5th International Conference on Information Systems and Technology Management
5º Congresso Internacional de Gestão da Tecnologia e Sistema de Informação
De 04 a 06 de Junho de 2008 - São Paulo - Brasil

PS-877

KNOWLEDGE MANAGEMENT FOR SUSTAINABLE DEVELOPMENT

Feruccio Bilich (Universidade de Brasília, DF, Brazil) - bilich@unb.br
Ricardo DaSilva (Universidade Católica de Brasília, DF, Brazil) - ricardos@ucb.br

The purpose of this work is to analyse the scientific and technological productivity management of several countries and their impact on economic sustainable growth including in Latin American countries using multi-criteria analysis. In other words, how the knowledge management can contribute to development. It was verified that as the country valorises more its R&D scientists and engineers through investing more in R&D greater would be the scientific productivity. The Latin American countries, among all the countries of the World, will have the highest response, in terms of scientific productivity, to increases of investment in R&D, measured in terms of expenditure per R&D scientist or engineer. In conclusion, the R&D scientists and engineers of the World will produce more, write more and publish more if they are better paid and have better equipment for doing research.

Keywords: Multi-criteria, Economic Growth, Research and Development, Knowledge Management, Scientific Productivity, Technological Productivity

INTRODUCTION

The instruments and weapons made out of stone that primordial human beings left, may indicate that the technical abilities were more developed than the capability of acquiring knowledge. However, this probably is not the case because if human beings were developing weapons and instruments, it was due to their ability to acquire knowledge from intuitive or even thought out experiments. This knowledge was transmitted to succeeding generations through, signs, drawings, languages and later writings. Knowledge, in those times, was more tacit while nowadays it is more explicit. The mastery over fire, ceramics, agriculture and metallurgy left witnesses of technological development and its underlying necessarily acquired knowledge, through the times. But only in Ancient Greece was the true spirit of science born, the ideal of which is the finding of the truth. During the Middle Ages, science and technology laid dormant in the Western World. The cross-fertilization between science and technology only began to happen during the Renaissance bringing the understanding that true knowledge can only be accrued based on experimental methods.

It seems that knowledge and technique, or science and technology, has always been a factor of disequilibria since its beginnings. Early Man used it to improve his chances of survival against Nature and other animals. More recent Man uses it to dominate not only Nature but, also, to foster his quality of life. Consequently, the domination of science and technology, which is becoming an increasingly production factor, is also facilitating the domination of the market with consequent domination of the people.

When, in England, the work relations and capital evolved to create the industrial system, that implies the control of the production and maximization of profits, the society, having suffered profound changes, was already divided between capitalists and workers and, the employers and workers had, already, become two antagonistic forces. As a result of this conflict and the competitiveness that developed inside the capitalist class, technological innovation became a must. To produce more and better, at lower cost, and make the productive process ever less dependent on manual labour has been the thrust for technological development up to now. An interesting consequence of this process of technological development is that, while the production process is becoming less dependent on manual labour it is becoming, although indirectly, more dependent on brain or thinker labour. In other words, this means that while in the beginning of the Industrial Revolution the production process required workers that had to use basically only their hands and very little of their brains to think up the work, nowadays the production process depends much less on the workers' use of their hands and more on the workers' use of their brains.

Hence, the purpose of this work is to analyse the scientific and technological productivity of several countries and their impact on economic growth including in Latin American countries.

SCIENCE AND TECHNOLOGY INDICATORS

In order to analyse the world scientific and technological productivity and compare them among the countries, a set of indicators, suitable to this analysis, was identified. The basic data employed included: Gross Domestic Expenditure on R&D; Patents Granted to residents; Total Number of Researchers (Full Time Equivalent - FTE); Total Number of Publications in Science Citation Index - SCI per country.

Circa 1970, the developing countries were investing on average, 0.35% of their Gross National Income - GNI in Research and Development - R&D. Circa 1980, they had an increased in over 50% their percentage of GNI in R&D to an average of 0.53%.

Circa 2000, indicators of the countries presented in Table 1 show that the percentage of GNI expenditure in R&D increased to an average of 1.17% and that the average expenditure per researcher became US$ 22,251.25.

SCIENTIFIC PRODUCTIVITY

Scientists and engineers engaged in R&D expend their time not only inventing and patenting. They also expend their time writing and publishing their work.

Scientific productivity is the amount of scientific knowledge generated per unit of input.

Bibliometrics is an evaluation technique that maps cognitive changes in research fields at an international level by journal-to-journal citation.

According to Okubo (1997) …"bibliometric indicators are practical tools which can be used in combination with others indicators". "The purpose is to measure the output of scientific and technological research through data derived not only from scientific literature but from patents as well."

Table 1: Science and Technology Indicators Circa 2000

Country	PUB/RES	RES	GNI	PAT/RES	EXP/RES
Argentina	17,23	26420	444,63	5,49	16,83
Bolivia	12,25	600	22,87	1,67	38,11
Brazil	20,48	55103	1371,66	54,9	24,89
Canada	35,83	90810	963,55	12,3	10,61
Colombia	1	4240	301,22	4,95	71,04
Cuba	12,03	5378	28,21	6,69	5,24
Chile	37,47	5629	160,99	6,57	28,6
Ecuador	13,41	1014	47,99	6,9	47,33
USA	19,47	1261227	10871,1	67,45	8,62
El Salvador	5,8	293	32,63	17,06	111,36
Honduras	5,43	479	18,52	6,26	38,67
Mexico	23,48	21879	934,55	5,39	42,71
Nicaragua	7,65	340	13,83	11,76	40,67
Paraguay	6,24	481	26,66	6,24	55,42
Peru	4,09	5576	142,98	1,61	25,64
Uruguay	12,51	2806	27,99	1,07	9,97

