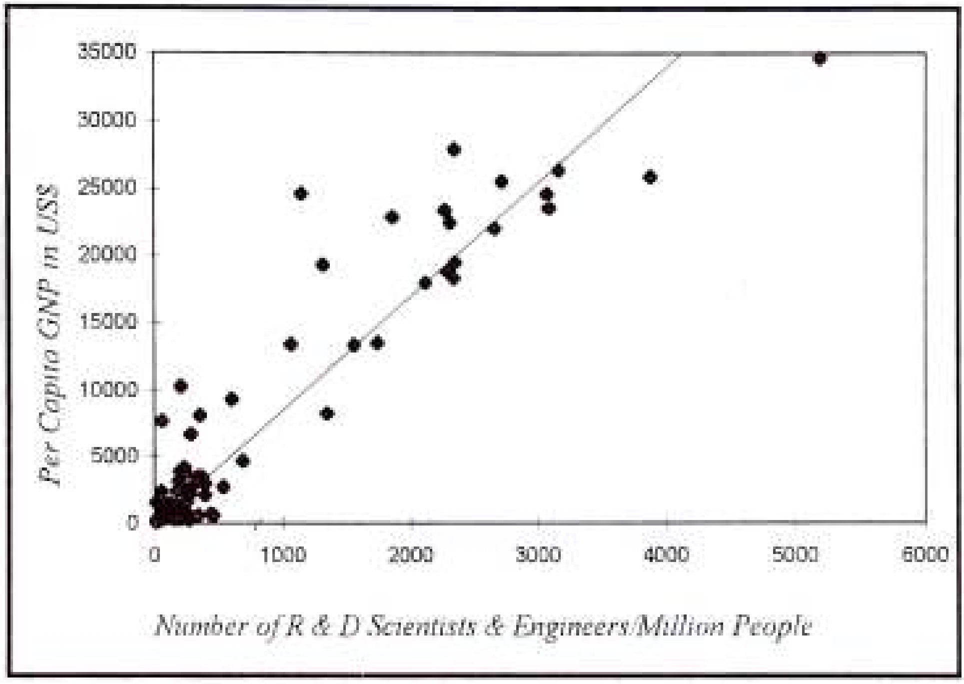

Figure 1. *Scattergram of PCGNP and SE/MP among 70 Countries of the World*

be removed from a subsequent analysis because any effect of R & D expenses on income can only come through the scientists and engineers who conduct R & D work.

With data from only sixty-three (63) countries the regression analysis reveals that for every increase of one (1) per cent of GNP spent on R&D activities, there occurs a corresponding increase in per capita GNP of $9,866.82 among the nations. Furthermore, the accuracy of the prediction in the.variance of per capita GNP (82 percent) by the values in GERD/GNP is very high. Finally, there is only one (1) chance in one hundred thousand (100,000) that the results obtained in the data would occur if in fact the variables were unrelated. An examination of the relationship between the two variables is provided by scattergram (Figure 2).

C. *Time-Series Data from Japan, South Korea and Taiwan*

(1) Japan

The time-series data from Japan cover the period 1953 to 1994 or 42 years. PCGNP was measured in yen (¥), not in US dollars. An examination of the data (Table 2) shows that PCGNP rapidly grew from ¥ 81,157 in 1953 to ¥3,831,640 in 1994 or over 46 times in 42 years. For the same period the number of R & D scientists and engineers per million population (SE/MP) increased from 437 in 1953 to 5,505 in 1994 or over 11 times, while the gross

