INNOVATION RATE OF CHANGE MEASUREMENT PART 2: GLOBAL INNOVATION INDEX (GII)

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ABSTRACT

It is generally believed that humanity is in an intense ever-changing process. Changes in information technology favored the globalization of economic and social processes. They have also sparked an increase in the rate of change of diverse processes, machinery manufacturing and technology management. In fact, a dynamic and complex feedback system apparently exists in which the development of radical innovations in information technology promotes the innovation of complementary technology and vice versa. In the second part of this work, we propose the use of the technological platform concept as an indirect measurement method for global innovation. The definition of a non dimensional Global Innovation Index (GII) allows us to determine in a graph the behavior of the global innovative activity. Results coincide with the K-waves proposed by Modelski [41]. Finally, quantitative GII analysis allows us to conclude, by comparison with the phenomena that happened during the second technological revolution, known as the Industrial Revolution, that we are living in a third modern-era Technological Revolution. Perhaps in the future this era will be known as the Information Technology Technological Revolution.

RESUMEN

Generalmente se cree que la humanidad se encuentra en un proceso de cambio continuo. Los cambios en la tecnología de la información favorecieron los procesos de globalización económica y social. También propiciaron un incremento en la tasa de cambio de diversos procesos, maquinaria, manufactura y administración tecnológica. En efecto, aparentemente existe un complejo sistema dinámico realimentado en el cual el desarrollo de innovaciones radicales en tecnología de la información, promueven la innovación de tecnología complementaria y viceversa. En la segunda parte de este trabajo proponemos el uso del concepto de plataforma tecnológica como un método de medición indirecta de la innovación global. La definición de un índice de Innovación Global Adimensional (GII, por sus siglas en inglés), nos permite determinar en una gráfica el comportamiento de la actividad innovativa global. Los resultados coinciden con las ondas "K" propuestas por Modelski [41]. Finalmente, el análisis cuantitativo del GII nos permite concluir por comparación con el fenómeno sucedido durante la segunda revolución tecnológica, mejor conocida como la Revolución Industrial, que estamos viviendo en la era de la Tercera Revolución Tecnológica moderna. Tal vez en el futuro esta era sea conocida como la Revolución Tecnológica de las Tecnologías de la Información.

KEYWORDS: Technology Rate of Change, Technology Platform, Global Innovation, Technology Revolution

INTRODUCTION

Technology has been frequently considered as a measure of progress. Hadjilambrinos [16] points out that the main objective of Science, Technology & Society, as a discipline, is to study and understand scientific and technological development as social processes, that is, processes that affect and are affected by social organizations.

In that regard, the concept of progress is rather a unique development of western civilization. Its origins can be traced back to the 5th century B.C., Greece, to the writings of the philosopher Xenophanes: "the gods did not reveal, from the beginning, all things to us, but in the course of time, through seeking, men find that which is better".

Francis Bacon believed that technological development had a greater impact than anything else on the course of human history. Apianus, German Geographer, declared that without new inventions "life would return to the state of ancient man who lived without laws and civilization". In fact, technological development had already become the standard by which progress, and indeed, the level of "civilization" were to be measured.

ECONOMIC GROWTH AND AGGREGATE MEASURES OF INNOVATION

Ever since Schumpeter [44], technology development has been related to economic growth. For Gomulka [14], most of the mathematical theory of growth began with the advent of innovative ideas due to Ramsey, Von Neumann and Harrod in the 1930's, and has continued with extensive ramifications and generalizations by a large number of authors in the post war period.

The emphasis of the theory has been largely on the growth effects of capital accumulation under various specifications of the initial production technology, assuming that the subsequent technological change is given and cost-free.

In a number of empirical studies, it appears that a consensus has emerged that the observed strong variation in growth rates of outputs among nations and over time is largely due to differences in the rate of change of the productivities of primary inputs such as labor.

There are differences between original, radical inventions and innovations; the analytical power of this distinction lies in the apparent fact that the rise of substantially new branches in economic activity and radical changes to the existing branches can almost always be traced to the discovery of substantially new products and radically new processes.

Gerhard Mensch's [40] study showed that basic innovations varied quite considerably over the past two centuries. The time unit he chose was 10 years. A different choice of time unit and initial year, and the arbitrary choice of inventions, will affect the distribution, without a doubt; however, it appears safe to accept that basic innovations will tend to come in clusters with periods of unusually high inventiveness.

Nelson [42] notes that much of the research work in the field of growth and technological change has been concentrated on answering the following separate questions: What lies before a particular country's growth rate and its variation over time? What explains differences in levels and rates of changes in productivity among countries? Why do certain firms and industries experience much faster productivity growth than others?

De Long [8] studied a large group of industrial nations including Canada, Germany, Italy, Japan, the United Kingdom and the United States; he found that, since 1950, economic growth has always been strongly associated with machinery investment.

Ayres [1] proposed a different method to measure technological progress based on historical data. He compared the efficiency with which energy resources are converted into final services. The measure is decomposed into two components, the thermodynamic efficiency of converting an energy source into mechanical work, and the efficiency with which mechanical work is used to produce final services. The neoclassical production theory was introduced in the late 19^{th} century; its research was directed toward building an economic production function that explicitly reflects technological change.

In summary, none of the economic models that are in use today for measuring technological development are attractive for long-run forecasting; the fact is that the independent variables that are selected in forecasts that include economic models do not necessarily undergo changes in periods longer than several decades, thus, a somewhat different approach to the long-term problem that includes the technology innovation variable may be appropriate.