Venezuela	25,15	4688	125,42	4,48	26,75
Australia	31,19	66099	579,66	25,34	8,77
Austria	39,19	18715	241,55	57,23	12,91
Denmark	41,37	18439	170,39	44,8	9,24
Belgium	33,24	30395	293,84	42,18	9,67
Germany	24,6	257874	2279,13	83,37	8,84
Netherlands	44,93	41896	476,91	71,41	11,38
Italy	47,74	66110	1559,32	57,15	23,59
France	26,37	170628	1632,12	41,89	9,57
Norway	26,91	18295	169,01	19,62	9,24
Sweden	37,18	39921	238,73	55,61	5,98
United Kin	41,35	158156	1606,85	35,32	10,16
Japan	10,68	647572	3582,52	27,9	5,53
Hungary	25,45	15180	147,47	7,11	9,71
Czech Rep	32,97	13582	167,81	5,01	12,35
Poland	18,21	55174	443,94	0,63	8,05
Switzerland	51,12	25808	221,69	78,77	8,59
Russia	4,81	487477	1318,83	0,42	2,71
Spain	29,87	76670	915,07	9,59	11,94
Greece	37,12	14371	213,31	3,2	14,84
China	4,14	810525	6435,84	7,24	7,94
New Zealand	41,89	10064	84,9	27,52	8,43
Portugal	20,13	17724	187,96	1,75	10,6

PUB/RES = Ratio of total number of publications in Science Citation Index - SCI Search per thousand scientists and engineers engaged in R&D – FTE; FTE = Full Time Equivalent;
GNI = Gross National Income in billions US$; RES = Number of researchers – FTE;
PAT/RES = Ratio of total number of patents granted to residents per thousand scientists and engineers engaged in R&D
EXP/RES = Total expenditure in US dollars per thousand scientists and engineers engaged in R&D
Sources: EUROSTAT Yearbook 2004.OECD. **Main Science and Technology Indicators 2004.** RICYT. **El Estado de la Ciência 2003.**

To OECD (2001) “publications are the major output of scientific research”.

Here, the scientific productivity is measured as the ratio between the total number of publications of the country, published in the Science Citation Index of the ISI and the total number of scientists and engineers of this country engaged in research and development (R&D). The column headed by (PUB/RES) in Table 2 presents the scientific productivity circa 2000. This measure, if used individually or comparatively, can express the worth or value of scientists and engineers of a country, in terms of producing knowledge.

Table 2 - Scientific Productivity Circa 2000

RANK	COUNTRY	PUB/RES	RANK	COUNTRY	PUB/RES
1.	Switzerland	51.12	21.	Mexico	23.48
2.	Italy	47.74	22.	Brazil	20.48
3.	Netherlands	44.93	23.	Portugal	20.13
4.	New Zealand	41.89	24.	United States	19.47
5.	Denmark	41.73	25.	Poland	18.21
6.	United Kingdom	41.35	26.	Argentina	17.23
7.	Austria	39.19	27.	Ecuador	13.41
8.	Chile	37.47	28.	Uruguay	12.51
9.	Sweden	37.18	29.	Bolivia	12.25
10.	Greece	37.12	30.	Cuba	12.03

11.	Canada	35.83	31.	Japan	10.68
12.	Belgium	33.24	32.	Nicaragua	7.65
13.	Czech Rep.	32.97	33.	Paraguay	6.24
14.	Australia	31.19	34.	El Salvador	5.80
15.	Spain	29.87	35.	Honduras	5.43
16.	Norway	26.91	36.	Russia	4.81
17.	France	26.37	37.	China	4.14
18.	Hungary	25.45	38.	Peru	4.09
19.	Venezuela	25.19	39.	Colombia	1.00
20.	Germany	24.60			

PUB/RES = Ratio of total publication in SCI Search per thousand researchers – FTE
FTE = Full Time Equivalent
Sources: EUROSTAT Yearbook 2004. OECD. **Main Science and Technology Indicators 2004.** RICYT. **El Estado de la Ciência 2003.**

According to Bilich (1989) circa 1970, among the industrialized market economies, Canada had the highest scientific productivity, followed by Denmark and United Kingdom. Japan had one of the lowest scientific productivity but above average, technological productivity. Countries like Sweden, United Kingdom, Switzerland and Austria should keep up high, both scientific and technological productivity.

Among the newly liberalized economies, Hungary had the highest scientific productivity and Romania, the lowest.

Among the developing countries Spain had the highest scientific productivity, followed by Nigeria, Greece and Israel. At this time, if compared to all other countries, Spain was in the fifth place, being surpassed in scientific productivity only by Canada, Denmark, United Kingdom and Sweden.

Nowadays, scientists and engineers engaged in R&D are more careful and reticent in publishing ideas or results from their researches. To Bilich (1989 p. 117) it seems that, usually when the scientist and engineer engaged in R&D of a country, dedicate more time to scientific productivity, the technological productivity lags behind and vice-versa. Pistoi (2002) has the same impression when says that "the number of patents is still overwhelmingly higher in the U.S. than in the Old World, which suggests that U.S. researchers may be more likely to seek a patent than to divulge their results immediately".

Table 2 presents the scientific productivity by rank. Circa 2000, indicators of scientific productivity presents Switzerland as the country with the highest scientific productivity followed by Italy, Netherlands, New Zealand, Denmark and United Kingdom.

TECHNOLOGICAL PRODUCTIVITY

Technological productivity is the amount of technological knowledge generated per unit of input.

The technological productivity is defined as the ratio of the total number of patents granted to residents per total number of scientists and engineers engaged in research and development (R&D). Table 3 presents the technological productivity by rank.

