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RELATIONSHIP BETWEEN GROWTH IN GROSS DOMESTIC PRODUCT (GDP) AND GROWTH IN THE CHEMICAL ENGINEERING LITERATURE IN FIVE DIFFERENT COUNTRIES

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Data were compiled and linearly correlated on the growth in the gross domestic product (GDP) with the academic chemical engineering literature over a recent 26-year period for five different English-speaking countries, namely, the United States, Canada, Great Britain, India and Australia. The publication figures were also scaled to the total number of chemical engineering schools in the country; furthermore, all of these data were normalized from zero to unity, using the figures for the most recent year (1996) as the denominators, and then correlated against each other in linear fashion. Resulting confidence levels were in excess of 99% for each of the individual five countries, as well as for the entire set of normalized data for all of the countries.

Introduction

The gross domestic product (GDP) of a country is typically accepted as the general benchmark for that country's economic health and vitality. Furthermore, data are readily available on these indicators for most countries over a significant period of time. On the other hand, there are innumerable measures of a country's scientific and research's activities. Such data might include monies spent on basic research, educational budget summaries, number of people engaged in scientific and/or technological pursuits, etc. In this work, we chose to use the number of research articles published by the chemical engineering academic community in a country as a general measure of scientific activity. The growth in this latter activity is then correlated with the growth in that country's gross domestic product in an effort to elucidate a relationship between these two quantities.

The usage of publication figures to gauge the quality and efficacy of scientific research activities is, rightly or wrongly, a long established practice. Furthermore, the requisite data in this area are readily available in such compendia as *Science Citation*

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Index (SCI),[1] specifically the Corporate Index thereof, wherein the annual number of publications issuing from a given geographic entity (e.g., country, state, university, department, etc) can be identified.

The concept of ranking the research quality of academic programs by journal publications is certainly not a novel one either. This technique, including some elaborate variations thereof, has been employed in the management or business area for many years, and wherein an extensive literature[2,3] devoted to this ranking subject already exists. Another recent example, specifically of annually ranking the practical content of research programs, occurs in the operations research/management science[4] area. More germane to the present work, however, various rankings of the academic research programs of chemical engineering departments based upon literature publications cited in SCI have also been constructed. These results, covering various countries such as the United States,[5,6] Canada[7] and Great Britain[8] have appeared elsewhere, and some of the data therefrom are used in this work. Specifically, the annual total number of chemical engineering publications originating from the universities of a country are obtained in these ranking studies. These ranking results, at least for the United States, are in generally good agreement with the results from other published rankings,[9,10] including ones from the popular press.[11]

Another study,[12] again using the SCI, was made of the citation frequency of papers published by University of Kentucky chemical engineering faculty members over the time period of 1977–1988. Analysis of the SCI data here included the time distribution of the citations to faculty publications, in an effort to identify "high-impact" papers. As a side result from this latter study, *Johnson* and *Hamrin*[12] report an SCI capture rate of 76.3% of papers published by University of Kentucky chemical engineering professors during this period. In general, capture rates, i.e., the percentage of papers actually published that are then reported in the SCI, of 75–80% are quite common in work of this nature.

The chemical industry is admittedly a small but important sector of the economy of developed nations. Also, the field of chemical engineering, perhaps because of its small but well defined arena of technical endeavor, is often used in the performance of scientometric and science policy studies. Thus, a recent study[13] tried to identify the extent to which various factors influence the number of citations received by articles published in chemical engineering research. In related work, *Peters* and *van Raan*[14,15] have constructed a series of cluster maps in an attempt to monitor and identify significant research developments in this field.

The development of relationships between economic indicators and research activities is a common activity in the field of scientometrics. Thus, by way of recent example, *Rousseau* and *Rousseau*[16] describe a tool known as data envelopment analysis (DEA) for constructing such relationships to identify the research and development efficiency of countries. In this work, inputs to their model include gross domestic product among other quantities, while publications and patents comprise the outputs.

