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Economic Growth from a Theoretical Perspective of Knowledge Economy: an Empirical Analyisis for Mexico

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Abstract. *This paper analyzes some theoretical aspects of the knowledge economy and measures the effects of the knowledge factor on Mexico's economic performance over the two past decades. We propose specific indicators to measure the activities of production, acquisition, diffusion, and application of knowledge and verifying their relationship to the GDP per capita through a co-integration econometric model. The overall results agree with the economic theory, since the global knowledge economy indicator is positive and significant. Analyzing the activities individually we found that production and application performed as expected; whereas the values found for acquisition and diffusion are not significant. The amount of knowledge generated in the world increases constantly so that the acquisition of this production cannot keep pace and the capabilities of Mexico to implement knowledge are lagging behind. The acquisition of knowledge has different unregistered elements, such as the informal acquisition, the different qualities of the acquired knowledge and the characteristics of who acquires the knowledge. Perhaps, the most complex indicator is the diffusion of* *knowledge, which mainly occurs through invisible channels, from person to person, linking tacit knowledge, this phenomenon is hard to quantify.*

Keywords: *knowledge economy, technological knowledge, knowledge indicators, economic development, intellectual property, Mexico.*

Introduction

Since ancient times, knowledge has been considered an inherent quality in humanity for being an adaptive characteristic of it. It was not until three decades ago when we began to think about the implications of an emerging new social system that is different from industrialization as well as other types of societies that preceded industrialization. This new system is founded on the direct relationship of knowledge, mainly technological, with an increase in economic and social wellness as a result of its implementation.

The Information Revolution has led to the expansion of networks and provided new opportunities for access, generation and transmission of information. The life cycle of products is shorter and the needs of innovation accelerate. For example in 1990, the transition period between concept and production in the automotive industry took six years, while at the beginning of 21st century, this process took approximately two years (OECD, 2001). Likewise, patent filings and a large number of international requests for intellectual and industrial property are increasing.

Industrial economies have evolved to knowledge-based economies as they have shifted from adding value to raw materials in manufacturing processes to generating value through ideas and innovation as sustainable means for growth. One way to measure this production is by the Technology Balance of Payments (TBP). It consists of foreign money received or paid for the use of patents, patterns, industrial designs, technical services, studies of design and engineering, and for research and experimental development of enterprises. Expenditure on technological knowledge has grown significantly, not only from industrialized economies, but worldwide (Figure 1).

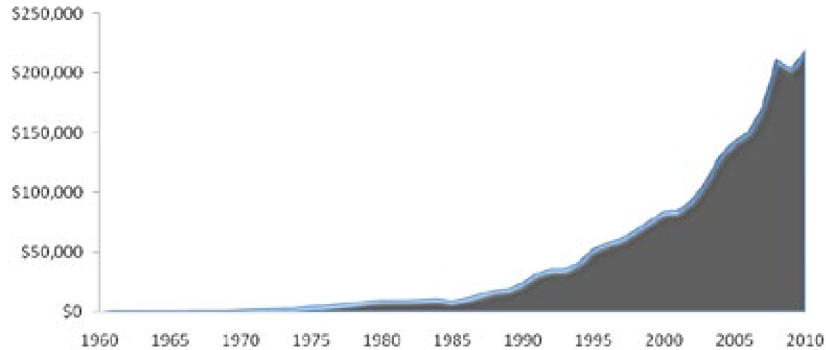

Figure 1. Global expenditure on technological knowledge (TBP payments, million US$, 2005)

In the 1960's and 1970's, international transactions related to knowledge were just forming. The expenditures at the time were $40.2 and $848.9 million dollars which seem insignificant compared to the $8,548 million dollars invested in 1980. Meanwhile, the expenditures from 2008 to 2010 were higher than $200 billion dollars, thus it is noted that the expenditures are not only increasing, but have shown exponential growth from 1960 to 2010.

The group of activities related to knowledge: production, acquisition, diffusion and application have had a more dynamic increase, representing the emergence of a new society called «post-industrial society» (Bell, 1999), where a bigger proportion of a nation GDP is originated in the field of knowledge. Nicolae and Vițelar (2013, p.88) suggest that concepts of global village, post-industrial society, information society/age, and knowledge society are frequently used in reference with the society we live in. Based on the above, a question arises: what kind of relationship exists between the diverse activities of knowledge and the economic performance of a country, in this case Mexico? To answer this question it is necessary to know: what paths will the aforementioned knowledge activities have taken? Also, what activities have had the greatest impact on Mexican economic performance?