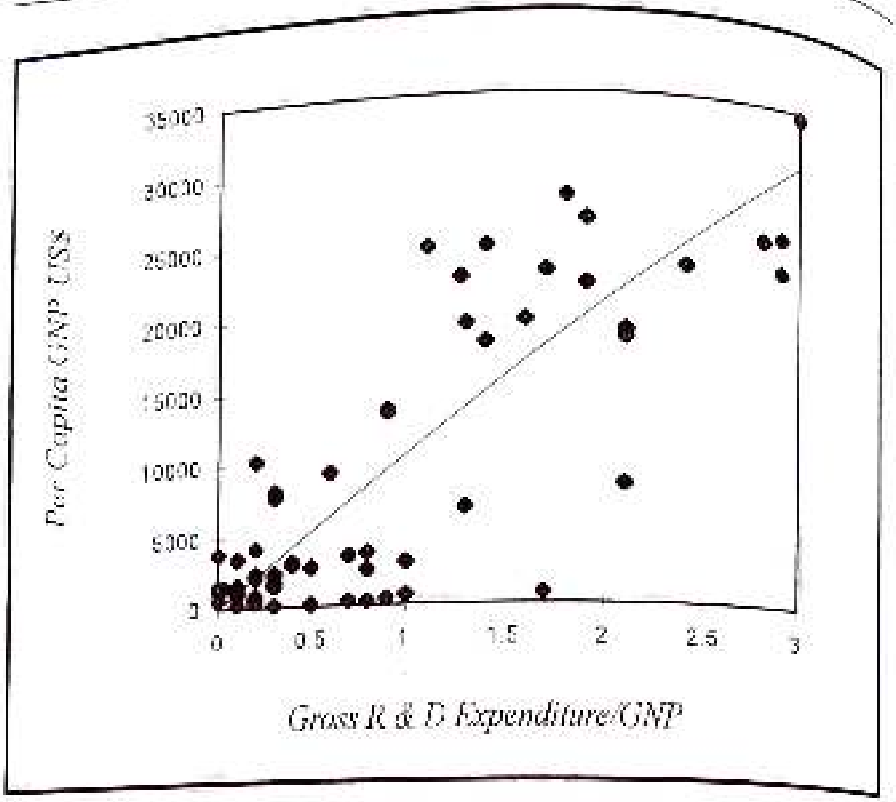

Figure 2. Scattergram of PCGNP and GERD/GNP among 63 Countries of the World

expenditure on research and development as percentage of GNP (GERD/GNP) increased from 0.45 in 1953 to 2.86 in 1994 or over 5.3 times.

For a twenty year period from 1954 to 1973, Japan's number of R & D scientists and engineers per million population (SE/MP) grew annually (year on year) at an average rate of 10.92%, while its expenditure on R & D as percentage of GNP increased an annual (year on year) average rate of 7.2% (Table 3). During the same period its GNP grew an annual (year on year) average rate of 14.85% and its per capita GNP increased by an annual (year on year) average rate of 13.57%.

Expectedly, when in the next twenty years (1974-1993) the average annual (year on year) increases in SE/MP fell to only 2.54% and that of GERD/GNP to only 3.19%, respectively, the annual (year on year) rate of growth of GNP also fell to only 7.51% and that of PCGNP to only 6.78%, respectively. It is thus very tempting to attribute the decline in the Japanese economy's annual rates of growth in the last twenty years to its unsustained level of increases in R & D commitment, while attributing its increasing GNP and PCGNP annual rates of growth during the early twenty-year period to its increasing annual increases in SE/MP and GERD/GNP.

Under regression analysis, SE/MP and GERD/GNP explain 90 percent and 88 percent in the variance of PCGNP, respectively, which results show that indeed the two measures of the independent variable predict almost accurately the

Table 2. Time-Series Data from Japan (1953-1994)

No.	Year	PCGNP (yen)	GERD/ GNP	SE/MP
1	1953	81157	0.45	437
2	1954	88724	0.52	571
3	1955	98851	0.53	674
4	1956	107852	0.53	731
5	1957	121874	0.54	781
6	1958	125531	0.65	898
7	1559	139529	0.73	946
8	1960	165776	1.10	1265
9	1961	202832	1.10	1345
10	1962	222767	1.30	1507
11	1963	254524	1.30	1720
12	1964	297561	1.27	1896
13	1965	325165	1.37	1984
14	1966	371779	1.36	2167
15	1967	434820	1.32	2299
16	1968	509217	1.36	2546
17	1969	581919	1.47	2527
18	1970	661720	1.51	2762
19	1971	753986	1.71	2957
20	1972	842560	1.89	2956
21	1973	1018249	1.61	3293
22	1974	1197088	1.67	3367
23	1975	1301179	1.86	3540
24	1976	1453886	1.81	3577
25	1977	1625175	1.79	3105
26	1978	1775111	1.79	3052
27	1979	1909815	1.62	3126
28	1980	2051066	1.89	3307
29	1981	2178631	2.04	3438
30	1982	2272291	2.22	3538
31	1983	2348242	2.33	3651
32	1984	2483482	2.40	3880
33	1985	2646997	2.46	3966
34	1986	2750352	2.66	4254
35	1987	2850335	2.64	4286
36	1988	3026145	2.65	4487
37	1989	3215885	2.69	4650
38	1990	3434488	2.78	4874
39	1991	3628332	2.90	5029
40	1992	3721535	2.97	5153
41	1993	3734947	2.96	5343
42	1994	3831640	2.85	5505

Sources: Historical Statistics of Japan, 1987
Japan Statistical Yearbooks, 1979-1996

Table 3. Japan's Average Annual Growth Rates Per 20 Year Periods

20-Year Period	GNP	PCGNP	GERD/ GNP	SE/MP
1954-73	14.85%	13.57%	7.50%	10.92%
1974-93	7.51%	6.78%	3.19%	2.54%
Simple arithmetic average of the annual (year on year) rates of growth for each 20-year period.				

variance in the dependent variable. Furthermore, both statistical results are significant at the .00001 level which suggests that there is only one chance in 100,000 that the same would occur if in reality the variables are not related.

