SCIENCE, RELIGION AND ECONOMIC DEVELOPMENT

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SUMMARY

The correlations between scientometric indices, macroeconomic variables and results from attitude polls in different countries were explored. The results show that a minimum threshold of economic development (around GDP per capita of 1000US$) is required for science and the economy of a country to interact. Above that threshold, a positive interaction can be observed between economic development, scientific development and tolerant moral-religious attitudes. The way these interactions occur remains to be uncovered.

RESUMEN

Se exploraron las correlaciones entre los índices cientométricos, las variables macroeconómicas y los resultados de encuestas sobre la actitud moral-religiosa en diversos países. Los resultados muestran que se requiere de un umbral mínimo de desarrollo económico (alrededor de 1000US$ de PIB per capita) para que la ciencia y la economía de un país interactúen. Por encima de ese umbral se evidencia una interacción positiva entre el desarrollo económico, el desarrollo científico y actitudes moral-religiosas tolerantes. Desconocemos todavía los mecanismos de estas interacciones.

The emergence of science is probably the most important phenomenon for humanity in the last millennium, and occurred after a prolonged period characterized by the emergence, development and expansion of the religions that dominate the world today (deSolla-Price, 1961; Jaffe, 2000). Science and technology are now the backbone of modern economic development. However, many questions about the relationship between science and economic development are still unanswered. Four of these questions are followed herein:

1- How strong is the relationship between science and economic development?

2- What are the cultural attitudes that most favor economic and/or scientific development?

3- Is the relationship between scientific and economic development the same in rich and poor countries?

4- Does economic development drive scientific development or vice versa?

Partial answers to these questions can be obtained by using scientometric indices (Braun and Schubert, 1988; Glänzel and Schoepflin, 1994; Macias-Chapula, 1994; Braun *et al.*, 1995; Leydesdorff, 1995; May, 1997; Macias-Chapula, 1998; Spinak, 1998; Bharvi *et al.*, 2003; King, 2004). For example, regarding question 1, the existence of a strong correlation between scientific productivity and economic development is shown in Table I. Interestingly, scientific productivity per capita, whether measured by using a public database (PubMed) or a private one (ISI) lead to similar results. Scientific productivity correlated less well with the Human Development Index (HDI) pro-

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RESUMO

Exploraram-se as correlações entre os índices cientométricos, as variáveis macroeconômicas e os resultados de pesquisas sobre a atitude moral-religiosa em diversos países. Os resultados mostram que se requer de um umbral mínimo de desenvolvimento econômico (por volta de 1000US$ de PIB per cápita) para que a ciência e a economia de um país interatuem. Por encima de esse umbral se evidencia una interação positiva entre o desenvolvimento econômico, o desenvolvimento científico e atitudes moral-religiosas tolerantes. Desconhecemos ainda os mecanismos de estas interações.

TABLE I
CORRELATIONS BETWEEN ECONOMIC DEVELOPMENT INDICATORS AND INDICES FOR SCIENTIFIC AND ARTISTIC PRODUCTIVITY PER CAPITA

2003	GDP	HDI	InvR&D
PM03/c	0.93*	0.64*	0.61*
SCI/c	0.93*	0.69*	0.66*
SSCI/c	0.61*	0.42	0.49
A&HCI/c	0.61*	0.40	0.49
Movies/c	0.73*	0.59*	0.51

Economic development as provided by the World Bank. GDP: Gross Domestic Product per capita in Purchasing Power Parity; HDI: Human Development Index; InvR&D: Investment in research and Development as % of GDP.
Per capita indices for scientific and artistic productivity for the 44 countries polled by the Pew Global Attitudes Project (2002). PM: number of publications each country produces in the biological and medical sciences that are recorded on the PubMed 2004 data base run by the National Library of Medicine in the USA. SCI: number of scientific articles researchers in each country publish in natural sciences as recollected by Thomson ISI for 2004. SSCI: same in the social sciences. A&HCI: same in arts and humanities. Movies: the number of movies of all types produced in the country as recorded by the International Movie Data Base (IMDB, 2004). Numbers were collected for the year 2003 and divided by country population to obtain a per capita index.
* Correlation coefficients are significant at the level p<0.01).

duced for several countries by the UNDP. Indices such as the SSCI, A&HCI, and Movies produced per capita gave lower correlations with the classical economic indices than with those measuring scientific productivity. Movies produced per capita, which can be considered to be an independent measure of creativity, showed higher correlations than indices for social science and arts and humanities. Among the economic indicators used, investment in research and development for 2003 correlates least well with the indices for scientific and artistic productivity. This probably suggests that many expenses classified as investment in science and technology are not related to scientific productivity. Thus, among the indices explored and others listed in the UNDP annual report, the index related to science and education that correlates strongest with the wealth of a nation as measured through GDP is scientific productivity. Next on the list is the average educational level attained by the population. That is, the number of years at which more than 90% of the population is enrolled correlates strongly with GDP (r= 0.76), as does the percentage of enrollment in any kind of educational program between ages 15-19 (r= 0.79) and 20-29 (r= 0.81).