The main objective of this work is to determine the type of relationship as well as the impact of the activities of knowledge and economic performance of Mexico for the period 1990-2010, under the assumption that the activities related to the production, acquisition, diffusion and application of knowledge positively and significantly influence the performance of the Mexican economy.

This paper consists of five sections. First, we present the theoretical vision of the knowledge economy and how it explains economic performance. The Mexican capabilities in the various measurements of technological knowledge are presented in the following section; while in sections number three and four, the methodology and the results are shown. Conclusions are presented in section five.

The knowledge economy

Knowledge can be defined as a dynamic human process to justify a personal belief to be certain. From an economic point of view, it is worth noting two elements of this definition: First, knowledge is related to human action and second, the generation of knowledge is dynamic; it is created within the interactions among individuals, groups, organizations and societies, hence to be considered an economic activity. In this activity, knowledge is a productive resource and merchandise subject to commercialization.

As a productive resource it is part of the economic activity, both as knowledge incorporated and unincorporated into capital. In the production function it is incorporated into capital, and it is found unincorporated in labor (innovative entrepreneur and human capital); therefore both types of knowledge are a strategic resource for economic activity, i.e. knowledge is the fundamental input to produce knowledge itself, goods and services.

This factor is not only an implicit resource for the production of all goods and services, but also a good, subject to economic transaction. A first approximation to the characteristics of knowledge goods can be observed in their cost structure: they are expensive to produce, cheap to reproduce and easy to copy, so that the degree of appropriability is essential for production. They are emergent goods so consumers should try them to determine their usefulness. The easy access to these goods generates a diminishing marginal utility and they have significant barriers to exit, as they have network externalities arising from the progressive usefulness to consumers in a growing number of users (Archibugui & Lundvall, 2001).

Knowledge as a commodity is reflected in all goods and services from the economy. In some instances, knowledge is more specialized than in others, and the degree of reproduction varies substantially (Foray, 2004), we have for example, knowledge goods with a high degree of specialization and reproduc-

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tion as patents for pharmaceutical or electronics industries, and knowledge incorporated in high-tech goods. On the other hand, there are knowledge goods with low specialization, whose field is the application of basic science, for example patents in the textile industry. Knowledge is traded as a good on par with other goods and services, since the transactions include the technology used in the economic activity to produce them. The term knowledge transfer has various meanings depending on the contexts in which it is used (Nicolae & Vițelar, 2013, p.90)

A knowledge-based economy is one where knowledge is created, acquired, transmitted and used more effectively by enterprises, organizations, individuals and communities in which these processes are the principal drivers of growth, wealth and employment (Chen & Dahlman, 2006; Toh, Tang & Choo, 2002).

One approach used in the literature to analyze the activities of knowledge is the National Innovation System (NIS). This system is made up of elements and relationships which interact in the production, diffusion and use of new and economically useful knowledge, developed within the borders of a particular nation-state (Lundvall, 1992). In relation to the NIS, Freeman (1991) defines the organizational forms that are the most conducive for developing and efficiently using new technologies, while Nelson (1994) focuses on the question of how different institutional schemes solve the private/public dilemma about information and technological innovation. Lopez (2002) thinks that a NIS comprises therefore, the forms of production, diffusion and application of knowledge of the different activities that society from a country undertakes. The generation and introduction of technological innovations are now viewed as the result of complex alliances and compromises among heterogeneous groups of agents (Antonelli, 2009)

According to Soete, Verspagen and Weel (2010), the main players of a system of innovation are: *a)* the policies of a country; *b)* corporations of R&D; *c)* human capital, and *d)* industrial structure. They summarize the insights of a system of innovation in five points: *1)* sources of innovation, *2)* institutions and organizations, *3)* interactive learning, *4)* types of interactions, and *5)* social capital.