Table 3 – Technological Productivity Circa 2000

RANK	COUNTRY	PAT/RES	RANK	COUNTRY	PAT/RES
1.	Germany	83.37	21	China	7.24
2.	Switzerland	78.77	22.	Hungary	7.11
3.	Netherlands	71.41	23.	Ecuador	6.90
4.	United States	67.45	24.	Cuba	6.69
5.	Austria	57.23	25.	Chile	6.57
6.	Italy	57.15	26.	Honduras	6.26
7.	Sweden	55.61	27.	Paraguay	6.24
8.	Brazil	54.90	28.	Argentina	5.49
9.	Denmark	44.80	29.	Mexico	5.39
10.	Belgium	42.18	30.	Czech Rep.	5.01
11.	France	41.89	31.	Colombia	4.95
12.	United Kingdom	35,32	32.	Venezuela	4.48
13.	Japan	27.90	33.	Greece	3.20
14.	New Zealand	27.52	34.	Portugal	1.75
15	Australia	25.34	35.	Bolivia	1.67
16.	Norway	19.62	36.	Peru	1.61
17.	El Salvador	17.06	37.	Uruguay	1.07
18.	Canada	12.3	38.	Poland	0.63
19.	Nicaragua	11.76	39.	Russia	0.42
20.	Spain	9.59			

PAT/ RES = Ratio of number of patents granted to residents per 1000 number of researchers - FTE
FTE = Full Time Equivalent
Source: EUROSTAT Yearbook 2004. OECD. **Main Science and Technology Indicators 2004.** RICYT**. El Estado de la Ciência 2003.** WIPO. **Industrial Property Statistics.2002**

To Bilich (1989) circa 1970, the country with the highest technology production among industrialized market economies was the United States, followed by Japan, United Kingdom and France. In terms of GNI expend in R&D, also the United States was the leader, followed by the United Kingdom, Netherlands and West Germany. In terms to number of scientists and engineers engaged in R&D per thousand inhabitants, Japan was the leader, followed by the United States and Switzerland.

Circa 1970, among the new liberalized economies, the Soviet Union was the country with the highest technology production, measured in terms of patents granted to residents, in terms of GNI expended in R&D and with respect to number of scientists and engineers engaged in R&D per thousand inhabitants.

METHODOLOGY

Science and technology data was collected for several economies including Latin American countries. With this data the scientific and technological productivity indicators were developed. Econometric analyses were performed relating the scientific and technological productivity to their science and technology producing factors respectively. A further analysis related scientific and technological productivity to economic indicators.

The dependent and independent variables were related in a linear-in-the-logarithms formulation. The linear-in-the-logarithms formulation has proved relevant and useful over the years for a long series of empirical studies. This affords a pragmatic basis for its use here. Among its advantages can be listed the following: (1) it is easy to fit; (2) the individual terms possess economic significance – the coefficients of the independent variables are the elasticity; (3) its residuals or error perform better than, for example, simple linear formulations, because the use of logarithms will in theory stabilize the variance of the conditional distribution of the dependent variable given the independent variables (Bilich, 1978) and this formulation is in perfect agreement with Stevens's law of Psychophysics (Stevens, 1961) giving a solid theoretical basis for this formulation.

The sample of data was composed by the set of countries listed in Table 1.

ANALYSIS OF SCIENTIFIC AND TECHNOLOGICAL PRODUCTIVITY

Analysis of Scientific Productivity.

The scientific productivity measured in terms of number of publications per R&D scientist or engineer (PUB/S&E) can be related to science producing factors such as number of scientists and engineers engaged in R&D (S&E), and the amount of expenditure per R&D scientist or engineer (EXP/S&E), in a linear-in-the-logarithms formulation.

Circa 2000, the scientific productivity is explained by expenditure in R&D per researcher (EXP/RES) in econometric terms.

Let be:

LPUB/RES = neperian logarithm of publications in SCI per 1000 researchers circa 2000;

LEXP/RES = neperian logarithm of expenditure in R&D per 1000 researchers circa 2000;

The resulting econometric equation is:

$$LPUB/RES = 0.955\ LEXP/RES \qquad (1)$$
$$(0.078) \qquad F = 151.588 \qquad R^2aj = 0.79$$

In equation (1), the term in parenthesis is the standard error of the coefficient estimate and indicates that the t statistics (ratio of the coefficient per the standard error) is significant. Therefore the coefficient is statistically different from zero. The statistic F indicates that the regression equation is significant and the R^2aj (coefficient of determination adjusted for the degrees of freedom) indicates that the independent variable explains 79% of the variance of the dependent variable.

The elasticity of substitution between the variable scientific productivity (number of publication in SCI per 1000 researchers and the variable (expenditure in R&D per 1000 researchers (EXP/RES)) is 0.955. Hence, circa 2000, for each 1% increase in expenditure in scientists and engineers engaged in R&D there is an increase of 0.955% in scientific productivity.

Analysis of Technological Productivity.

The technological productivity measured in terms of the ratio of the total number of patents granted to residents of the country per total number of scientists and engineers engaged in R&D (PAT/RES) can be related to technology producing factors such as number of scientists and engineers engaged in R&D (S&E), and the amount of expenditure per R&D scientist or engineer (EXP/S&E), in a linear-in-the-logarithms formulation.

The technological productivity is explained by expenditure in R&D per researcher in econometric terms.

Let be:

LPAT/RES = neperian logarithm of patents granted per researcher circa 2000;

LEXP/RES = neperian logarithm of expenditure in R&D per researcher circa 2000;

The resulting econometric equation is:

LPAT/RES = 0.844 LEXP/RES (2)

(0.093) F = 82.030 R^2aj = 0.67

In equation (2), the term in parenthesis is the standard error of the coefficient estimate and indicates that the t statistics (ratio of the coefficient per the standard error) is significant. Therefore the coefficient is statistically different from zero. The statistic F indicates that the regression equation is significant and the R^2aj (coefficient of determination adjusted for the degrees of freedom) indicates that the independent variable explains 67% of the variance of the dependent variable.