Data collection

As indicated above, most of the data on literature publications in the chemical engineering field were obtained from earlier studies,[5–8] related to the ranking of academic research programs. It remained then to merely collect data on gross domestic products for the five English-speaking countries considered in this work. Ten different years of data, covering a total span of 26 years, were assembled for each of these countries. These ten years were *1970*, *1980*, *1985*, *1990* and the six individual years from 1991 to 1996, inclusively.

Table 1
Growth in the academic chemical engineering literature and gross domestic product of the United States.
No. of chemical engineering schools = 147

5-Year period ending	Number of publications			Gross domestic product (GDP), billions of US $
	5-Year totals	1-Year average	Per school per year	
1970	2048	409.6	2.79	3643
1980	6564	1312.8	8.93	4959
1985	9808	1961.6	13.34	5730
1990	14563	2912.6	19.81	6600
1991	15075	3015.0	20.51	6536
1992	15636	3127.2	21.27	6714
1993	15994	3198.8	21.76	6864
1994	16749	3349.8	22.79	7101
1995	17213	3442.6	23.42	7248
1996	18237	3647.4	24.81	7545

Table 1 shows the raw data for the United States used in this study. In the case of the academic literature publications, the data were averaged over a 5-year period to get an annual publication figure, as was also done in the ranking studies referenced earlier. It has been found that these averaged data are much less volatile than individual annual publication figures. This averaging procedure is somewhat like reset or integral action employed in the field of automatic control. Thus, for example, the figure of 3647 publications shown for the year 1996 in Table 1 is actually the sum of the academic chemical engineering publications issuing from the 147 American chemical engineering schools considered (18 237) over the 5-year period from 1992 to 1996 inclusively, divided by the duration of this period, or five years. The gross domestic product (GDP) of the United States in each of the ten years examined in this study is shown in the last or rightmost column of Table 1.

Similar raw data for Canada, Great Britain, Australia and India (including the number of chemical engineering schools identified in each country) are presented in Tables 2, 3, 4 and 5, respectively. All GDP figures shown in these five tables are in units of US $. Also, in all of these tables, the annual publication figures for a given country were ratioed to the number of chemical engineering schools identified in that country. Thus, Tables 1 and 2 show that the 1996 average publication rates for both the United States and Canada are approximately identical at about 25 publications per school per year. Similarly, from a comparison of Tables 3 and 4, an average publication rate of around 15 papers per school per year is observed for Great Britain and Australia. The average publication rate of Indian chemical engineering schools is currently about 7 papers per school per year and increasing (see Table 5).

Table 2
Growth in the academic chemical engineering literature and gross domestic product of Canada. No. of chemical engineering schools = 20

5-Year period ending	Number of publications			Gross domestic product (GDP), billions of US $
	5-Year totals	1-Year average	Per school per year	
1970	394	78.8	3.94	308
1980	1210	242.0	12.10	482
1985	1404	280.8	14.04	556
1990	2042	408.4	20.42	642
1991	2141	428.2	21.41	631
1992	2232	446.4	22.32	636
1993	2295	459.0	22.95	650
1994	2402	480.4	24.02	680
1995	2501	500.2	25.01	694
1996	2559	511.8	25.59	715

Table 3
Growth in the academic chemical engineering literature and gross domestic product of Great Britain.
No. of chemical engineering schools = 25

5-Year period ending	Number of publications: 5-Year totals	1-Year average	Per school per year	Gross domestic product (GDP), billions of US $
1970	827	165.4	6.62	683
1980	1097	219.4	8.78	829
1985	1128	225.6	9.02	915
1990	1311	262.2	10.49	1070
1991	1340	268.0	10.72	1048
1992	1394	278.8	11.15	1043
1993	1477	295.4	11.82	1067
1994	1606	321.2	12.85	1108
1995	1829	365.8	14.63	1138
1996	2043	408.6	16.34	1144

Table 4
Growth in the academic chemical engineering literature and gross domestic product of Australia.
No. of chemical engineering schools = 11