In globalization, the patterns to produce knowledge have been transformed on par with the participants in their production (Archibugui & Lundvall, 2001). In fact, new economic agents have emerged; among them, universities and R&D institutions. Under the scheme of «triple helix» (Etzkowitz & Leydesdorff, 1997), public institutions take part in new markets of knowledge when they patent and market their results or promote spin-offs from the universities. These new agents and their link with industry were established in the United States through the Bayh-Dole Act passed in 1980. This new vision of linkage meant the transition from one model of open science to another oriented to industry and commercialization. It also had a great impact on the institutional design of policies for science and technology, not only in industrialized countries but also in developing countries (Correa, 1989).

As a result of emergence of new agents immersed in the process of innovation, Antonelli (2009) suggests to study it using the economics of complexity, which is built on a number of basic assumptions: *1)* heterogeneous agents, *2)* location matters, *3)* local knowledge, *4)* local context of interaction, *5)* creativity, and *6)* systemic interdependence.

The production of new knowledge concentrated in industrialized economies creates technological knowledge transfers among countries. As a result, in general terms, two types of economies are recognized: industrialized economies that are net exporters of technology; and developing countries that are net importers. Therefore, countries that acquire knowledge from abroad adopt the transfers to the extent that they are capable of purchasing and/or appropriating it for further implementation in their national economic activity. The modern endogenous growth theory postulates that innovation is produced within a national innovation system, subject to economic incentives, and is considered as output, resulting from inputs, where physical, human capital, R&D, and economies of scale all play major roles (Mokyr, 2010, p. 13).

Although the channels of diffusion are formally the same, the transfer of knowledge between the country's producers of knowledge (industrialized) and the developing countries are not homogeneous, nor do they maintain the same patterns. Lall (1992) explains that this is because the technological capabilities to absorb the flows of external knowledge are different between countries. Technological capabilities play a dual role: they are mechanisms of adaptation; but also, depending on their strengths (human capital, technological infrastructure, learning ability, etc.), they can create the conditions to move from the stage of knowledge assimilation to be producers of new knowledge. Stoneman and Battisti (2010), using the Historical Cross Country Technology Adoption Dataset (HCCTAD) development a set of empirical regularities of international patters in the production, diffusion, and use of new technologies. Also, Stoneman (2013) suggests that diffusion of a new process technology across an industry has two dimensions, inter-firm and intra-firm.

Aboites (2009) explains that imitation is not only more common than innovation, but is currently the predominant method of business growth and profits. He also says that imitation is the most powerful mechanism of diffusion of new knowledge. Without imitation, the knowledge that creates new markets would not have economic repercussions. However, from the perspective of the knowledge producer, these features become uncertain in the appropriation of the benefits resulting from the inventive effort and can erode the basis for the production of new knowledge. Knowledge imitation is uncontrollable if no institutional barriers are set to hinder it. Intellectual property rights are the institution that controls and regulates the industrial exploitation of knowledge and its diffusion.

When there are certain strengths and institutional conditions, for example, incentives and government subsidies, a process of knowledge application-production is triggered. In other words, implementation and production are not only mutually exclusive, but both processes must interact to strengthen one another. Thus, application of knowledge is a necessary process in the generation of new knowledge.

Social capacities of a country are very important in strengthening the activities of knowledge application. Fagerberg, Srholec, and Verspagen (2010) point some aspects that are considered to be particularly relevant for a "social capacity" of a country: *a)* technical competence (level of education); *b)* experience in the organization and management of large scale enterprises; c) financial institutions and markets capable of mobilizing capital on a large scale; *d)* honesty and trust, and *e)* the stability of government and its effectiveness in defining and enforcing rules and supporting economic growth.

The produced and stored knowledge should be used to create value through its productive application. The application involves a process of experimentation to find effective solutions to problems, supported by the human resources practices, organizational and cultural factors and a broad view of productivity, which allows room for experimentation and fault tolerance.

The economic benefits of an expanding knowledge base are achieved when they are adopted and employed by the labor force in the production of goods and services. The constant stream of technological advances in the global economy reduces production cycles and accelerates the depreciation of human capital, so the application of knowledge is even more critical (Toh et al., 2002). The commercial benefits of knowledge application provide information to the producing community and drive the next round of innovation and adaptation of this new knowledge.

The importance of the application lies, not only in the level of knowledge specialization, intensive or non-intensive knowledge industries, but in the quality of the application process, i.e. if it achieves high or low productivity in certain economic activities.

There are independent, empirical studies from the perspective of knowledge activities. There is extensive literature on studies of knowledge production following the approach of the knowledge production function proposed by Griliches (1979) and Romer (1991), but they weakly observe this process as a dynamic activity.