The purpose of this work is to develop a simple methodology to measure global innovation activity.

METHODOLOGICAL FRAMEWORK

An alternative to the economic-based research is the "Technology Indicators" research, which is used to obtain different indicators that measure the different aspects of technology and, consequently, have different implications for policy issues in both macro and micro levels.

Three approaches to research on technology indicators have been identified. The first approach was initiated by Gellman Research Associates (GRA) in the United States. It uses literature as the primary source for defining the population of innovations. The universe of innovations is defined by consulting scientific and technical magazines. Subsequently, experts are consulted regarding the ratings of these innovations.

GRA employed a panel of five experts who rated approximately 1200 innovations on a 4 point scale, as follows: radical innovation and major technological change, improvement of existing technology, and imitation of existing technology. Chakrabarti [6].

They used the same scale, but sought the help of a large group of experts in a narrowly defined field of technical expertise.

The second approach, used by researchers at the University of Sussex, uses a large panel of experts to define populations of innovations. The third approach used in many countries in Europe relies on surveys of firms.

In this work, we will use modified literature-based research, knowing that this approach presents the following problems:

- It is low cost but extremely tedious and time consuming
- A certain degree of expertise is required to evaluate the item before one decides to incorporate it into the database.
- Some familiarity with the technical area is required for the data collection process.
- One has to investigate changes in the editorial policy of specific journals over the time to insure proper coverage of the field.

For this work, we adopt and make an extension of the innovation categories in processes, materials, instruments and equipment. Chakrabarti [5].

The measurement method presented, similarly to the one used in Part I of this work, is based on the construction and exploitation of a database (DB) that gathers basic information on the breakthrough innovations that have occurred throughout human history.

The units of analysis adopted were radical innovations and technologies, assuming that some measurement problems can be overcome. For example, it is supposed that the adoption of a new technology is carried out more or less instantaneously, i.e. no diffusion lags exist. We also suppose that there is no slowness in imitation, that epidemic diffusion does not occur, and we do not take in account the spatial analysis of diffusion. Lissoni & Metcalfe [38].

A PREVIOUS CONCEPT: THE TECHNOLOGICAL PLATFORM (TP)

Man has always made use of available natural resources for his subsistence and progress. By working in teams, he has transformed these resources into commercial goods for the benefit of humanity. In this process, individuals and their organizations have learned empirical work techniques, have developed science and, using all this knowledge base, have in turn generated new technology in a seemingly endless dynamic feedback process.

Throughout history, individuals, as much as their organizations, have developed and used technology to drive their economic and productive activity. In modern times, true technology is created within companies that face production challenges, Del Rio [9]. However, now we know that in the world there are an increasing number of individual inventors whose actions benefit international patent systems.

In Table I of Part 1 of this article: Information Technology (IT), human history is divided into six historical time periods. In the "technological characteristic" column, some technology inventions or innovations are included. Special emphasis is given to the resources of communication column, which describes the availability of global communications and transmission media, classified as information technology (IT).

Table I Technology evolution database sample

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Entry No.	Date	Place	Technological Platform Technological devices	A	dT_A/dt	B	dT_B/dt	C	dT_C/dt	$dT_A/dt+$ $dT_B/dt+$ dTC/dt = GI Globa	GII = GI/GIR = GI/49.64 = Global Innov Index
	B.C.E.										
1	Paleolithic	All world	Fire			3	0.0003				
2	9000		Stone tools					3	0.00033		
3	8000		Plow thrown by oxen					3	0.003		
4	7000		Oars ship	3	0.003						
5	4000	Mesopotamia	Irrigation Systems			3	0.003				
Σ (Technological Gradients 10000-3500AC)					0.003		0.0033		0.00333	**0.0096333**	**7.429E-05**
6	3500	Sumerian	Copper Tools					3	0.006		
7	3500		Wheels Vehicles	3	0.006						
8	3500	All world	Palm leaves paper, oil	3	0.006						
9	3500	Sumerian	Cuneiform Writing	3	0.006						
10	3200	Europe	Cattle raising and Agriculture					2	0.00667		
11	3200	North Europe	Marine Trade	2	0.00667						
12	3200	Alps	Pottery					2	0.00667		
13	3200		Spindles and Looms					3	0.01		
14	3200		Stone Tools					2	0.00667		
15	3200		Hoe and Sickles					2	0.00667		
16	3000	Mesopotamia	Pottery with lathe					2	0.01		
17	3000	Persia	Hieroglyphic	3	0.015						
Σ (Technological Gradients 3500-3000AC)					0.03967		0		0.05267	**0.0923333**	**0.00071205**
18	2500	Egypt	High sea sailboats	2	0.004						
19	2250	Egypt	Watering dams					1	0.004		
20	2000	Europe	Copper process					2	0.008		

The resultant graph of the rate of change in IT suggested exponential growth during the first part of the 21st century. One of the conclusions in the first article was the need for awareness regarding the type of technology that we should use and its compatibility with generational assimilation periods. In this part of the article, we will try to understand global processes of the technological gradient. The objective is to determine whether IT innovation sparks further technological development or if its behavior is independent.

There is a complex problem, because organizations cannot develop their activities using only one type of technology. In fact, according to Iansiti and West [31], more and more technologies are integrated every day to produce new devices and technological products. In addition, the number of companies and the diversity of their activities in each historical time are enormous, making it impossible to review even a small fraction of them.

To limit the complexity of the analysis of technological evolution within an historical perspective, we propose and use the "technological platform" concept. Following this concept made it possible to identify and group the preponderant technology from each time period. We were able to carry out quantitative analyses of the technological variables that have influenced organizations in different time periods throughout history.