5-Year period ending	Number of publications: 5-Year totals	1-Year average	Per school per year	Gross domestic product (GDP), billions of US $
1970	98	19.6	1.78	187
1980	295	59.0	5.36	260
1985	409	81.8	7.44	305
1990	560	112.0	10.18	359
1991	535	107.0	9.73	353
1992	554	110.8	10.07	360
1993	571	114.2	10.38	374
1994	620	124.0	11.27	393
1995	672	134.4	12.22	405
1996	751	150.2	13.65	411

Table 5
Growth in the academic chemical engineering literature and gross domestic product of India.
No. of chemical engineering schools = 27

5-Year period ending	Number of publications			Gross domestic product (GDP), billions of US $
	5-Year totals	1-Year average	Per school per year	
1970	399	79.8	2.96	478
1980	596	119.2	4.41	656
1985	643	128.6	4.76	852
1990	706	141.2	5.23	1148
1991	735	147.0	5.44	1162
1992	777	155.4	5.76	1215
1993	820	164.0	6.07	1257
1994	855	171.0	6.33	1335
1995	908	181.6	6.73	1409
1996	931	186.2	6.90	1479

Table 6
Slopes, intercepts and correlation coefficients for the linear equations correlating the relationship between gross domestic product (GDP) and the annual rate of academic chemical engineering publications in five English-speaking countries

Country	No. of data points (N)	Slope (a), 10^9 US $/ publication	Intercept (b), 10^9 US $	Linear correlation coefficient squared (r^2)
United States	10	1.1226	3332.7	0.988
Canada	10	0.8694	266.0	0.971
Great Britain	10	1.8466	485.6	0.782
Australia	10	1.8404	154.3	0.986
India	10	10.005	−375.6	0.947
All 5 countries (Both a and b are dimensionless)	50	0.6298	0.3677	0.718

Methodology and results

Cursory inspection of the publication and GDP figures of Tables 1 through 5 indicates a roughly linear growth in each of these two variables with time. For the purposes of this work, however, the time behavior was not specifically considered; the growth rate in the American chemical engineering literature was explored in an earlier study.[6] Rather, in this current research the focus was on the nature of the relationship between publication volume and GDP for the five countries of interest. Specifically, linear correlations between these two variables were developed for each country and the accuracy of these correlations was quantified.

The linear correlation for the United States is displayed in Fig. 1, wherein the ordinate is the GDP in billions of US $ and the abscissa is the 5-year average annual number of American academic chemical engineering publications reported in the SCI. Each data point thus corresponds to one of the year entries in Table 1 and, with the more or less linear increase in each of these two variables with time, the most recent data (e.g., 1996 data) appear in the upper right part of this graph, and the oldest data (1970) in the lower left corner. The dotted lines on each side of the solid correlation line in this figure denote the error limits at a 95% confidence level of the correlation.