The elasticity of substitution between the variable expenditure in R&D per researcher (EXP/RES) and the variable technological productivity (number of patents granted per researcher (PAT/RES)) is 0.844. Hence, circa 2000, for each 1% increase in expenditure in scientists and engineers engaged in R&D there is an increase of 0.844% in technological productivity.

ECONOMIC INDICATORS AND S&T PRODUCTIVITY

The economic indicators are explained by S&T productivities in econometric terms.

Let be:

LGNI = neperian logarithm of Gross National Income of countries circa 2000;

LPUB/RES = neperian logarithm of scientific productivity of countries circa 2000;

LPAT/RES = neperian logarithm of technological productivity of countries circa 2000;

It was run a multivariate regression with the dependent variable (LGNI) and the possible explanatory variables (LPUB/RES, LPAT/RES) employing stepwise method.

The resulting econometric equation is:

LGNI = 1.767 LPUB/RES (3)

(0.113) F = 244.437 R^2aj = 0.859

In equation (3), the term in parenthesis is the standard error of the coefficient estimate and indicates that the t statistics (ratio of the coefficient per the standard error) is significant. Therefore the coefficient 1.767 is statistically different from zero. The statistic F indicates that the regression equation is significant and the R^2aj (coefficient of determination adjusted for the degrees of freedom) indicates that the independent variable explains 85.9% of the variance of the dependent variable.

So, circa 2000, the scientific productivity was the explanatory variable of the variable Gross National Income (GNI) and the technological productivity did not enter the regression equation. The elasticity of substitution between the variable Gross National Income (GNI) and the variable scientific productivity (PUB/RES) was 1.767. This indicates that circa 2000 for each 1% increase in scientific productivity resulted in 1.767% increase in GNI. Hence, the World economies, circa 2000, are becoming knowledge driven in contraposition to previous decades where the World economies were technology driven.

ANALYSIS OF LATIN AMERICAN COUNTRIES VERSUS NON LATIN AMERICAN COUNTRIES

GNI versus S&T Productivities for Non Latin American Countries

In order to compare the Latin American countries in terms of scientific and technological productivity and their impact on economic indicators with the remaining countries, an analysis of the remaining countries will be performed.

The economic indicators are explained by S&T productivities in econometric terms.

Let be:

LGNI = neperian logarithm of Gross National Income of non Latin American countries circa 2000;

LPUB/RES = neperian logarithm of scientific productivity of non Latin American countries circa 2000;

LPAT/RES = neperian logarithm of technological productivity of non Latin American countries circa 2000;

It was run a multivariate regression with the dependent variable (LGNI) and the possible explanatory variables (LPUB/RES, LPAT/RES) employing stepwise method.

The resulting econometric equation is:

$$LGNI = 1.843\ LPUB/RES \qquad (4)$$
$$(0.137) \qquad F = 181.988 \qquad R^2aj = 0.883$$

In equation (4), the term in parenthesis is the standard error of the coefficient estimate and indicates that the t statistics (ratio of the coefficient per the standard error) is significant. Therefore the coefficient is statistically different from zero. The statistic F indicates that the regression equation is significant and the R^2aj (coefficient of determination adjusted for the degrees of freedom) indicates that the independent variable explains 88.3% of the variance of the dependent variable.

So, for the non Latin American countries the scientific productivity produces more Gross National Income than considering all the countries together. The elasticity 1,843 for non Latin American countries is higher than 1,767 the elasticity for all the considered countries.

Latin American Countries GNI versus S&T Productivity

The economic indicators are explained by scientific and technological (S&T) productivities in econometric terms.

Let be:

LGNI = neperian logarithm of Gross National Income of Latin American countries circa 2000;

LPUB/RES = neperian logarithm of scientific productivity of Latin American countries circa 2000;

LPAT/RES = neperian logarithm of technological productivity of Latin American countries circa 2000;

It was run a multivariate regression with the dependent variable (LGNI) and the possible explanatory variables (LPUB/RES, LPAT/RES) employing stepwise method.

The resulting econometric equation is:

LGNI = 1.731 LPUB/RES (5)

(0.203) F = 72.515 R^2aj = 0.827

In equation (5), the term in parenthesis is the standard error of the coefficient estimate and indicates that the t statistics (ratio of the coefficient per the standard error) is significant. Therefore the coefficient is statistically different from zero. The statistic F indicates that the regression equation is significant and the R^2aj (coefficient of determination adjusted for the degrees of freedom) indicates that the independent variable explains 82.7% of the variance of the dependent variable.

So, for the Latin American countries the scientific productivity produces less Gross National Income than considering the remaining countries. The elasticity 1.731 for Latin American countries is lower than 1.767 the elasticity for all the considered countries and even lesser than the elasticity (1.843) for the non Latin American countries.

<u>Latin American Countries Technological versus Scientific Productivity</u>

The technological productivity of the Latin American countries can be explained by scientific productivity in econometric terms.

Let be:

LPAT/RES = neperian logarithm of patents granted per researcher (technological productivity) for Latin American countries circa 2000;

LPUB/RES = neperian logarithm of scientific productivity for Latin American countries circa 2000;

The resulting econometric equation is:

LPAT/RES = 0.88 LPUB/RES (6)

(0.08) F = 122.59 R^2aj = 0.835

All the statistics are significant and the elasticity of the technological productivity with respect to scientific productivity is 0.88.