The technology used at factory level is known as "technological package". It is grouped into product, process, equipment and operational technology. The Technological Platform (Tp) broad concept appears as a generalization to include the generic processes and business technology used by human beings and organizations throughout history, including crafts and handmade goods.

Focusing our attention on the identification of the basic processes of individuals organized in companies and the technological platforms that have supported them along the centuries, we determine that:

· During the 1.8 million B.C.e. – 500 B.C.e. period, the fundamental technological platform was determined by agricultural cultivation methods used for rough terrain, animal upbringing and the gathering of medicinal herbs. In those times, useful low-impact technologies such as basketwork, the treatment of animal skins, and clothes making, were developed.

· During the 500 B.C.e. / 1000 A.D. / 1500 A.D. period, after man had settled in communities and developed sailing methods, he began his trips and military interventions to dominate other lands and communities. The dominant technological platforms were basic military devices, food production processes, craft technology, sailing procedures and writing and printing technology.

· During the industrial period (1500 A.D. / 1800 A.D. / 1950 A.D.), factories producing products in series were established and the need for an increase in productivity arose. This was solved by improvements in the process and logistics of organizational technologies such as raw materials and goods, products and services, transport, and distribution media. The technological platform became an extension of the technological package used.

· In modern times, corresponding to the last fifty years (1959-2000 A.D.), it has been determined that critical business technology is related to information exchange, data communications, and the development of knowledge. For this reason, this period has been called "The Information Age", as discussed in the first part of this article.

From this simple analysis, we can say that the technological platform that individuals and organizations have been able to use in each historical time, has been the sum of products developed during previous and present time periods. For example, once man dominated brass or iron production and the processes of manufacturing metallic tools, these products became a human legacy for future times, making it unnecessary to develop them again. Eventually, innovative improvements to the processes have been made continuously through user activities.

Trying to quantify these phenomena, we proposed that, in order to measure a time frame of a technological platform, we needed to quantify the innovations through the integral or mathematical sum of discreet innovative efforts.

Then, the technological platform concept (T_P) can be simply defined as:

$$T_P \equiv \sum_{i=1}^{n} T_i$$

where T_P represents the available technology in a given moment, measured in innovation units. Due to the abundance and diversity of technology, for the purpose of this work we stated that all available technology could be categorized into a minimum of three major groups:

· Type "A" technology (T_A) or Information Technology (I_T), including innovations in communications, electronics, software, computers, semiconductors and transport technology. These were analyzed in the first part of this article.

· Type "B" technology (T_B), including electrical products, food, military, civilian artifacts, pharmacy and all other technologies.

· Type "C" technology (T_C), including innovations in machinery and general chemical or manufacturing processes.

Following this, the technological platform could be defined as:

$$T_P \equiv T_A + T_B + T_C$$

Global Technological Gradient and Global Innovation Index (GII)

We will define the Global Technological Gradient (GTG) as a measure of the rate of change in technology. It can be calculated through the algebraic addition of the technological group gradients in the technological platform.

$$GTG = \frac{dT_P}{dt} = \frac{dT_A}{dt} + \frac{dT_B}{dt} + \frac{dT_C}{dt}$$

On the other hand, the Global Innovation Index (GII) tries to find a comprehensive explanation to man's evolutionary process and his organizations. The GII is a continuous and non-dimensional variable that seeks to give a relative global measure of the technological radical innovation phenomenon throughout history. Therefore, the GII is a function of the world technological platform that exists in a particular historical moment.

To calculate the GII, it was necessary to establish the relationship between a given analysis time of the technological platform gradient $(dT_P/dt)_{AT}$, and a reference time of the technological platform gradient $(dT_P/dt)_{RT}$.

$$GII = \frac{(\frac{dP_T}{dt})_{AT}}{(\frac{dP_T}{dt})_{RT}} = \frac{(\frac{dT_A}{dt} + \frac{dT_B}{dt} + \frac{dT_C}{dt})_{AT}}{(\frac{dT_A}{dt} + \frac{dT_B}{dt} + \frac{dT_C}{dt})_{RT}} = \frac{GTG_{AT}}{GTG_{RT}}$$

Research methodology

The investigation process was carried out through the historical revision and exploitation of data from the database developed. The DB intended to quantify breakthrough innovations that have occurred throughout history.

Furthermore, information technology gradients (dT_A/dt), complementary technologies (dT_B/dt) and machinery, and chemical and manufacturing processes technology (dT_C/dt) were calculated. Calculation of the Global Technological Gradients and the Global Innovation Index (GII) was conducted afterwards.

Database development

The database that we built consists of around 1500 records. It gathers basic information on technological innovations that have occurred from the year 3500 B.C.e. until today. It was developed from the analysis of references [4], [7], 10] to [13], [15] [18], to [37], [42], and [47] to [49]. The analysis performed was similar to the one carried out for the information technology in the first part of this article. The steps taken to gather world scale technological development data were basic revision and the study of some important sources in technological history. The research included the time period from the beginning of human history to the end of the 20th century.

The first objective was to identify as accurately as possible all of the radical technological innovations that have substantially contributed to humanity's development, from about 3500 B.C.e. to 2000 A.D.