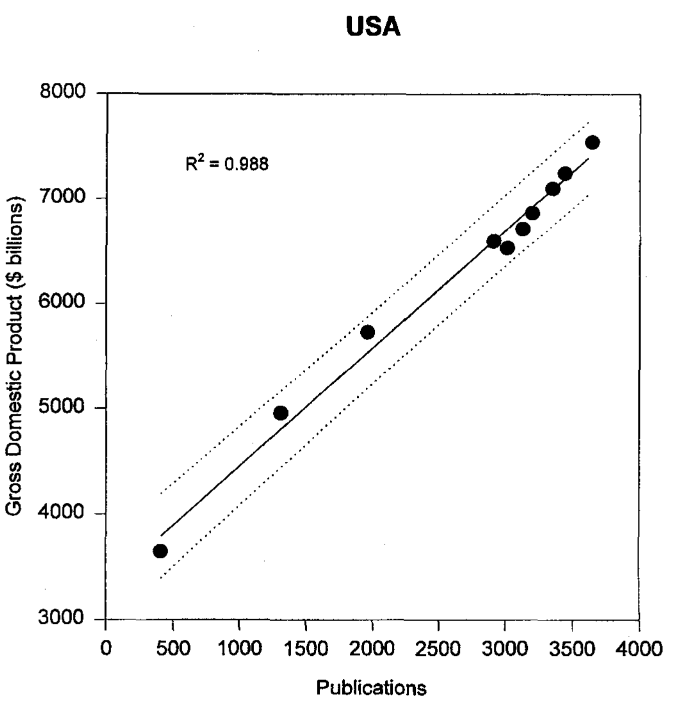

Fig. 1. Correlation between gross domestic product (GDP) and annual number of academic chemical engineering publications for the United States

The square of the linear correlation coefficient (r^2) for the straight-line relationship is, as indicated in Fig. 1, equal to 0.988. With ten data points or eight statistical degrees of freedom, the overall confidence level of this correlation is thus well in excess of 99%.[17]

Figures 2 through 5 then display similar results of the correlation of GDP with 5-year average annual number of academic chemical engineering publications for the other four countries included in this study – Canada, Great Britain, Australia and India, respectively. In all of these cases, excellent correlation between these two variables is observed; with the exception of Great Britain, the linear correlation coefficient squared is greater than 0.9, again demonstrating confidence levels well above 99%.

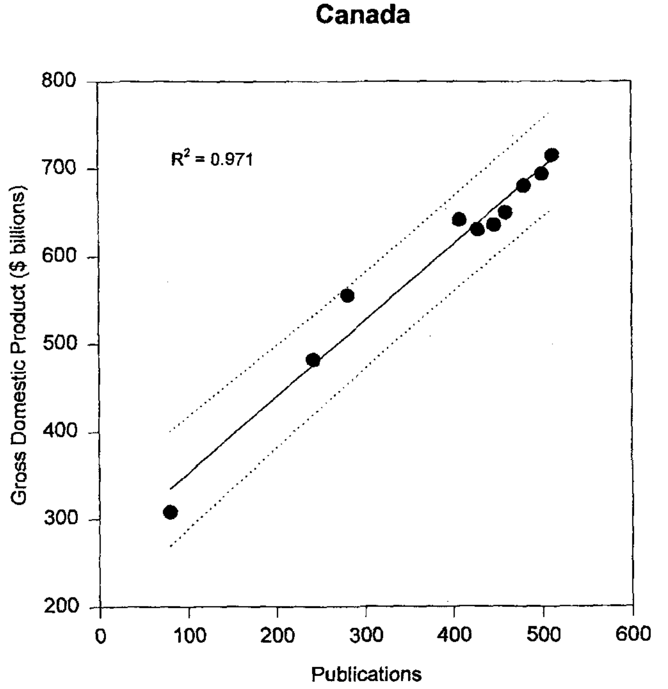

Fig. 2. Correlation between gross domestic product (GDP) and annual number of academic chemical engineering publications for Canada

This statistical measure (r^2) is only equal to 0.782 in the case of Great Britain, but which still corresponds to a confidence level better than 99%. Inspection of Table 3 and Fig. 3 quickly discloses the reason for this poorer correlation for Great Britain. That is, the average annual numbers of academic chemical engineering publications from this country experience a steep increase for the 5-year periods ending in 1995 and 1996, deviating sharply from the roughly linear annual growth rate for the preceding 25 years. Presumably, this rapid increase in publication rate for this country is directly related to recent policy changes in financial resource allocation to universities in that country, where specific resource allocation is tied to, among other things, the research productivity of a given university.