Research on knowledge production embraces the hypothesis that the ideal situation is one in which knowledge can be created locally, that is to say, at national level. However, there are no empirical studies that analyze the effects of external knowledge acquisition, i.e. import, and its subsequent spread to the domestic economy. On the other hand, the literature about diffusion states that knowledge flows from various sources and industries, but sometimes it is not appropriate, and goes beyond the geographical boundaries of the region where it was generated.

Meanwhile, empirical studies about the application of knowledge analyze the different institutions that use this resource with economic objectives such as productivity or production itself. Furthermore, the evolution of the application of knowledge through studies developed in knowledge intensive firms that are part of the tertiary sector, finding that knowledge-intensive companies have a superior performance compare with other companies is being examined.

Mexico in the knowledge economy

The rapid pace of all the activities related to knowledge and its increasing commercialization has led to research and attempts to measure knowledge economy. One of the main research works on this matter is the Knowledge

Economy Index (KEI) developed by the World Bank. The index consists of four pillars: *1)* economic incentive and institutional regime, *2)* education and human resources, *3)* the innovation system, and *4)* information and communication technology. Mexico has ranked in the 55, 61, 59 and 72 positions (in 1995, 2000, 2008 and 2012 respectively), placing the country in a low position.

In 1995, Denmark, Finland and the United States ranked in the first three positions. In 2000 were Sweden, the Netherlands and Denmark. In 2008 and 2012, Denmark, Sweden and Finland appeared in the top positions again. China and Brazil have shown progress by moving 20 and 10 positions respectively, from 1995 to 2008; however, the effect of the economic crisis of 2008 is observable in the loss of 7 and 4 positions in 2012. Moreover Mexico, Costa Rica and the United States have descended by 17, 13 and 9 positions respectively. The results are similar in the TBP, by analyzing the balances, the total transactions and the coverage rate it is possible to observe the economic structure of knowledge. Mexico is involved in this global dynamic, however the indicators are unfavorable.

Table 1. Technology balance of payments, 2009. Selected OECD countries (million US$)

Country	Receipts	Payments	Balance	Total Trade	Coverage Ratio
United States	89,056.0	55,807.0	33,249.0	144,863.0	1.60
Germany	55,132.9	46,403.2	8,729.7	101,523.1	1.19
United Kingdom	43,234.4	24,228.9	19,005.5	67,463.3	1.78
Japan	21,538.2	5,716.6	15,821.6	27,254.8	3.77
Belgium	1994.3	10964.0	-8,970.6	12,959.2	0.18
Italy	10,042.3	15,448.1	-5,405.8	25,490.3	0.65
South Korea	3,581.9	8,438.1	-4,856.2	12,020.0	0.42
Finland	9,502.4	9,061.9	440.5	18,564.4	1.05
Canada (2008)	2,661.6	1,059.0	1,602.6	3,720.6	2.51
Portugal	1,768.3	1,632.5	135.8	3,400.8	1.08
Mexico	94.3	1,822.5	-1,728.2	1,916.8	0.05

Source: Overall Conditions of Science and Technology, 2011 (CONACYT, 2012).
Coverage Ratio = Receipts / Payments

Table 1 shows that countries with a greater flow of knowledge transactions have the most advanced economies; nine of the eleven economies from the table above belong to the highest quintile of the KEI in 2008. Only Portugal and Mexico are in the fourth and third quintile respectively in the same period. The difference in the flow of technological knowledge between Mexico and the other OECD member countries is noticeable; not only in the flow of knowledge, but in the low coverage ratio, i.e., the knowledge that is sold is small compared to other countries, with a coverage ratio of only 5%.

The total transactions of technological knowledge in 2009 show the poor performance of Mexico compared to the other OECD members. It has the lowest coverage ratio and the total transactions are few. To objectively evaluate Mexico's performance, it is necessary to analyze a longer period. Figure 2 shows the evolution of technological knowledge transactions from 1990 to 2010.