To facilitate the use of information, the following sequential fields were included in the database:

1. Approximate or exact date of occurrence reported for the technological innovation.
2. Place where innovation occurs.
3. A brief description of the device type, system, or innovation.
4. The innovations were grouped into three large groups or columns to reduce the complexity of assignments:

T_A = information, transport and communications technology (electronics, software, computers, semiconductors and general devices)

T_B = electrical products, civilian artifacts, military, food, pharmacy and all other technologies, except those included in T_A and T_C.

T_C = general processes and machinery technology.

All T_A, T_B and T_C variables were measured in innovation units.

As can be seen in the database sample of Table II .1, the fields of columns "A", "B" and "C" were filled with numeric values and were considered arbitrary according to the impact that the technological innovation had on humanity, as follows:

- Value 1 is low-impact innovation
- Value 2 is medium-impact innovation.
- Value 3 is high-impact innovation.

Next to columns "A", "B" and "C" were three other columns included in the technological gradient calculation of each technological group, dT_A/dt, dT_B/dt and dT_C/dt. Since it is impossible to obtain continuous form-derived values, the technological gradient variables become discrete. Gradients dT_A/dt, dT_B/dt and dT_C/dt were measured in innovation units per year.

5. Gradient calculations were performed by dividing the assigned innovation numeric value between the number of years in which the precedent radical innovation was presented in the immediate previous time period. For example, passing from the Paleolithic age to the year 4000 B.C.e., it may have taken humanity about a thousand years between each radical innovation. Later on, from 3500 B.C.e. to 3000 B.C.e., it may have taken a hundred years. Soon afterwards, time between innovations was dozens of years. It is difficult to determine what occurs in modern times, it may take one year for dozens of radical innovations. Therefore, we defined one year as the limit between radical innovations. The following are some calculation examples:

Table II Type "B" technology patents granted by the US Patent Office

Year	Electrical	Civil	Textile	Construction	Pharmacy	Food	Home	Agriculture	Σ	Points
1976	17438	83	2013	25225	98	2763	1794	448	49862	49.862
1977	16264	82	1643	23365	92	2390	1715	420	45971	45.971
1978	15753	98	1656	23366	85	2372	1739	409	45478	45.478
1979	12107	65	1218	17469	57	1936	1360	305	34517	34.517
1980	15091	102	1339	22375	77	2582	1754	411	43731	43.731
1981	15936	115	1448	23343	101	2608	1894	452	45897	45.897
1982	14708	74	1224	20345	94	2337	1687	395	40864	40.864
1983	14303	84	1147	19825	82	2148	1589	378	39556	39.556
1984	16478	118	1230	23574	106	2504	1764	374	46148	46.148
1985	17567	114	1234	24926	112	2786	2047	412	49198	49.198
1986	16846	114	1165	24942	139	2611	2048	335	48200	48.2
1987	20630	159	1319	29146	150	3014	2546	409	57373	57.373
1988	19009	129	1303	26520	170	3029	2402	391	52953	52.953
1989	22920	170	1630	31879	236	4151	3116	546	64648	64.648
1990	21828	171	1380	29447	199	4007	3025	537	60594	60.594
1991	23433	194	1531	30909	230	4166	3235	598	64296	64.296
1992	23707	197	1497	30478	238	4366	3333	634	64450	64.45
1993	23351	208	1518	30064	239	4612	3387	583	63962	63.962
1994	25337	208	1580	31266	262	4631	3542	581	67407	67.407
1995	25524	245	1495	30773	301	4713	3803	575	67429	67.429
1996	27938	235	1573	33217	354	5463	4740	651	74171	74.171
1997	28044	287	1654	33439	506	5887	4895	718	75430	75.43
1998	37470	364	2133	43561	606	7419	7009	962	99524	99.524
1999/2000	69916	669	3841	76787	1202	14263	13567	1719	181964	181.964
Suma	541598	4285	37771	706241	5736	96758	77991	13243		
All Years	541598	4285	37771	706241	5736	96758	77991	13243		

Between 8000 B.C.e. and 7000 B.C.e., the appearance of oar ships was recorded. This is the case of an innovation that is reported in a 1000-year period. For that reason, we considered 1000 years as the time value. The innovation was recorded in the "A" group since it includes transport technology. It is a maximum impact innovation with 3 innovation units. Therefore, the calculated gradient value is $dT_A/dt = 3/1000 = 0.003$ innovation units per year.

· In the year 3200 B.C.e., "Spindles and Looms" appeared in the Alps. This case involves a handmade process. For that reason, the product corresponds to group "C" with a value of 3 innovation units. The innovation reported in the immediate previous period occurred in the year 3500 B.C.e., so there was a lapse of 300 years. The value of the corresponding gradient is $dT_C/dt = 3/300 = 0.003$ innovation units per year.

· In 1837, the invention of the Jonval axial flow turbine was reported in Continental Europe. It corresponds to group "C" of general machinery. Its impact was moderated and restricted to certain specific areas, so it was assigned a value of 2 innovation units. The previous immediate innovation took place in the year 1836. It only took one year to develop a radical innovation in those years, therefore, one year determined as the time value, which is the lower limit for gradient calculation. The value of the corresponding gradient is $dT_C/dt = 2/1 = 2$ innovation units per year.

· In 1912, Germany patented the "photographic mechanical choke". This technology is a small mechanism that was applied to the photographic industry, assigned to group "B" and qualifying as one of great impact. The database reports innovations that occurred in the year 1911, so we used a minimum time period of one year. The value of the corresponding gradient is $dT_B/dt = 3/1 = 3$ innovation units per year.

6. To visualize the increasing effect of the gradients, the values of the database variables were summed in pre-defined periods of time, in accordance with the readiness of data. This way, concentrated innovation values of the technological gradients were added up every 500, 100 or 10 years, or whenever necessary, in terms of the abundance of information.