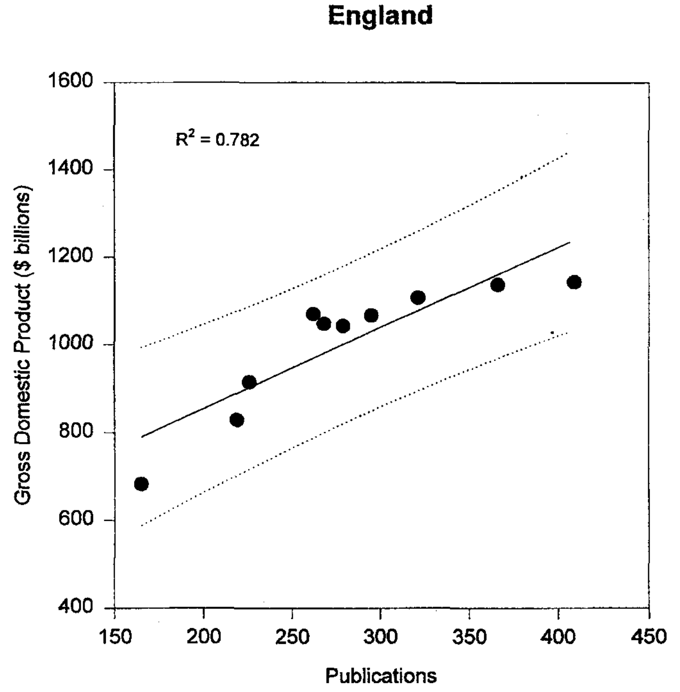

Fig. 3. Correlation between gross domestic product (GDP) and annual number of academic chemical engineering publications for Great Britain

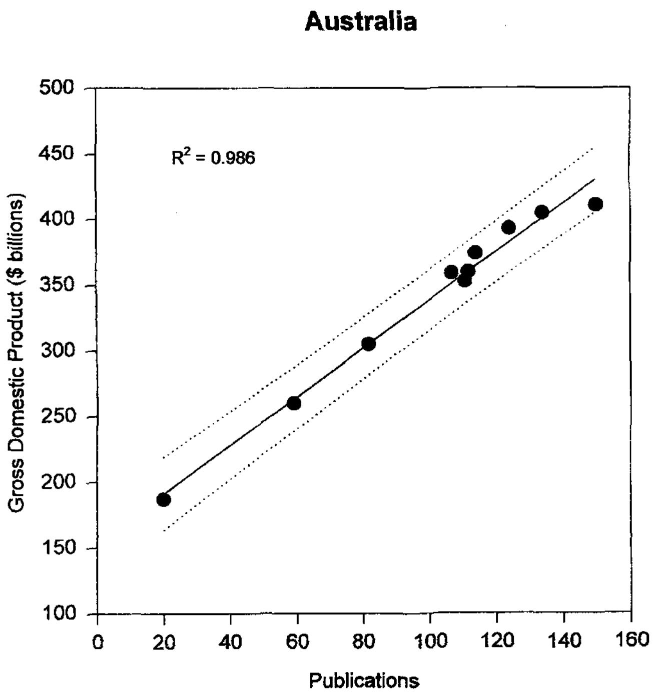

Fig. 4. Correlation between gross domestic product (GDP) and annual number of academic chemical engineering publications for Australia

Figure 6 shows a general correlation between GDP and 5-year average annual number of academic chemical engineering publications for all five English-speaking countries. For this purpose, both figures for an individual country in a given year were normalized to that country's values for the year 1996. Thus, both of these normalized quantities were equal to 1.0 for each country in 1996. This methodology allowed us to organize all of the GDP-publications data for the five countries on one graph. The square of the linear correlation coefficient for this general relationship is only equal to 0.718 but, with a total of 50 data points here, the confidence level demonstrated is still well above 99%. Thus, the conclusion of a strong positive relationship between gross domestic product and academic chemical engineering publication rate in each of these five countries can be generalized to include the entire English-speaking community of nations, and presumably would be valid for most other countries also.