Looking for answers to question 2, the most complete international survey available was used, the Pew Global Attitudes Project (2002). The results of this survey for a range of questions on attitudes and moral beliefs in 44 countries were correlated with indicators of economic development and scientific productivity, and the most statistically significant results are given in Table II. These correlations show that high levels of ethical and religious tolerance among the citizens of the population, as indirectly measured through the last and the first two questions in the table, are correlated with high economic development and high scientific development. The strongest correlation found was between scientific productivity and the answers given to two of the questions in the Pew questionnaire: "It is not necessary to believe in God to be moral" and "Homosexuality should be accepted by society" (Table II). The percentage of answers to the first of these questions is plotted in Figure 1. These data show that scientific development in a country and liberal attitudes towards homosexuality and religion among its citizens are strongly correlated. That is, a tolerant or even liberal attitude towards matters religious and moral seems to coexist with scientific development. These correlations would suggest that science is a secularizing agent and may encourage tolerance, or that secular tolerant societies favor scientific productivity. A fact supporting the first alternative is that this tendency seems to be conspicuous not only at the level of populations but also at the level of individuals engaged in scientific activities. The answers to a questionnaire among 200 Venezuelan scientists showed that scientists defining themselves as religious were less likely to have been classified by their peers, in a procedure completely independent from the questionnaire, as highly successful scientists (Figure 2). Scientific success among Venezuelan scientists also correlated positively with modesty. That is, highly productive scientists were more likely to rank their contributions to society lower than less productive scientists (r= -21, p=0.006). Both these results are robust in the sense that controlling for age and other variables

TABLE II
CORRELATIONS BETWEEN POSITIVE ANSWERS TO QUESTIONS FROM THE PEW GLOBAL ATTITUDES PROJECT AND INDICATORS FOR ECONOMIC DEVELOPMENT AND SCIENTIFIC PRODUCTIVITY

Pew's attitude 2002 vs. S CI 2003	GDP	HDI	PM	SCI	Movies
Homosexuality should be accepted by society (N=41)	0.64 ***	0.74 ***	0.56 ***	0.66 ***	0.61 ***
It is not necessary to believe in God to be moral (N=38)	0.68 ***	0.73 ***	0.62 ***	0.79 ***	0.61 ***
Success is not determined by forces outside our control (N=44)	0.44 **	0.34 *	0.44 **	0.31 *	0.52 ***
Religion is a personal matter and should be kept separate from government (N=39)	0.33 *	0.11	0.31 *	0.38 *	0.29

***; ** and * indicate p <0.001, 0.01 and 0.05 respectively

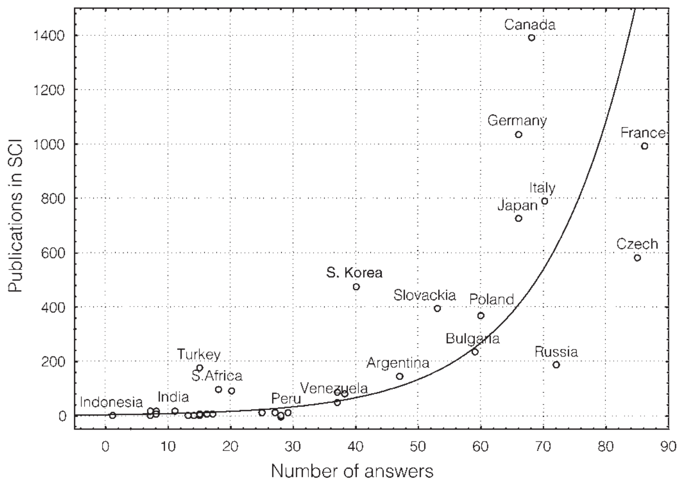

Figure 1. The percentage of positive answers to the question "It is not necessary to believe in God to be moral" is plotted against the scientific productivity measured by SCI/c for a selection of countries.