7. A column was included next for the calculation of the Global Technological Gradient (GTG) variable. The calculation of this variable was made only within the added lines in order to obtain the integrated value of the GTG = $(dT_A/dt+ dT_B/dt+ dT_C/dt)$.

8. The information reported in the references is abundant for the years 4000 B.C.e. to 1950 A.D. Before 1950 A.D., information was widely dispersed and disseminated. We know that inventive activity increased; however, these changes in activity are not noted in the books of technological history. To address this problem, we used the records of the United States Patent System [30] since patenting activity can be used as an indicator of technical strength, Sciberras [45]. Jacob Schmookler [46] also focused on inventions and patents to investigate the dynamic relationship between economic growth and development of technology.

9. US Patent databases were revised for each technological type. The data obtained from the years 1976 A.D. to 2000 A.D. are presented in Tables II.2 and II.3 for technological types "B" and "C". The data corresponding to information technology or type "A" were included in Table III of the first part of this article. To include these data in our DB, we first added the number of patents per year issued by the US Patent Office.

10. We know that not all patents will become innovations. To compensate for this effect, we simply took the arbitrary approach of dividing the number of patents by a thousand units to obtain the equivalent radical innovation units.

11. Although the previous approach is arbitrary, it sounded reasonable after carrying out some trial and error graphic equivalence tests in which we obtained comparative values to those already reported as such in the technological history books. The practical meaning is that for each thousand patents registered, it is possible that a radical innovation of high impact will occur. In this way, the graphic results became comparable to those obtained for the already well-known periods. For example, in 1976 the US Patent Office granted 8874 patents for type "A" technology. In that year, there were 8.874 innovation points. Similarly, in the year 1990 A.D., 60594 patents were granted for type "B" technology. The adjusted impact was in the order of 60.594 innovation points and so forth.

12. Between 1963 and 1977, Japanese firms accounted for 33% of television patents taken out in the United States: the two leading Japanese firms accounted for a number of US patents equal to the two US leaders in their own home market. In that regard we made a graphic adjustment which also takes into account the inventive activity of other countries such as the European Economic Community or Japan, instead of considering only US patenting activity as the essential indicator of world-scale inventive activity. Further research can be conducted to determine the error percentage and propose an algorithm or a better adjustment strategy.

13. Finally, a simple scaling factor technique was used to obtain the GII. The reference GTG_{TR} value was considered as the total gradient value for the 100-year period from 1700 A.D. to 1800 A.D.

14. Once the numerical GTG_{TR} value was obtained, the Global Innovation Index GII was calculated by dividing the time analysis Global Technological Gradient GTG_{TA} by the reference GTG_{TR} value.

15. According to developed methodology, the GII represents an indirect, non-dimensional measure of humanity's technological platform rate of change. Its reliability is based on the fact that it is a result of the integration of all the different technological gradients in relation to a constant reference that occurred when humanity passed through one of the greatest development and technological advance periods, known as the Industrial Revolution.

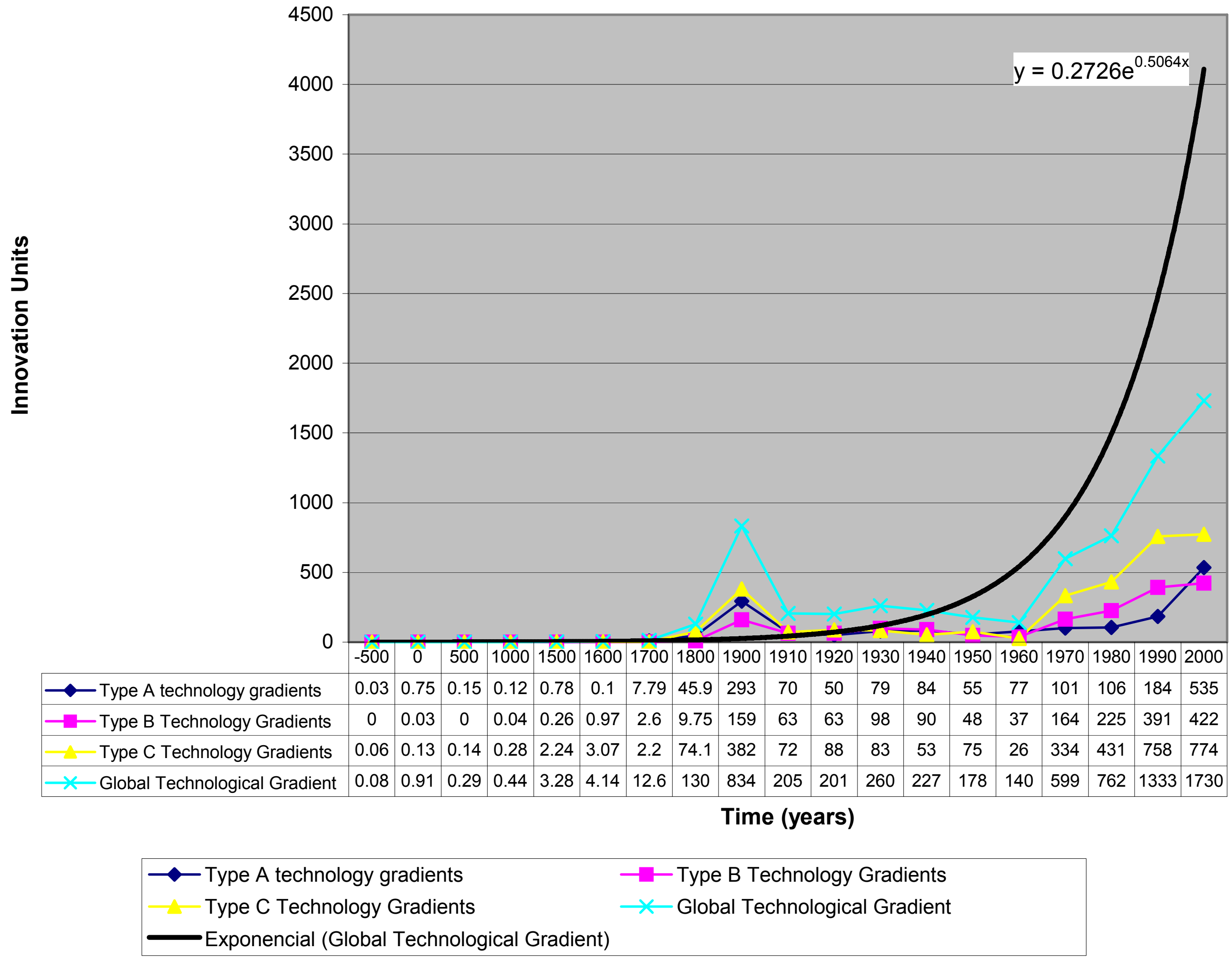
Table III Type "C" technology patents granted by the US Patent Office