When a time lag of five years was used on the time-series data from Japan between SE/MP (with 437 in 1953 as case #1 and so on) and that of PCGNP (with ¥139,529 in 1959 or five years after 1953 as case #1), in conformity with the five-year time lag used on the world-wide data, the percentage of the variance in PCGNP explained by the values of SE/MP increased to 93.

The improved result in the prediction of PCGNP with the five-year time lag confirms the notion that indeed the employment of an increasing number of R & D scientists and engineers preceded the occurence of increasing levels of PCGNP. On the other hand, the almost equally high percentage of variance in PCGNP (90%) explained by SE/MP when no time lag was used suggests that there is a dynamic positive interaction between the dependent and the independent variables, whereby the increasing number of R & D scientists and engineers were not only creating greater amounts of per capita GNP but that the increasing levels of PCGNP were also providing more resources for the training and employment of bigger numbers of R & D scientists and engineers and so on.

A positive dynamic interaction of the variables is confirmed by the presence of autocorrelation as shown by the Durbin-Watson test. In order to assess the full extent of autocorrelation, the time-series data from Japan were predicted using a model that incorporated the fullest extent of autocorrelation possible and using the Yule-Walker estimates, the same model could predict over 99% of the variance in the dependent variable. The same Yule-Walker estimates showed that at least 61% of the variance in the dependent variable is not attributable to autocorrelation. A visual examination of the time series data is provided in Figure 3.

(2) South Korea

The time-series data from South Korea cover the period 1972 to 1994 of

23 years. An examination of the data (Table 4) shows that per capita GNP in US dollars grew steadily from $304 in 1972 to $8,508 in 1994, which is predicted with great accuracy by the growing number of R & D scientists and engineers per million population from 167 in 1972 to 2,586 in 1994. More than 97 percent of the variance in PCGNP is predicted by the values in SE/MP for the 23-year period. The level of significance is at .00001, which means that there is only one chance in 100,000 that the configuration in the data would occur if the two variables were in reality unrelated. Under the Yule - Walker Estimates, when the full amount of autocorrelation of the variables is assessed, over 99% of the variance in the dependent variable is predicted by the values of the independent variable. Yet, at least 91% of the same variance is not attributable to autocorrelation. A visual examination of the relationship between the variables is provided in Figure 4.

With respect to the regression analysis of PCGNP on GERD/GDP on the time-series data from South Korea, it was found that GERD/GNP explains 92 percent of the variance in PCGNP, a result which is significant at the .00001 level.

(3) Taiwan

The time-series data from Taiwan cover the period 1979 to 1992 or 14 years. An examination of the data (Table 5) shows that PCGNP progressed

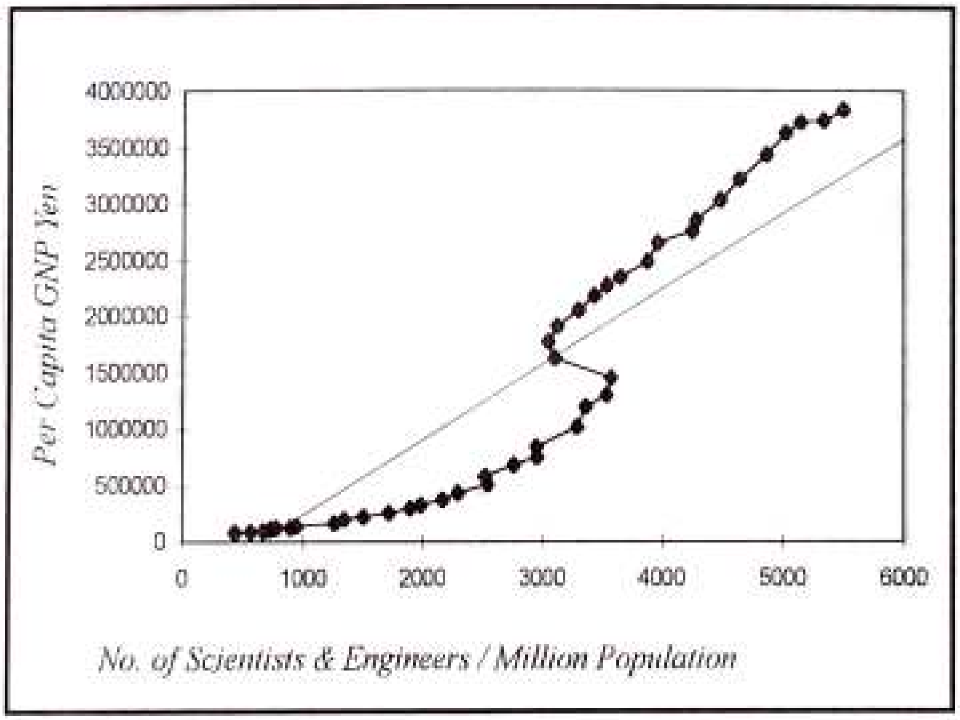

Figure 3. Plot of Time-Series data from Japan (1953-1994)