<u>Non Latin American Countries Technological versus Scientific Productivity</u>

The technological productivity of the non Latin American countries can be explained by scientific productivity in econometric terms.

Let be:

LPAT/RES = neperian logarithm of patents granted per researcher (technological productivity) for non Latin American countries circa 2000;

LPUB/RES = neperian logarithm of scientific productivity for non Latin American countries circa 2000;

The resulting econometric equation is:

LPAT/RES = 0.809 LPUB/RES (7)

(0.129) F = 39.39 R^2aj = 0.706

All the statistics are significant and the elasticity of the technological productivity with respect to scientific productivity is 0.809.

Non Latin American Countries Technological Productivity versus Expenditure in R&D

The technological productivity of the non Latin American countries is explained by expenditure in R&D per researcher in econometric terms.
Let be:
LPAT/RES = neperian logarithm of patents granted per researcher;
LEXP/RES = neperian logarithm of expenditure in R&D per researcher;
The resulting econometric equation is:

$$LPAT/RES = 1.265\ LEXP/RES \qquad (8)$$
$$(0.130) \quad F = 95.333 \qquad R^2aj = 0.797$$

In equation (8), the term in parenthesis is the standard error of the coefficient estimate and indicates that the t statistics (ratio of the coefficient per the standard error) is significant. Therefore the coefficient is statistically different from zero. The statistic F indicates that the regression equation is significant and the R^2aj (coefficient of determination adjusted for the degrees of freedom) indicates that the independent variable explains 79.7% of the variance of the dependent variable.

The elasticity of technological productivity with respect to expenditure in R&D per researcher is 1.265 for non Latin American countries.

Latin American Countries Technological Productivity versus Expenditure in R&D

The technological productivity of Latin American countries is explained by expenditure in R&D per researcher in econometric terms.
Let be:
LPAT/RES = neperian logarithm of patents granted per researcher;
LEXP/RES = neperian logarithm of expenditure in R&D per researcher;
The resulting econometric equation is:

$$LPAT/RES = 0.588\ LEXP/RES \qquad (9)$$
$$(0.095) \quad F = 37.997 \qquad R^2aj = 0.698$$

In equation (9), the term in parenthesis is the standard error of the coefficient estimate and indicates that the t statistics (ratio of the coefficient per the standard error) is significant. Therefore the coefficient is statistically different from zero. The statistic F indicates that the regression equation is significant and the R^2aj (coefficient of determination adjusted for the degrees of freedom) indicates that the independent variable explains 69.8% of the variance of the dependent variable.

The elasticity of technological productivity with respect to expenditure in R&D per researcher is 0.588 for Latin American countries.

KNOWLEDGE ECONOMICS

Circa 1980

The economic indicators are explained by S&T productivities in econometric terms.
Let be:
LGNI = neperian logarithm of Gross National Income of all countries circa 1980;
LPAT/RES = neperian logarithm of technological productivity of all countries circa 1980;
LPUB/RES = neperian logarithm of scientific productivity of all countries circa 1980;

It was run a multivariate regression with the dependent variable (LGNI) and the possible explanatory variables (LPAT/RES, LPUB/RES) employing stepwise method.

The resulting econometric equation is:

$$LGNI = \underset{(0.035)}{0.701}\ LPAT/RES \qquad F = 397.419 \qquad R^2aj = 0.932 \tag{10}$$

In equation (10), the term in parenthesis is the standard error of the coefficient estimate and indicates that the t statistics (ratio of the coefficient per the standard error) is significant. Therefore the coefficient is statistically different from zero. The statistic F indicates that the regression equation is significant and the R^2aj (coefficient of determination adjusted for the degrees of freedom) indicates that the independent variable explains 93.2% of the variance of the dependent variable.

So, circa 1980, the technological productivity was the explanatory variable of the variable Gross National Income (GNI) and the scientific productivity did not enter the regression equation. The elasticity relating GNI and PAT/RES, circa 1980, was 0.701.

Circa 2000

The economic indicators are explained by S&T productivities in econometric terms.
Let be:
LGNI = neperian logarithm of Gross National Income of all countries circa 2000;
LPAT/RES = neperian logarithm of technological productivity of all countries circa 2000;
LPUB/RES = neperian logarithm of scientific productivity of all countries circa 2000;

It was run a multivariate regression with the dependent variable (LGNI) and the possible explanatory variables (LPAT/RES, LPUB/RES) employing stepwise method.

The resulting econometric equation is:

$$LGNI = \underset{(0.113)}{1.767}\ LPUB/RES \qquad F = 244.437 \qquad R^2aj = 0.859 \tag{11}$$

In equation (11), the term in parenthesis is the standard error of the coefficient estimate and indicates that the t statistics (ratio of the coefficient per the standard error) is significant. Therefore the coefficient is statistically different from zero. The statistic F indicates that the regression equation is significant and the R^2aj (coefficient of determination adjusted for the degrees of freedom) indicates that the independent variable explains 86.9% of the variance of the dependent variable.

So, circa 2000, the scientific productivity was the explanatory variable of the variable Gross National Income (GNI) and the technological productivity did not enter the regression equation. The elasticity relating GNI and PUB/RES, circa 2000, was 1.767.

MULTI-CRITERIA ANALYSIS

System of Decision Making

The major problems in policy maker transformations are sometimes causing rapid rate of technological productions in patents and innovations. Three specific features of theses technologies have been instrumental to bring about further structural transformations in the economic, social and organizational society, opening up an increasing number of sectors in the international trade.

First the dramatic reduction in the productions costs, second to technologically driven patents; and third the rapid growth in the international patent networking.