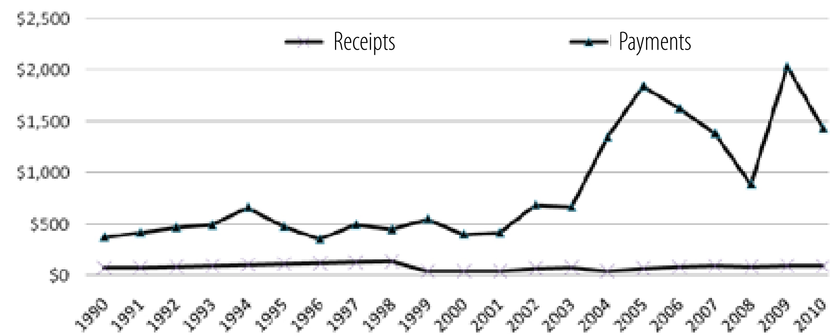

Figure 2. Technology balance of payments, Mexico 1990-2010 (million US$ of 2005)

The TBP progress has been slow, especially the income. From 1990 to 2010 the coverage ratio has fallen considerably. Furthermore the average receipts have not reached 100 million dollars. On the other hand, payments have shown a different dynamic, though with slow growth until 2003, it increased in 2004, 2005 and 2009, reaching more than 2 billion dollars.

Another indicator usually used is the technological self-sufficiency rate (proportion of patent applications filed by residents to the total patent applications in the country), in Mexico it had a value of 0.13 in 1990, while for 2010 was 0.07. The rate of invention (patent applications per 10 thousand inhabitants) had an average of 0.06 for the period 1990-2010, while in most OECD member countries the same indicator is greater than 2.0. Similarly, the dependency ratio (number of patent applications by non-residents for each patent claimed by a resident) in 1990 was 6.67, in 2000, it recovered to 29.3, but in 2009 decreased to 16.37, showing another evidence of weak performance related to the technological capabilities in the country. On the other hand, the low-tech patents that are registered in Mexico are detrimental to the country (Ruiz, 2004); in the period of 1990-2010 only 21.57 % of the registered patents have had high technological content. Despite this, there has been progress in the registration of intellectual property and economic growth.

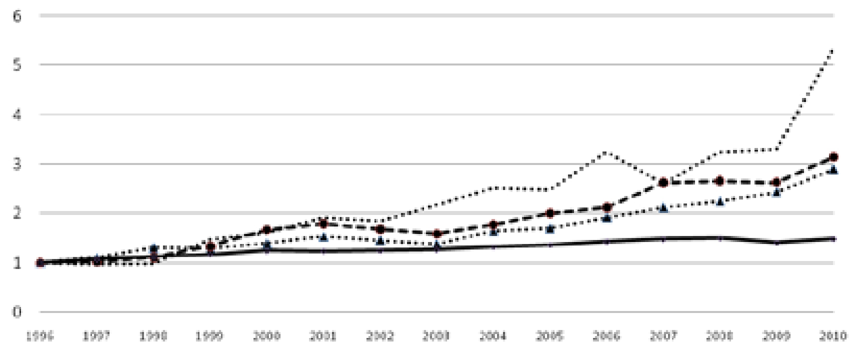

Figure 3. Records of intellectual property and economic growth in Mexico, 1990-2010 (1996=1)

Source: World Intellectual Property Organization (WIPO) http://www.wipo.int/ipstats/en/statistics/country_profile/countries/mx.html

From 1996 to 2010 the registrations of intellectual property and economic growth in Mexico evolved positively. Figure 3 shows a significant increase in the industrial design registration in 2010 since the number of registrations in 1996 quintupled. Registration of trademarks and patents has increased about three times, meanwhile, GDP grew by 48%. Although GDP has a less pronounced growth than intellectual property registration, the positive trend indicates that to some extent these indicators influence economic performance.

In 1990 the added value of manufacturing high-technology industries accounted for about 7% of total manufacturing (excluding petroleum and petroleum products), while in 2000 and 2004 these sectors achieved 12% and 9.5% respectively (Rivera, 2007), which provides a pattern, albeit small, to consider a change in the manufacturing industry by the increase in the technological content of production.

In addition to the above, Mexico's economic growth has been slow over the past twenty years, since it does not show a clear trend towards a substantial acceleration. The average per capita GDP growth from 1990 to 2010 was 5.87%; however the growth rate of sub-periods was very uneven. For example, from 1990 to 1995 GDP per capita grew on average 1.94%. From 1995 to 2000 it increased by 6.32. Then, from 2000 to 2005 it increased at a rate of 5.92%, while from 2005 to 2010 the growth rate was 3.23%.