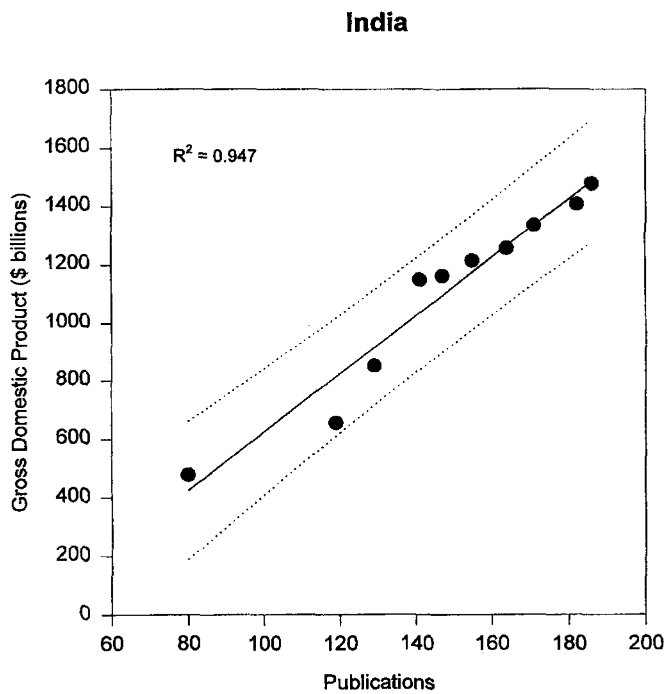

Fig. 5. Correlation between gross domestic product (GDP) and annual number of academic chemical engineering publications for India

Lastly, the specific parameters for each of the linear correlations developed are summarized in Table 6; these parameters include, in addition to the square of the linear correlation coefficient (r^2), the slope (a) and intercept (b) of the correlating line:

$$y = a\,x + b$$

for each of the five countries as well as the general normalized correlation of Fig. 6. Here, y is the ordinate variable, i.e., GDP in Figs 1–5 or normalized GDP in Fig. 6, while x represents the abscissa variable – number of publications in Figs 1–5 or normalized number of publications in Fig. 6.

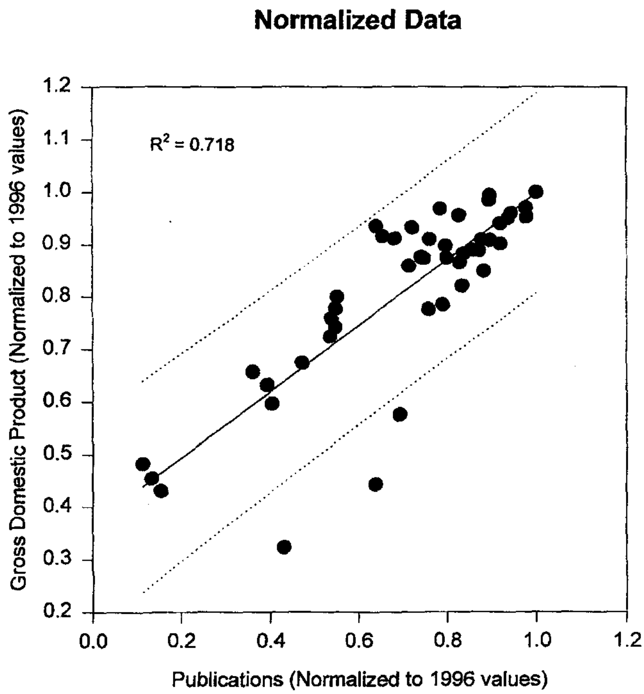

Fig. 6. Correlation between gross domestic product (GDP) and annual number of academic chemical engineering publications for all five English-speaking countries. All data were normalized to the 1996 figures for a given country

Conclusions

In this work, we have collected data on the annual gross domestic products (GDP) and 5-year average annual number of academic chemical engineering publications for five different English-speaking countries – the United States, Canada, Great Britain, Australia and India – over the time period of 1970 to 1996. We then proceeded to develop linear correlations between these two variables for each of these countries. In all cases, a positive linear correlation with a confidence level greater than 99% was obtained, indicating a strong positive dependence of GDP upon publication volume in this area. Also, a general relationship, normalized to the latest 1996 values for these two variables for each individual country, was developed, and a strong positive correlation (confidence level in excess of 99%) was again demonstrated for the entire community of five nations.

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