Year	Process	Machines	Environment	Water	Air	Soil	Petroleum	Σ	Innovation Points
1976	29878	6019	5498	26536	23280	1904	4319	97434	97.434
1977	27210	5600	5441	23972	21250	1955	3928	89356	89.356
1978	27471	5453	5418	23726	21378	1802	3859	89107	89.107
1979	20594	4034	4191	17955	16176	1278	2851	67079	67.079
1980	26373	4975	5553	22771	20377	1622	3420	85091	85.091
1981	29159	5314	6058	24760	22023	1651	3612	92577	92.577
1982	25737	4687	5355	20850	18971	1545	3161	80306	80.306
1983	25701	4578	5443	20518	18883	1378	3242	79743	79.743
1984	29578	5395	6525	23358	21657	1599	3713	91825	91.825
1985	31348	6023	6953	23836	22673	1654	3579	96066	96.066
1986	30972	5845	7131	22913	21629	1730	3110	93330	93.33
1987	36554	6421	8603	26343	25061	1835	3320	108137	108.137
1988	35572	5979	8377	25628	23593	1818	3157	104124	104.124
1989	45115	7319	10864	31655	28991	2386	3894	130224	130.224
1990	43636	6760	10491	30552	27915	2247	3510	125111	125.111
1991	47219	7362	11684	32131	29553	2322	3732	134003	134.003
1992	49908	7526	12469	33195	30488	2354	3802	139742	139.742
1993	52056	7747	13291	34137	30611	2437	3841	144120	144.12
1994	54367	8230	14642	33758	31256	2502	3731	148486	148.486
1995	55426	8544	15258	33065	30216	2573	3407	148489	148.489
1996	61250	9722	17543	34925	32749	2906	3410	162505	162.505
1997	64306	9725	18788	37058	33361	3037	3647	169922	169.922
1998	85657	13179	26024	4520	42115	3685	4218	179398	179.398
1999/2000	158757	25375	49477	81880	76705	6631	7495	406320	406.32
Suma	1093844	181812	281077	690042	670911	54851	89958		
All Years	1093844	181812	281077	690042	670911	54851	89958		

TABULAR AND GRAPHICAL RESULTS

Table IV presents general numerical results in eight columns. The first column indicates the final year in a time period, followed by three columns that include the numerical values for the dT_A/dt, dT_B/dt, and dT_C/dt gradients added per period.

The graphic results in Figure 1 clearly show the changes in the Innovation Gradient of type "A" information technology, compared to changes that occurred to technologies classified as types "B" and "C". In some cases, the inflection points become more marked. Three curves maintain clear continuous growth. It is evident that slope changes occur on approximately the same dates. Figure 1 also includes the Global Technological Gradient (GTG) curve that integrates the effects of the individual technology gradients. Obviously, the GTG variable maintains the five changes and it is a continuous growing exponential curve.



	-500	0	500	1000	1500	1600	1700	1800	1900	1910	1920	1930	1940	1950	1960	1970	1980	1990	2000
Type A technology gradients	0.03	0.75	0.15	0.12	0.78	0.1	7.79	45.9	293	70	50	79	84	55	77	101	106	184	535
Type B Technology Gradients	0	0.03	0	0.04	0.26	0.97	2.6	9.75	159	63	63	98	90	48	37	164	225	391	422
Type C Technology Gradients	0.06	0.13	0.14	0.28	2.24	3.07	2.2	74.1	382	72	88	83	53	75	26	334	431	758	774
Global Technological Gradient	0.08	0.91	0.29	0.44	3.28	4.14	12.6	130	834	205	201	260	227	178	140	599	762	1333	1730

Figure 1 Technological Gradients by technology type and Global Technological Gradien

The GTG innovation units calculated for the time period between 1700 A.D. and 1800 A.D. were taken as a dividing reference for GII calculation purposes. For this, the GII value for the year 1800 A.D. is determined. Compensation was included for the earlier time periods for which there was a shortage of data. We can observe that the GII contains 5 slope changes, as does the GTG. The changes in dates accurately correspond to the Technological Innovation Gradients shown in Figure 2.