Table 4. Time-Series Data from South Korea (1972-1994)

No.	Year	PCGNP (US$)	SE/MP	GERD/GDP
1	1972	304	167	0.29
2	1973	375	177	0.29
3	1974	501	219	0.31
4	1975	573	292	0.43
5	1976	765	325	0.46
6	1977	965	350	0.63
7	1978	1,279	399	0.66
8	1979	1,624	418	0.59
9	1980	1,605	483	0.57
10	1981	1,735	535	0.64
11	1982	1,800	723	0.88
12	1983	1,884	804	1.01
13	1984	1,999	918	1.19
14	1985	2,277	1,016	1.48
15	1986	2,564	1,141	1.68
16	1987	3,147	1,268	1.77
17	1988	4,124	1,346	1.87
18	1989	4,962	1,561	1.9
19	1990	5,883	1,647	1.88
20	1991	6,757	1,765	1.94
21	1992	7,007	2,035	2.09
22	1993	7,513	2,244	2.32
23	1994	8,508	2,586	2.61

Sources: *Korea Statistical Yearbooks (1962-1996)*

Note: Due to different base years used, some data vary from one edition to another

as SE/MP increased. The regression analysis shows that SE/MP explains 96 percent, while GERD/GDP explains 94 percent, respectively, in the variance of PCGNP, both results being significant at the .00001, which means that in both cases there is only one chance in 100,000 that such result would be obtained if in reality the two variables were unrelated. Under the Yule-Walker estimates, when the full extent of autocorrelation is accounted for, over 97% of the variance in PCGNP is predicted by the values in SE/MP. Yet, at least 93% of the same variance is not due to autocorrelation. A visual examination of the relationship between the variables is provided in Figure 5.

It must be stated at this point that science and technology capability (STC) building and a heavy emphasis on research and development (R & D) work are both essential elements of the national strategies for industrialization and economic development adopted by Japan and the four Asian "NIC's", especially South Korea and Taiwan.

Particularly for Japan, the learning of Western science and technology started in earnest since the Meiji restoration in 1867. Realizing after its defeat in World War II that it had not yet attained technological parity with the West, especially the USA, Japan accelerated its catch-up game so that it eventually overtook the USA first in consumer electronics, then in the automobile industry and ultimately in all other areas of technology, except in space research, super-computers and heavy weaponry.

The Japanese experience in economic growth that emphasized both consumer products and heavy industries for both the domestic and the export markets served a good model for the four Asian "NIC's," which for lack of adequate domestic markets primarily targetted the export market. This is very true in the case of South Korea which greatly emphasized the role of science and technology (S&T) and research and development (R&D) in all its 5-year economic development plans since 1962.

Conclusions

Under statistical inference, there are three conditions which must be satisfied before one can establish causality between two variables, namely: (1)