Methodology

Partial and indirect indicators are used to measure the performance of a knowledge-based economy. In order to achieve this, several proposals have been developed, among which stand the alternatives arising from the OECD, that include the categories of inputs, outputs, flows and stocks, distribution of knowledge and learning.

This research uses the same compound indicators as the World Bank, such as the KEI and some of the variables suggested by the OECD. The period of time under review is 1990-2010 which corresponds with the boom of intensive use of knowledge in the world economy. It would not be significant to study an earlier period, because of the difficulty of obtaining information through representative official sources.

Knowledge production should happen locally as a result of human and material resource application, as well as the export revenues from it. Knowledge production is generally measured through indicators of intellectual property as the number of patents granted.

The acquisition of knowledge happens when locals acquire knowledge produced abroad, either through formal means such as trade, or informal methods such as uncontrolled knowledge drains or imitation. The trade of knowledge is carried out in two ways; incorporated or unincorporated, through the import of HTP (High Technology Products) and the payments registered in the TBP. Another means of acquiring knowledge is by penetrating an industry with knowledge-intensive companies. In the economic literature, it is generally accepted that (FDI) Foreign Direct Investment is a good indicator of openness to external influence and knowledge.

Today, the universities are active organization to transfer knowledge. Nicolae and Viţelar (2013) study the knowledge transfer in Romanian higher education and they conclude that in the knowledge society higher education is one of the key drivers of development; Universities are expected not only to generate but also to transfer knowledge to society. One very different way is the process of imitation. Richter and Streb (2011, p. 1006) write that: "*Today, German* *machine toolmakers accuse their Chinese competitors of violating patent rights and imitating German technology. A century ago, German machine toolmakers used the same methods to imitate American technology*".

The diffusion of knowledge is expressed by the impact of its production and purchase in many different fields by extending the benefits of that knowledge as a resource and commodity. Its diffusion largely occurs through the Information and Communications Technology (ICT) infrastructure; given the ease these means transmit information.

On the other hand, the application of knowledge lies in its adaptation and local use, and what production, acquisition or diffusion has been developed within the country. The application of knowledge in the production of goods and services allows for the economic benefits of this resource to be achieved since the adoption and implementation of knowledge by workers provides information to the production community, promoting innovation and appropriation of new knowledge. According to the above, the variables used to exemplify knowledge activities are listed in Table 2.

Table 2. Specification of knowledge activity indicators

Activity	Proxy Variable	Aspect of knowledge to measure	Source
Production	Patents, trademarks, models and designs.	Intellectual property indicators: Quality of scientific creation recorded in Mexico offices.	WIPO
	Scientific articles	Research efforts made	World Bank
	HTP exports	Incorporated knowledge in imported goods.	World Bank
	TBP receipts	Sale of unincorporated technologies: industrial or technology property rights, services with technical and intellectual content.	World Bank
Acquisition	HTP imports	Incorporated knowledge in imported goods.	World Bank and Conacyt (National Council for Science and Technology in Mexico)
	TBP payments	Purchase of unincorporated technologies: industrial or technology property rights, services with technical and intellectual content.	World Bank
	Foreign direct investment	Investor confidence in the economy. Opening to external influence and to knowledge	World Bank and INEGI (National Institute of Statistics, Geography and Informatics)
	Scholarship holders overseas	Tacit knowledge acquired through people	Conacyt

Activity	Proxy Variable	Aspect of knowledge to measure	Source
Diffusion	Internet users	Capacity to participate in e-commerce, to collect and diffuse	World Bank
	Mobile phone users	Indicator of the adoption of new technology.	World Bank
	Landline phone users	Main indicator of internal capacity in TIC's	World Bank
	.mx domains	Internet servers registered in regional territory	INEGI
Application	Public, private and university expenditures on R+D	Current resources allocated in R+D	World Bank and Conacyt
	Companies certified with ISO-9000	Companies with quality certification that adopt the standards of the International Standard Organization	World Bank Conacyt
	SNI (Researchers National System) members in hard sciences and researchers and technicians in R+D	Human Resources devoted to applied knowledge activities.	UNESCO Conacyt

With the indicators described in Table 2, four compound indices are developed: production, acquisition, diffusion and application. These four indices make up the Knowledge Economy Index. First, the indicators describe the development of knowledge activities under a descriptive statistical approach. Second, we present the long term relationship between knowledge and income by using the method of co-integration of Engle and Granger (1987).