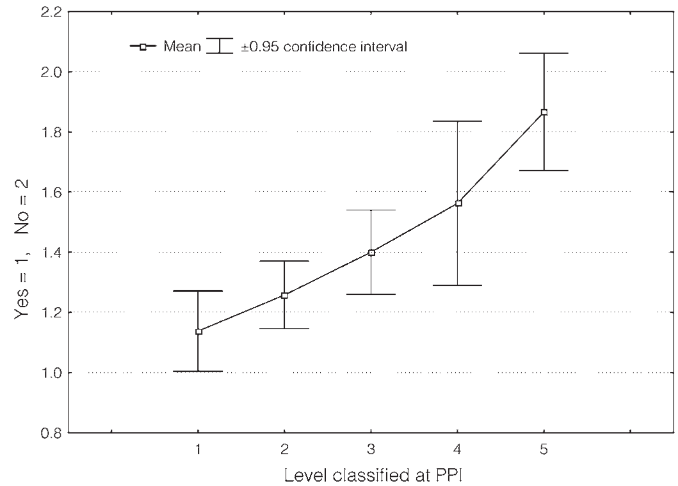

Figure 2. Answers to the question "Do you define yourself as religious?" for researchers classified according to their scientific productivity by a government program for the promotion of scientific researchers in Venezuela (SPI, 2004). The researchers were grouped in 5 levels of increasing scientific impact and productivity. The question, part of a questionnaire developed by Jaffe and Bressan (in preparation), was collected through internet in Jan/Feb 2005.

does not eliminate their statistical significance. Thus, although not conclusive, the data strongly suggest a relationship between secularity, tolerance, modesty and scientific success. Data from other countries and cultures should help in clarifying our understanding of these relationships.

Correlations by their own are unable to determine causal relationships between different phenomena. Yet, significant correlations show that the relationship revealed can not be explained away by chance. Correlations occur mainly for the following reasons: A causal one- or bi-directional relationship between the correlated variables exists; or no causality between the correlated variables exists but a third factor or group of factors affects each of the correlated variables. Whatever the case, significant correlations hint to interesting phenomena that require further study.

The facts published so far suggest that more and better science aids development in technology, which in turn stimulates economic growth, as was shown to be true in rich countries by the OECD and others (Dowrick, 2003, but see Spiegel-Roesing and Price, 1977). But is this true always and for all counties? Figure 3 shows the relationship between scientific productivity and economic development for a sample of 105 countries. The Figure reveals that for all countries, the scientific productivity as measured by SCI correlates strongly with economic development as measured with GDP. This correlation is statistically highly significant ($r(96)= 0.92$; $p<0.0001$); but this correlation disappears among poor countries with a GDP of less than 1000 US$/c ($r(40)= 0.21$; $p=0.19$). That is, the relationship between economic wealth and scientific productivity is not evident among poor nations but is very conspicuous among the richer ones. A threshold of a certain minimum wealth has to be reached for a nation to start to have a positive interplay between economic growth and science, providing an answer to question 3.

Countries in Figure 3 falling below the line of linear fit have a lower scientific productivity than expected from their economic development, while those above the line show a scientific productivity that is above average for their category. Among the latter, we find countries like Israel or Switzerland, with a clear long term national policy favoring science, and among the first group we pick up countries with economic developments affected by favorable world prices in commodities, such as Saudi Arabia and Norway. The data for Japan can be interpreted as suggesting that this country bases part of its economic development on research performed outside its frontiers and that its endogenous research efforts are still not fully developed.

Regarding question 4, scientific and economic development correlate differently for poor (GDP/c <1000US$) and richer countries (GDP >1000US$). Strong evidence hints the fact that science drives economic development in rich countries (Dowrick, 2003) and is not just a luxury sub-product of wealth as sometimes proposed (Spiegel-Roesing and Price, 1977). At the statistical level, however, no correlations between increases in GDP from 1993 to 2003 and the corresponding increase in number of publications in PubMed could be detected ($r(105)= 0.02$, $p=0.83$). Countries with over

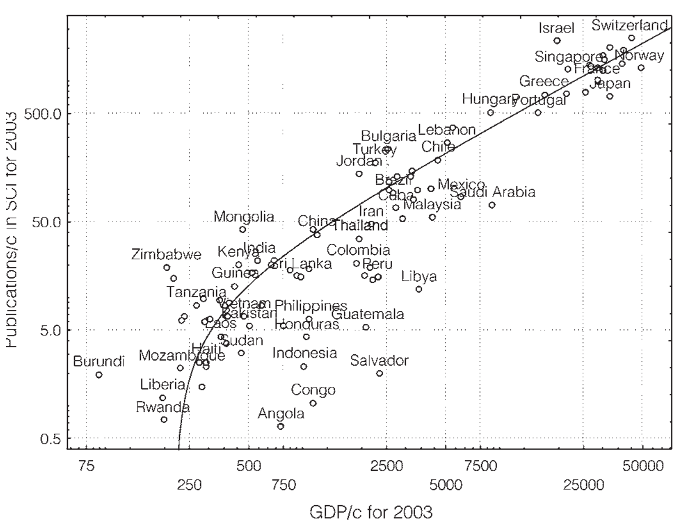

Figure 3. Relationship between GDP/c (in US$ for 2003) and scientific productivity (in papers cataloged by SCI for 2003), for 105 countries in the World Bank database with populations over 1 million and status as independent countries for over 15 years. Data is plotted in a log-log scale and the line gives the linear fit for the data.