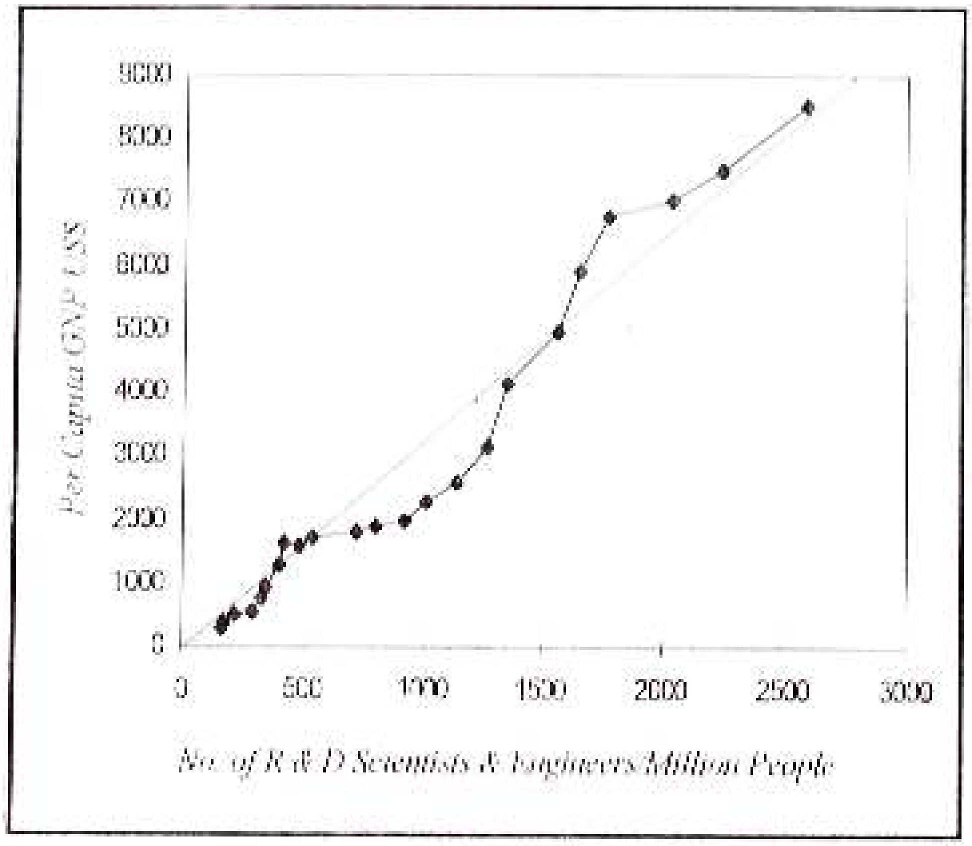

Figure 4. Plot of Time Series Data from South Korea (1972-1994)

Table 8. *Time Series Data from Taiwan (1979-1992)*

No.	Year	PCGNP (US$)	SE/MP	GERD/GDP
1	1979	1,758	498	-
2	1980	2,155	767	0.71
3	1981	2,443	863	0.93
4	1982	2,419	999	0.89
5	1983	2,573	993	0.91
6	1984	2,890	1,176	0.95
7	1985	2,992	1,261	1.01
8	1986	3,846	1,430	0.96
9	1987	4,825	1,575	1.12
10	1988	5,798	1,780	1.22
11	1989	6,889	1,977	1.38
12	1990	7,284	2,269	1.65
13	1991	8,050	2,252	1.7
14	1992	10,455	2,336	1.78

Sources: *China Statistical Yearbooks (1980 - 1995)*

Note: Due to different base years used, some data vary from one edition to another.

that the two variables must be strongly related, (2) that the independent variable must precede the dependent variable, and (3) that the joint association between the two variables must not be due to other causes.

In the present study, it was first established that the association of the two variables is indeed very strong, with the independent variable predicting higher than 90 percent of the variance in the dependent variable. Second, the measures of the independent variable were taken an average of five (5) years before the measurement of the dependent variable so that the former definitely preceded the latter. Third, the results of the time series data from Japan, South Korea and Taiwan removed any doubts that the relationship between the variables are due to other causes.

On the basis of the results of this study, the following conclusions have been made:

(1) The number of R & D scientists and engineers per million population (SE/MP) and the gross expenditure on research and development as a percentage of the gross national product (GERD/GNP) both provide a very accurate prediction of the per capita gross national product (PCGNP) among nations and therefore the findings in this study provide a very strong support for the hypothesis that indeed economic success (ES) is a function of science and technology capability

(STC).

Furthermore, the time-series data from Japan, South Korea and Taiwan provide evidence that there is a strong positive dynamic interaction between the dependent and the independent variables whereby a nation can increase its PCGNP by employing great numbers of scientists and engineers to do R & D work and then it can use its increasing PCGNP to train and employ even greater numbers of R & D scientists and engineers to produce more PCGNP and so on.

(2) The findings of the present study are consistent with the earlier conclusions of Robert M. Solow (1957) and Edward Denison (1974) that, more than the billions of dollars in capital investment, it was technical progress which accounted for very big portions in the growth of economic output in the USA for two separate periods. The advantage of the new findings is that they can provide guidelines on how a country may develop a capability to attain industrialization and economic growth.

(3) The present findings, along with the conclusions of Solow and Denison, bolstered the notion derived from the experiences of the industrial revolution in Europe and that of the USA, Japan and the four Asian "NIC's" that the adoption of modern technology is the most important factor in industrialization and economic development.