Decision Making arises at all in science technology indicators - STI. A STI may be described as a "complex system", and can be made the following remarks:

• A complex system can be broken down into sub-systems according to the objectives of the first one. (Patents, GNI, *etc);*

• The methods of management must be arranged in order to propose solutions that fit the actual objectives;

• It is necessary to mix different disciplines such as Operational Research, Management and Econometrics in order to thoroughly understand and model a complex system.

These remarks make apparent the complexity of the decision processes in the STI. The desire to rationalize these processes to the extreme leads inevitably to an aberration (Roy, 1985) as certain factors, which occur in real time, cannot be taken into account in advance. The multi-criteria decision domain proposes a set of tools that enables to model the decision process more or less faithfully.

The representation of the decision process, or even simply the search for a correct decision, is conditioned by different elements, such as:

• Decisions do not exist all the time, sometimes only "orientations" exist.

• The decision maker is rarely a unique individual. Often there is a group of people that take decisions.

• The set of possible decisions (or actions, or alternatives) is rarely fixed, but tends to evolve in real time.

• Although the decision maker wants to choose the optimal decision, this perhaps does not exist or else he is incapable of differentiating between a good decision and the optimal solution.

Multi-Criteria Decision Making (MCDM) is a *descriptive* approach see (Roy and Bouyssou, 1993) and (Roy, 1990) as it consists of describing the problem:

• by defining the possible decisions;

• by defining the attributes (the consequences of these decisions) and the evaluation criteria;

• by incorporating in a utility function / the set of retained criteria.

Finally, we choose the decision that maximizes this function. This approach is based on a certain number of fundamental axioms (Roy, 1985) and (Roy and Bouyssou, 1993):

• When the decision maker makes a decision he maximizes, implicitly or explicitly, a utility function.
• An optimal decision exists in every situation.
• Two decisions which might be incomparable do not exist. We can make a choice or a sort between every pair of decisions.
• Formally, the decision maker's preferences hinge upon two binary relations: the preference *P* and the indifference.

Let us consider two decisions *a* and *b* where either *a* is preferable to *b* *(aPb),* or *b* is preferable to *a (bPa)* or *a* and *b* are indifferent *{ alb).*These two relationships are transitive.

For the solution it enables to model the problem by taking into account of the preferences and experience of the decision maker. It concerns a flexible approach (Roy, 1985) that, by successive dialogues with the decision maker, enables the analyst to propose some response elements. The decision process represents in this figure the considerations of the decision maker. In parallel, the decision aid process contains the set of elements highlighted by the analyst to help the decision maker. Thus, from the outset of the questioning by the decision maker, the analyst can construct models of the problem from which he can make a certain number of deductions. These contribute to helping the decision maker to make an explicit choice and therefore make a decision.

The basic axioms for Multi-Criteria Decision Aid are the following:

• There are problems for which there is no optimal solution.
• The set of decisions may evolve during the course of the study.
• There is a strong interaction between the decision maker and the analyst.
• The decision maker's preferences may be expressed by means of four basic relationships: the relationship of strict preference, of weak preference, of indifference and of incomparability (these relationships are not necessarily transitive).

More details are presented by (Roy, 1985) and (Roy and Bouyssou, 1993).

The theory occurs in the context of multi-criteria such theory provides results and methods for calculating best trade-off solutions when the preferences of the decision maker are known.

From a mathematical point of view, multi-criteria optimisation problems are a special case of vectors optimisation problems, defined by:

$\text{Min } Z\{x) \quad \text{with } Z\{x) = [Z_1\{x);...; Z_K\{x)]^T$

subject to

$x \in S$

$S = \{x/g_1\{x);.,,;g_m(x)^T\ ] <0\}$

Traditionally we can distinguish four axes in the field of vectors optimisation: cone dominance theory, the definition of efficiency, duality theory and the stability analysis of the set of efficient solutions. Cone dominance theory enables us to define order relation in vectorial space on which the sets *S* and *Z{ S)*are defined. This leads therefore to the notion of efficiency (or Pareto optimality).

Duality theory proposes results that enable us to characterize the efficient solutions. Finally, stability analysis allows us to study the behaviour of the set *Z{ S)* when the definition depends on one or several parameters.

Multi-criteria optimisation problems are vectors optimisation problems where solutions space *S* and criteria space *Z{ S)*are the vectorial Euclidian spaces of finite dimension; Q and K respectively, i.e. $S \subset R^Q$ and $Z\{S) \subset R^K$ with $1<Q,K < \infty$.

We firstly present definitions and basic results related to these problems. Afterwards, we study these problems more particularly within the framework of linear problems with real or integer variables defined by:

Min Cx
subject to
Ax = b
$x \in R^Q$

Where *C* is the matrix of the criteria coefficients of dimension (K x Q), A the matrix of the constraint coefficients of dimension (M x *Q)* and *b* is the vector of right-hand values dimension M, where *M* is the number of constraints.

In the context of STI, the planning phase is broken down hierarchically into different levels: patent, GNI. The STI at the tactical level determines the quantities of publication to make by time period. Its objectives are:

• to satisfy the researcher' requirements, that is to say to supply side with the publisher he wants, in the desired quantity and at the desired date,
• to balance continuously the existing resources and the resources necessary for production, by avoiding under loading as well as overloading,
• to ensure STI at lowest cost or at least with maximum thrust.

Next, at the operational level, the established plan must be followed as best as it can. This is not without bringing up some coherence problems, allied to the fact that the first module handles aggregated information, and the second detailed information. Scheduling has as principal objectives:

• to minimize work-in-process in written,
• to have high respect for the planned and promised delivery dates given to the publisher,
• and to optimise the researcher resources.

By its very nature therefore, a scheduling problem in the context of STI is very often multi-criteria, may also involve several criteria of time.

The problems are time/cost trade-off problems. As a general rule, and as (Roy, 1985) points out, taking several criteria into account enables.