Figure 2 displays the Global Innovation Index (GII) and an exponential adjustment curve.

We can observe in the graph that the innovation dynamics that occurred in the years following the invention of the steam machine, known as the Industrial Revolution, presented a single historic event. Their value generated an oscillation with a 20 units peak that was not surpassed until the 1960's and 1970's when the effects of the transistor and semiconductor invention were presented. The growth of the Global Innovation Index was exponential from that time towards the end of 2000 A.D., and it grew nearly seven times the absolute peak value obtained by the entire innovative movement coming from the industrial revolution. Finally, the graph shows that the behaviors of the GII and the GTG are quite similar, as expected.

Table IV General Database results

Final Year Period	dTa/dt	dTb/dt	dTc/dt	Global Technological Gradient GTC	Global Innovation Index GII	Period years	Compensated Index GIIc
-3500	0.003	0.0033	0.00333	0.00963	7.4264E-05	6500	0.00482718
-3000	0.03967	0	0.05267	0.09234	0.0007121	500	0.00356052
-2000	0.012	0	0.028	0.04	0.00030847	500	0.00154235
-1000	0.08	0.017	0.072	0.169	0.00130329	500	0.00651644
-500	0.02933	0	0.055	0.08433	0.00065033	500	0.00325166
0	0.745	0.03	0.13	0.905	0.00697914	500	0.03489571
500	0.15	0	0.14	0.29	0.00223641	500	0.01118205
1000	0.12	0.04	0.2781	0.4381	0.00337852	500	0.01689261
1500	0.78444	0.26	2.2373	3.28174	0.02530799	500	0.12653994
1600	0.1	0.97	3.07165	4.14165	0.03193941	100	0.03193941
1700	7.78846	2.60065	2.19519	12.5843	0.09704709	100	0.09704709
1800	45.8667	9.75	74.0554	129.6721	1	100	1
1900	293	159	381.5	833.5	6.42775123	100	6.42775123
1910	70	63	72	205	1.58091062	10	15.8091062
1920	50	63	88	201	1.55006358	10	15.5006358
1930	79	98	83	260	2.00505737	10	20.0505737
1940	84	90	53	227	1.75056932	10	17.5056932
1950	55	48	75	178	1.37269312	10	13.7269312
1960	77	37	26	140	1.07964628	10	10.7964628
1970	100.65	164.34	333.8	598.79	4.61772424	10	46.1772424
1980	105.84	225.497	431.063	762.4	5.87944515	10	58.7944515
1990	184.163	391.114	758.05	1333.327	10.2822967	10	102.822967
2000	534.53	421.91	773.64	1730.08	13.3419602	10	133.419602

Global Innovation Index for the k-20 wave

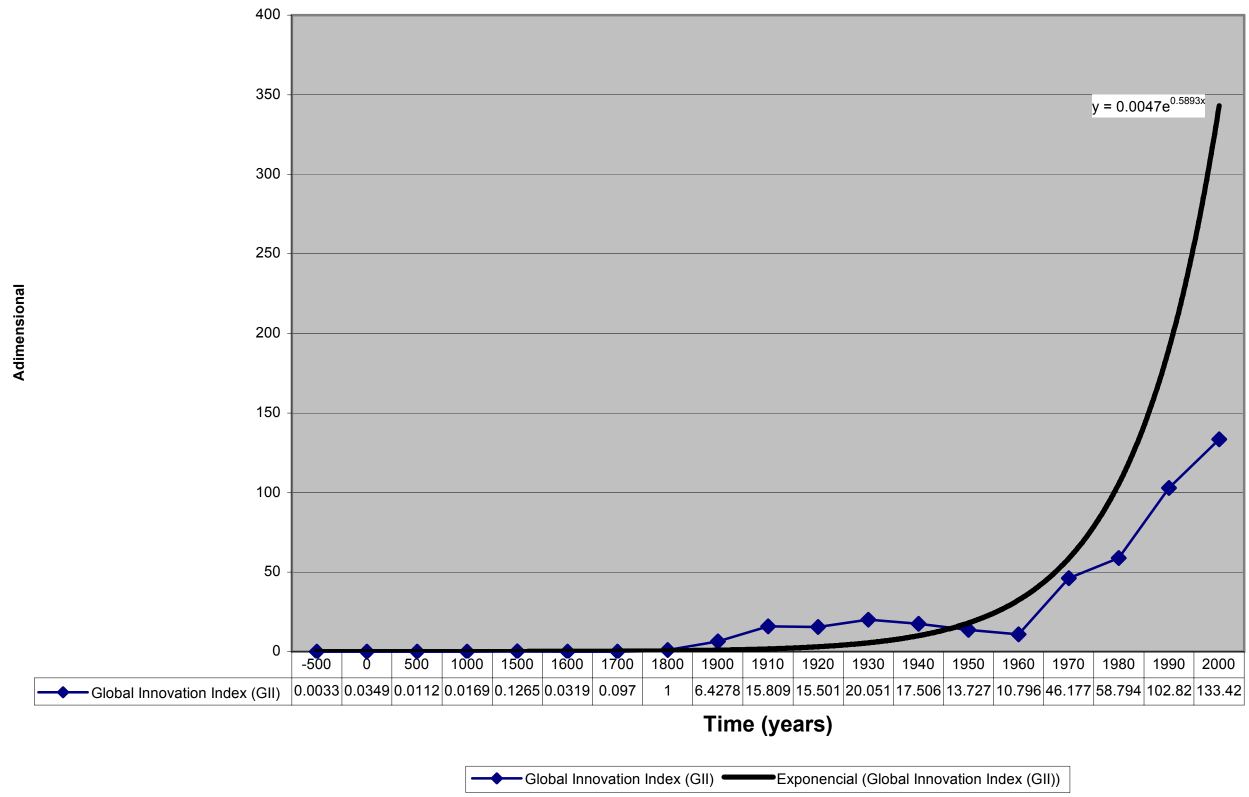
The exponential adjustment function for the Global Technological Gradient is GTG = 0.2726 exp (0.5064x). Extrapolating the value of the GTG for the year 2010, we have:

$$GTG\ (2010) = 0.2726 \exp((0.5064)(10)) = 43.13$$

This indicates that in ten years the patenting of innovations will be forty times greater than its value in the year 2000. This figure tells us that there will be growth, though it does not take into account man's innovative activity prior to 1950. For that reason, it is better to use information provided by the Global Innovation Index. The exponential adjustment function for the GII is IGI = 0.0047 exp (0.5893 x). Extrapolating the value of the IGI for the year 2010, we have:

$$IGI\ (2010) = 0.0047 \exp((0.5893)(10)) = 1.703$$

This implies that if innovative dynamics continue at the same rhythm, the value of IGI for the year 2010 will increase by 70.3%. The calculated GII value for the year 2000 was 133.4 non-dimensional units. For the year 2010, we could expect values in the order of 227.27 non-dimensional units.



	-500	0	500	1000	1500	1600	1700	1800	1900	1910	1920	1930	1940	1950	1960	1970	1980	1990	2000
Global Innovation Index (GII)	0.0033	0.0349	0.0112	0.0169	0.1265	0.0319	0.097	1	6.4278	15.809	15.501	20.051	17.506	13.727	10.796	46.177	58.794	102.82	133.42

Figure 2 Global Innovation Index (GII) and exponential adjustmen

CONCLUSIONS

Our research was focused on following innovation nature and impact characteristics. The analysis of data did not consider the source of innovation.

The results of this work show that, seemingly, in history there have been five significant changes in the Innovation Gradients that have existed. Similar changes are observed in technological types “A”, “B” and “C”.

The Global Technological Gradient (GTG) - an indirect measure of the Global Technological Platform -, also presents five big slope changes in its rate of change curve. The value of the GTG reaches an extraordinary peak towards the year 1900 A.D. This is due to the intense inventive and innovative activity that took place during the Industrial Revolution.

Since the 1960's, a new impulse has been generated for the growth of the GTG by more than 200% of the maximum value reached by the dynamics of breakthrough innovations during the Industrial Revolution. This result confirms that, starting from the 50's, we are in The Information Age, and we are also witnessing the growth of the Third Technological Revolution of the modern era, which explains the last line proposed in Table I, in the first part of this work.

The graph analysis of the Global Innovation Index allows us to observe the duration and oscillation of the K-18 Kondratieff Wave, which lasted about sixty years, between 1900 and 1960, and the appearance of the K-19 Wave, which will exhibit very noticeable growth in the decades to come. According to the economic theory, K-19 will end around the year 2020, thus opening the way to K-20. A simple extrapolation calculation indicates that there is a very strong probability that the GII will increase by more than four and half times its value in the year 2000.

The method used for the quantification of the GTG and GII variables offers graphic results that serve as foundation for the widespread idea that we are living in an era of exponential technological changes. The reliability of the results resides in the fact that the same method used for the behavioral tendencies of the variables is used throughout history.

Historical analysis and the extrapolation of the exponential adjustment curves demonstrated that, at the moment, we are witnessing the emergence of a new global paradigm. This confirms the need for awareness, as mentioned in the first part of this work, in order to respond to the intense speed of changes and dynamics of the global technological platform to which we are subject. This is a priority since it is impacting all aspects of life.

The sustainability of the evolutionary process will require not only the study of the productive functions and measurement indexes of energy conversion efficiency, Ayres [1], but also considering our role in the world, which is, trying to answer the question: how should we live? We also need to determine the importance of the following phrase:

> ... "Information technology has generated decline in meaning; we have all become indifferent towards the relationships among each other and everything else." Hook & Borgmann [18].

It is evident that in the new century, technology will continue building bigger and more surprising structures. New "technological waves" are developing, such as the wireless communication of Internet technology, Yen & Chou [49], and the standardized digital protocols, Halal et al. [17], among many more. We will promptly be diving into a virtual reality that will cause our isolation and the growth of ambiguity, Hook [op cit].

There is no general rule for the evolution of sustainable innovation, since innovation is a product of the evolution of social systems. Analyzing Figures 1 and 2, we agree with Pohlmann [43] in that apparently there are Long Waves of Innovation Models, with movements in mid-term periods. The global paradigms of innovation are changing in mid-term periods. In the model graphs obtained in this work, long waves of innovation are identified which coincide fairly well with Mensch's [40] results.

Finally, we can see in Figure 2 that the gradient of the TB and TC type technologies strongly follows the leadership of TA information technologies diffusion since all the function curves have the same slopes during the entire analysis period time. Hence, IT sparked an increase in the rate of change of diverse processes, machinery manufacturing and complementary technology.

For that reason, we need to be careful with the timing of diffusion of new technology products. Technology could become our ally and help us recover the meaning of things, within distributed justice, health, and security frontiers, taking into account the relationship between all the inhabitants of the world. On the other hand, technology developers must also be responsible for what occurs ecologically in order to achieve a respectful and sustainable relationship with the only world we have.

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