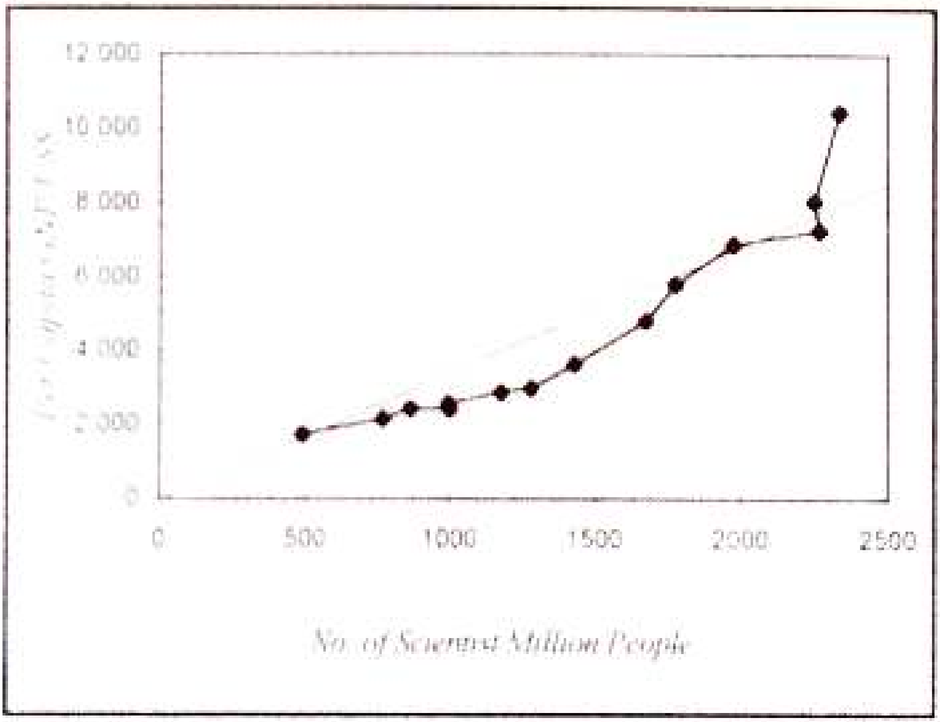

Figure 5. Plot of Time-Series Data from Taiwan (1979-1992)

Table 6. Tertiary Education Across Selected Pacific Rim Countries

Country	No. of Students at Tertiary Level	No. of Tertiary Students as % of Population	No. of Post-Baccalaureate Students	Post-Baccalaureate as % of Tertiary Students	No. of Post-Baccalaureate Science & Engineering Students	Post-Baccalaureate Science & Engineering as % of Post-Baccalaureate Students
China (1991)	2,124,121	0.17	80,459	3.79	59,748	74.26
Japan (1989)	2,683,035	2.13	85,263	3.18	54,167	63.53
South Korea (1991)	1,723,886	3.83	92,599	5.37	28,479	30.76
Australia (1991)	534,538	2.92	92,903	17.38	26,876	28.93
Singapore (1983)	35,192	1.13	1,869	5.31	532	28.46
Malaysia (1990)	121,412	0.58	4,981	4.1	1,251	25.12
Thailand (1989)	765,395	1.24	21,044	2.75	4,978	23.47
New Zealand (1991)	136,332	3.78	13,792	10.12	2,863	20.76
Philippines (1991)	1,656,815	2.39	63,794	3.85	5,520	8.65

Source: ***UNESCO World Science Report*** (1996)

(4) The findings in the present study, particularly the regression line, can explain the "cycles of booms and busts" that characterized Philippine economic history over the last 50 years as well as the recent economic difficulty faced by Thailand. Furthermore, it may be used to predict the future success or failure of the economy of any country in industrialization and economic growth.

Examining the regression line, it is evident that no country, unaided by special characteristics such as those found in either Singapore, Switzerland or Brunei, will be able to sustain earning incomes higher than the combined values of goods and services its R & D scientists and engineers can design, invent or create.

Anytime therefore that a country's economic output approaches or exceeds the regression line, as a result of a booming economy, its money supply available for investment also increases. Since the banks need to earn interest income, the bankers will therefore lend this money to whoever comes with adequate collateral requirements. If the money is not invested in the production of high-value-added goods and services, in the absence of R & D scientists and engineers to design them, the same money will be invested in some sector of the economy even if it means economic disaster for the country.

In the case of the Philippine "economic booms" in the past, the money mostly financed the importation of consumer goods, aided by an increasing disposable income among the people, but resulting in huge trade deficits, severe devaluation of the peso, high interest rates and economic chaos for the country. In the case of Thailand, lately, its lack of R & D scientists and engineers prevented it from shifting its production to high-technology, high-value-added products, making its property sector absorb a disproportionate share of the money available, leading to its collapse and that of the financial sector that supported it.

(5) The findings on the extremely low number of R & D scientists and engineers per million population in the Philippines at only 90 in 1985 (155 in 1997) explain the anomaly cited by studies in the 1970's that higher educational attainment among Filipinos did not contribute to the economic growth of the nation.