An approach to multi-criteria scheduling problems improves us to provide the decision maker with a more realistic solution. Some concrete examples are presented in this paper.

Different states-of-the-art of multi-criteria scheduling can be underlines:

• the necessity of knowing the results of the domain of multi-criteria optimisation to understand well the difficulties related to taking into account conflicting criteria,
• the need for a typology enables us to formalize the different types of problems and to unify the notation of these problems,
• the need for a knowledge of the results on single criterion scheduling problems.

Application of multi-criteria constitutes a field of activity that has been little explored until today mainly in STI.

Multi-criteria Analysis Applied to STI Productivity

The criteria employed in the analysis were:
Maximise Gross National Income;
Maximise PUB/RES;
Maximise PAT/RES; and
Minimise EXP/RES

It was considered that all the criteria were equally important. Therefore they received the same weight.

The Promethée multi-criteria method of analysis was employed. Table 4 presents the values Phi+, Phi-, Phi Net and the ranking obtained for the countries according to the multi-criteria.

From the analysis of the Table 4 can be identified that Switzerland achieved the first ranking followed by United Kingdom and Italy.

Figure 1 presents pictorially the ranking of the countries.

Figure 2 presents the GAIA planes for the analysis.

Let us take a close look on some of the Figure 1. In the first, it tells us that additional gravel has adverse to low investment in S&T. The main reason for this is that additional production is not likely to be very profitable in the stagnation on patents. Regarding value added in the most development countries constructions on patent systems was spending for several years of R&D. Comparing the results for the criteria in the countries of protection of patents has a positive effect on the economic performance. The rationale behind this is that patents systems must spending continuous adding of money, as shows the extended Promethée method was the weighing analysis is taking randomly selected combinations.

Alternative 1 seems to be preferred to alternative 4 if one looks at the avoidance of rank 4, but both alternative cannot be discriminated clearly. However, a final assessment of the ranking must be left to the decision-maker.

Table 4: Ranking of Countries According to Multi-criteria

	Phi Plus	Phi Minus	Phi Net	Ranking
Argentina	0,4276	0,5658	-0,1382	26
Bolivia	0,1842	0,8158	-0,6316	36
Brazil	0,4934	0,5	-0,0066	20
Canada	0,5263	0,4737	0,0526	18
Colombia	0,2303	0,7697	-0,5395	32
Cuba	0,4671	0,5329	-0,0658	24
Chile	0,6447	0,3553	0,2895	11
Ecuador	0,1776	0,8224	-0,6447	38
USA	0,7171	0,2829	0,4342	6
El Salvador	0,2171	0,7829	-0,5658	33
Honduras	0,2105	0,7895	-0,5789	34
Mexico	0,4276	0,5724	-0,1447	27
Nicaragua	0,25	0,75	-0,5	31
Paraguay	0,1974	0,8026	-0,6053	35
Peru	0,1842	0,8158	-0,6316	37
Uruguay	0,2697	0,7303	-0,4605	30
Venezuela	0,3092	0,6842	-0,375	29
Australia	0,6908	0,3092	0,3816	7
Austria	0,6579	0,3421	0,3158	10
Denmark	0,5461	0,4408	0,1053	17
Belgium	0,6645	0,3355	0,3289	9
Germany	0,6711	0,3289	0,3421	8
Netherlands	0,75	0,25	0,5	4
Italy	0,75	0,25	0,5	3
France	0,7237	0,2763	0,4474	5
Norway	0,5724	0,4211	0,1513	16
Sweden	0,75	0,25	0,5	3
United Kingdom	0,7566	0,2434	0,5132	2
Japan	0,5855	0,4145	0,1711	15
Hungary	0,4868	0,5132	-0,0263	21
Czech Rep	0,4408	0,5592	-0,1184	25
Poland	0,4671	0,5329	-0,0658	23
Switzerland	0,8026	0,1974	0,6053	1
Russia	0,4868	0,5132	-0,0263	22
Spain	0,5921	0,4079	0,1842	14
Greece	0,3882	0,6118	-0,2237	28
China	0,6316	0,3684	0,2632	12
New Zealand	0,6118	0,3882	0,2237	13
Portugal	0,5197	0,4803	0,0395	19

From a methodological point of view these results indicate:

- Despite the heterogeneity in the data of the multi-criteria matrix, the extended Promethée method can produce clear findings.
- Compared to the results, the multi-criteria analysis resulted in a similar but much more clear-cut scenario ranking.
- The inclusion of different types of uncertainty did not change the ranking.
- The first explorative analysis with Econometric already produced results that were confirmed in later stage of multi-criteria analysis.

According to the empirical tests and comparisons performed with Econometric and Promethée, the work developed here supports a new reliable tool of multi-criteria decision analysis that allows decision makers reach a consensus.

In Figure 1 is presented the ranking of the analysed countries according to the multi-criteria.