100 publications in PubMed for 2003 that increased more than five times in the last decade their publications were, in descending order, Iran, China, Republic of Korea, Turkey, Colombia, Tunisia, Morocco, Jordan, and Brazil; and with more than a three fold increase, Portugal, Greece, Poland, Uruguay, Cuba, and Pakistan (Jaffe, 2005). In contrast, the world average increase was 1.38. Figure 4 presents examples of four of this first group of countries, showing that increases in economic development occurred before the conspicuous increases in scientific publications and suggesting that, for developing countries, economic development may be a pre-requisite for scientific development, and only after a certain level of economic and scientific development has been achieved, science does start to drive economic growth. No unambiguous answer to question 4 is available, although government policy and external support for science are known to be fundamental for scientific development in developing countries (Holmgren and Schnitzer, 2004; Rahman and Nasim, 2004; Thorsteinsdóttir *et al.*, 2004). Further research in that area is required.

It can be concluded that

1- The free access PubMed database can reliably substitute the privately run ISI's for scientometric studies.

2- Acceptance of moral alternatives to religion is correlated with scientific productivity of a country. This is compatible with the suggestion that religious fundamentalism interferes with scientific development.

3- A minimum threshold of economic development (around GDP per capita of 1000US$) is required for science and the economy to interact. After that threshold, a positive interaction between economic development, scientific development and tolerant moral-religious attitude, seems to take place. The mechanisms of that interaction remain to be uncovered.

The conclusions listed here are of course tentative. Data from different cultures at different times, at the micro and the macro-population level, should help understand the influences of science, scientific skills and attitudes on society and vice versa.

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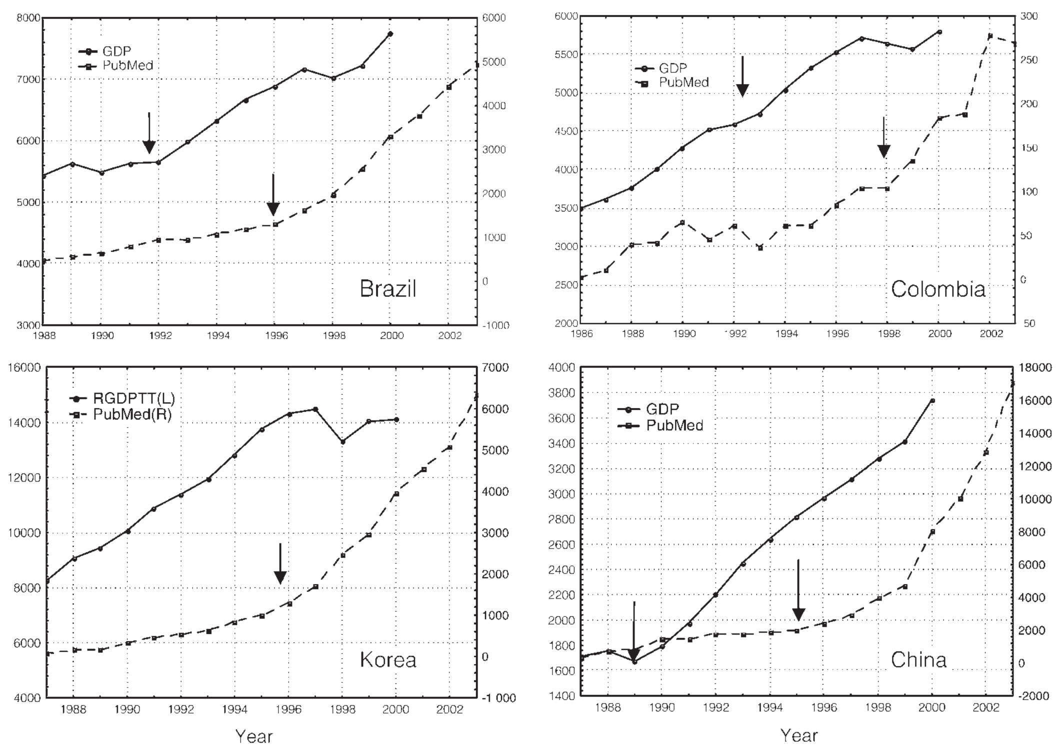

Figure 4. Examples showing increases in national wealth (GDP/c) occurring four to six years before important increases in the rate of scientific productivity, as measured by papers listed in PubMed. The arrows indicate the approximate timing of the change in the rate of increase.