It is evident (from Table 6) that the proportion of the Philippine population enrolled in tertiary education (2.39%) is greater than those of either China (0.17%) or Japan (2.13%). Furthermore, the number of Filipino students enrolled in graduate education as a proportion of the total national tertiary enrollment (3.85%) is definitely higher than those of either China (3.79%) or Japan (3.18%). However, in the critical disciplines that contribute to industrialization and economic development, the Philippines clearly lagged behind with only 8.65% of its graduate students enrolled in science and engineering, the lowest in the Pacific rim, as against those of China (74.26%) and Japan (63.3%), respectively. The extremely low proportion of graduate enrollment in science and engineering led to the very low number of scientists and engineers for the Philippines, which explains further its inability to rapidly industrialize and grow economically.

Furthermore, there are two disturbing features of the Philippine educational system which cast doubt on its competitiveness. First, basic education in the Philippines consists of only ten (10) years from grades 1 to 6 in the elementary level and from first year to fourth year in the secondary level, respectively. In contrast, other countries have between 12 and 13 years of basic education.

Second, there is a markedly poor performance of pupils and students in the Philippines in science and mathematics subjects as indicated by the Third International Mathematics and Science Study (TIMSS), which saw Philippine students occupy the 37th and the 38th places, respectively, among 39 countries in mathematics and science. Moreover, less than one half of all tertiary teachers in the country have graduate degrees, while only a small percentage of mathematics and science teachers in basic education have majors in the subjects they teach.

(6) It must be stated at this point that the accuracy of the prediction of the variance in per capita income (91%) explained by the values of the number of scientists and engineers per million population justifies the use of the beta weight in the regression equation in the calculation of returns on investments on the training of scientists and engineers for the conduct of R & D work. Under the equation, PCGNP = 8.44 SE/MP, we learn that every scientist or engineer trained and working for R & D provides his nation $8.44 million in added annual GNP or income. Thus, if a student finishes secondary school at age 17, completes college after 5 years at age 22, begins work at age 23 and retires at age 65, for a total expected working life of 42 years, he is expected to make a total lifetime contribution of $354.48 million. At the current exchange rate of P28.50=US$1.00, that means P10,102,680,000.00.

Assuming that a science or engineering student in the Philippines spends P100,000.00 a year for tuition, board, lodging, books and other expenses, the total investment for five years is only half a million pesos. This amount is practically negligible compared with the expected benefit of P10,102,680,000.00 during his lifetime. The return on investment (ROI) is, therefore, some 2,020,436 percent. This is real big business for the country.

Even if the Philippines decides to send students to the best universities overseas, as the four Asian "NIC's" did in the past, and which Malaysia, Indonesia and Thailand are currently doing, and spends an average of one (1) million pesos for every student a year, a five (5) million peso investment for a five-year period with an expected return of P10,102,680,000 still means an ROI of about 201,953.6 percent.

(7) The most important implication of the findings in the present study is that it provides a formula for any country to follow in its program of industrialization

and economic development, something which no previous study has done. This formula is found in the regression equations whereby per capita income is predicted by the number of R & D scientists and engineers per million population and by the percentage of GNP spent on research and development. Given the formula, all that a nation's leaders need is to decide how rich they want their nation to be and by producing the needed number of R & D scientists and engineers and spending the required amount for R & D, their country will achieve their desired level of development without failure.

(8) Futurists like John Naisbitt, Paul Kennedy, Alvin Toffler, and others have predicted that the nations of the Asian side of the Pacific rim will dominate the 21st century. Their advantage lies in their superior human resource development. Indeed, China, Japan, the four Asian "NIC's", and the new emerging Asian "tiger economies", particularly Malaysia, Thailand and Indonesia are trying very hard to upgrade their human resource capability by training more scientists and engineers.

Japan, with a per capita GNP in February 1997 of $36,315 that is more than one-third higher than that of the USA ($26,620), money reserves ($215.9 billion) which is almost four times that of the USA ($57.1 billion), in- spite of a population (125.8 million) which is less than half that of the USA (266.3 million), and an average human life expectancy which is the highest in the world (80 years), is arguably the richest nation in the world now. It has attained its present position by virtue of having the highest S & T capability in the world in terms of the biggest number of R & D scientists and engineers per million population and the highest proportion of gross national product devoted to R & D activities.

However, South Korea may become the richest and most industrialized nation in the world sometime in the 21st century. This is evident in its plan to train at least 6,000 scientists and engineers per million population (against Japan's 5,505 in 1994) and to spend at least 5 percent of its GDP (against only 3 percent for Japan in 1991) for R & D activities.