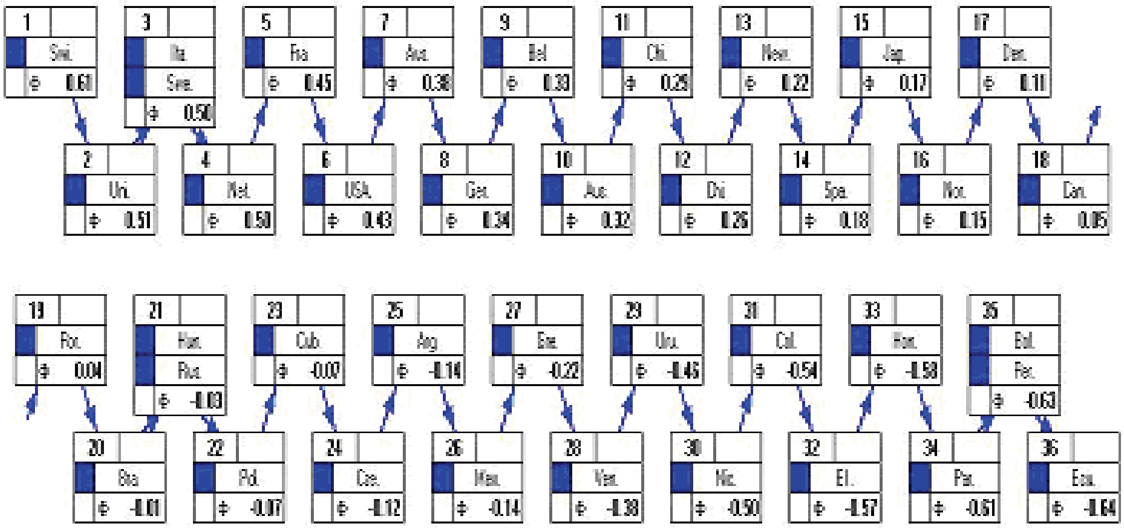
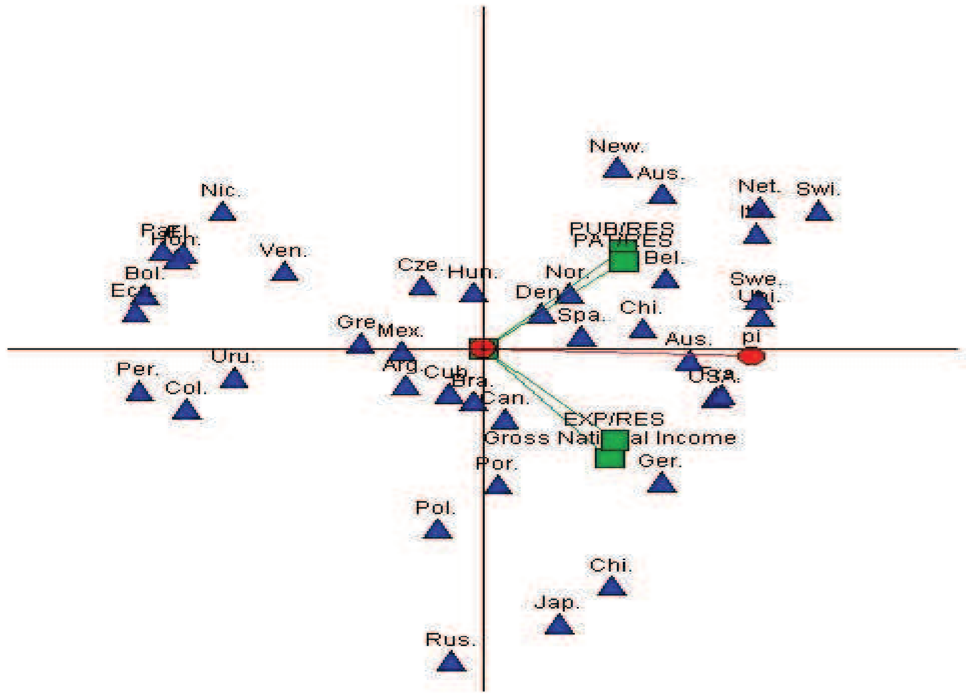


Figure 1: Ranking of Countries According Multi-criteria

In Figure 2 is presented the GAIA Planes of the analysed multi-criteria study.



Decision Stick

Figure 2: GAIA Planes

CONCLUSIONS

In this work the scientific productivity was expressed as the ratio between the number of publications and the number of scientists and engineers engaged in R&D, and it was explained in terms of science producing factors such as: amount of expenditure per R&D scientist or engineer. This variable is a controllable variable and therefore crucial in the implementation of scientific policy decisions in knowledge management.

The scientific and technological productivity were analysed and discussed for a substantial number of industrialized market economies, newly liberalized economies and developing countries, including semi-industrialized economies. The scientific productivity of Latin American countries was of special interest and the conclusions based on the results obtained from the econometric analysis are pleasantly surprising.

It was verified that as the country valorises more its R&D scientists and engineers through investing more in R&D greater would be the scientific productivity mainly in knowledge management.

The Latin American countries, among all the countries of the World, will have the highest response, in terms of scientific productivity, to increases of investment in R&D, measured in terms of expenditure per R&D scientist or engineer.

In conclusion it can be said that all the R&D scientists and engineers of the World will produce more, write more and publish more if they are better paid and have better equipment for doing research and apply in knowledge management. This is particularly true for R&D scientists and engineers of Latin American countries that will have the highest response in scientific productivity to increases in expenditure per R&D scientist and engineer.

With respect to which of the productivities is more relevant for producing increases in the Gross Domestic Product of the countries it was verified empirically through econometric analysis that circa 1980 the technological productivity was more relevant while circa 2000 the scientific productivity had become more relevant. This confirms empirically the notion that the countries of the World were moving towards a knowledge based economy that is broader and more sophisticated and dynamic than a mere technology based economy or society.

According to the multi-criteria analysis performed, the criteria maximization of GNI implies in high development, the maximization of PAT/RES implies maximization of technological productivity, the maximization of PUB/RES implies maximization of scientific productivity, and minimization of EXP/RES implies minimization of expenditure per scientist. Switzerland came up first in the ranking according to these criteria. The work developed here supports a new reliable tool of multi-criteria decision analysis that allows decision makers to reach a consensus to sustainable development.

BIBLIOGRAPHY

BILICH, F. (1978)

```
ERROR: syntaxerror
OFFENDING COMMAND: --nostringval--

STACK:

-mark-
/sfnts
false
```