But Malaysia's "Vision 2020" may really beat South Korea by the year 2020 so that before the latter can celebrate its victory as the world's richest and most industrialized country, Malaysia will be the one celebrating its own victory. To ensure its success, Malaysia has invested heavily in its educational system providing it with facilities and equipment which are the envy of ordinary American universities. Also, its ambitious mega-projects, particularly its Multi-Media Super-Corridor, are aimed at bolstering its objective for eventual world technological supremacy.

Singapore, the nation with the third highest per capita GDP in the world (at over $30,500 in July 1997, which is behind only that of Japan and Switzerland) seeks to make its National University to be the equal of Harvard University, and has launched an ambitious master-plan to wire the whole country with fiber optics and become the first "intelligent nation-state" in the world. Although a small state, Singapore cannot be ignored as a technological competitor. One of the paradoxes of the 21st century is that smaller entities will be more competitive than bigger ones.

But the most spectacular prospect of all in ultimate global competition is China, with the world's largest population and therefore its largest market. In the last 15 years, its economy has been growing annually at an average of between 10 and 15 percent without overheating. But more significant than its size is its totally focused advance education with over 74 percent of its graduate students going to science and engineering. As the nation earns more wealth, if the same proportion of its expanding enrollment goes to science and engineering, we foresee in the future the largest assembly of R & D scientists and engineers any nation in the history of mankind shall ever gather. This will certainly tip the balance in its favor in global competition.

Recommendations

In view of the foregoing findings, the Philippines must strengthen its science and technology capability in the shortest possible time if it wants to join the ranks of the industrialized and developed nations of the world in the 21st century. By concentrating national effort on inviting foreign investors to bring their money to the country, without providing the required science and technology capability, our national leaders only invite the early occurrence of an economic disaster similar to what Thailand just suffered from, thereby recalling the familiar "bust" that punctuated all past "booms" in Philippine economic history.

Thus there is a need to decide how many R & D scientists and engineers the Philippines should train and employ and how much R & D expenditure it should make every year. The UNESCO norm of 380 R & D personnel per million population, which the Department of Science and Technology (DOST) has adopted, included a technician component which is not considered in this study. The R & D scientists and engineers component of that norm is only 304 per million population. Using the regression beta weight of 8.44, this norm will give the Philippines an expected per capita income of only $2,565.76, which is almost twenty times lower than what South Korea expects to have ($50,340) when it reaches its goal of having 6,000 scientists and engineers per million population.

Likewise, the goal of the Revised Medium-Term Philippine Development Plan (MTPDP) launched by the National Economic Development Authority (NEDA) of a per capita GNP of $2,000 for the country in the year 2004 is more than 25 times lower than the goal of South Korea. We think the Filipino people deserve better.

Considering the competition provided by our neighboring countries, it is to the Philippines' best national interest to take up their challenge seriously. The Philippines should not settle for anything less than the goals of its neighbors. Hence, it is suggested that the Philippines should gradually but eventually produce and employ 6,000 R & D scientists and engineers per million population and also ultimately spend at least 5% of its GDP on R & D activities over the next 25 years. This will match the goals of South Korea and bring the Philippines at the top of the world.

In order to achieve these goals, it is recommended that within the next five years, a massive re-focusing of the Philippine eduational system be made so that:

(a) At least 75 percent of all enrollees and graduates in all tertiary and graduate institutions in the country shall be in science and engineering;

(b) At least 75 percent of all high schools in the country shall be converted to science and technology high schools;

(c) The number of subjects in the elementary and primary schools must be limited to about five (5) or six (6), which shall be concentrated on the teaching of basic skills, namely, reading, writing, arithmetic, right conduct and science; and

(d) In civics and social studies courses both in elementary and secondary schools, relevant portions of the biographies of national and international heroes, scientists and inventors and successful entrepreneurs should be taught in order to provide healthy role models to the youth.

Furthermore, there is a need to upgrade the quality of education in the Philippines at all levels of the educational ladder. More professional science, mathematics and engineering teachers should be trained at the elementary, the secondary, the tertiary, and the graduates levels, respectively. The country should seek steps to improve its performance in future science and mathematics international tests and aim to land within the top five to ten places. Also, a decision must be made to add one year each in both the elementary and the secondary levels, respectively, or one year at the collegiate level to make its graduates globally competitive.

Moreover, the Philippine government should immediately implement a policy to encourage Philippine-based companies to invest heavily in research and development (R & D) capability building by hiring more scientists and engineers and by spending more money on R&D activities in order to improve their international competitiveness. Finally, there must be a joint national effort by government, industry and academe to promote research and development (R & D) activities as a national strategy to industrialize and attain economic growth and development.

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