Given the diversity of scales and methodologies to construct the variables, it was decided to convert them into a single common standard. This standardization is carried out through re-scaling. This is done to transform the variables levels to the interval [0, 1], using the gap between the minimum and maximum values, taking into account all the variable data jointly, as follows:

$$y_t^i = \frac{x_t^i - min\ \forall_p (x_t^i)}{max\ \forall_p (x_t^i) - min\ \forall_p (x_t^i)} \qquad \in [0,1]$$

Where $y_1, \ldots, y_i$ are the variables $x_1, \ldots, x_i$ standardized, to make them independent from the magnitude and the units in which they are measured. The unit of analysis with a higher performance will have a value of 1 and the lower 0. As the re-scaling operates on the extreme values of the variable, it is important to verify the non-existence of atypical records because comparisons made on the basis of such values considerably distort the analysis and would put together the typical values in a narrow range within the interval [0, 1]. Also, if the variable values recorded lie within a narrow sub-interval, the application of the transformation would open the range of the records that were transformed.

In this case we use equiproportional weighting factors, because there is not a solid basis that indicates the need for discretionary weighting for the different variables. The weighting factor of the variables will be constant within each compound indicator and equal to 1 among the variables within it. Each compound indicator is the result of the weighted aggregation of subset variables relevant to each knowledge activity previously standardized using the following formula:

$$I_c = \sum_{i=1}^{n} \alpha_i \, y_i$$

Where $I_1, \ldots, I_4$ are compound indicators, y_i are standardized variables and α_i are the weights of the variables which are constant within each indicator. To summarize and conclude the statistical phase, KEI is calculated as the sum of the compound indicators.

Once the compound indicators are obtained, we search for associations between knowledge related economic activities and economic performance, which will allow testing the stated hypothesis. To accomplish this goal, we decided to use a co-integration procedure. Most of the time series are non-stationary and the conventional regression methods based on non-stationary data tend to produce spurious results. However, the non -stationary time series may be co-integrated if any linear combination of the series becomes stationary. Therefore, the co-integrated series will not deviate far from each other because they are linked in the long run. Among the tests to determine the stationarity of the variables are the Unit Root tests such as the ones from Dickey -Fuller, Phillips - Perron and KPS, which determine the integration order of the variables. Thus the co-integration tests are performed with the knowledge activities and GDP per capita.

The co-integration test is performed with the methodology of Engle-Granger (1987), as follows:

$$\boldsymbol{LogGDP_t = \alpha_{1j} + \alpha_{2j} LogKEI_t + \varepsilon_j}$$

where GDP is the gross domestic product per capita at time t, KEI is the set of knowledge activities indicator at time t and KEI = $\sum_{i=C1}^{C_4} C_{it} / 4$ represents the knowledge activities, the coefficient α_{1j} is a constant, α_{2j} represents the elasticity associated with the joint variable of knowledge and ε_j represents the stochastic error. Theory states that as knowledge activities strengthen, the values of production and the marketable knowledge will increase in the same direction, so it is expected that the statistical results are positive and significant.

Analysis and discussion of the results

From 1990 to 1993 the knowledge production indicator in Mexico increased substantially from 0.17 to 0.41 (Table 3 and Figure 4). Between 1993 and 2005, the indicator remained virtually unchanged, with an average of 0.39 within the period. These 12 years marked stagnation; there was no growth, and a delay in the production of knowledge was evident, so it was a wasted decade. In the period 2005-2010, the attention on these activities increased, generating the highest increase in the knowledge production indicator in twenty years; going from 0.42 to 0.71 in just five years.

Table 3. Indicators of knowledge economy in Mexico, 1990-2010

Year	Global Index (KEI)	Production	Acquisition	Diffusion	Application
1990	0.21	0.17	0.24	0.01	0.42
1991	0.21	0.15	0.23	0.01	0.45
1992	0.26	0.29	0.25	0.03	0.45
1993	0.26	0.41	0.41	0.05	0.19
1994	0.28	0.36	0.47	0.06	0.23
1995	0.26	0.32	0.37	0.07	0.27
1996	0.26	0.34	0.38	0.07	0.26
1997	0.32	0.34	0.47	0.08	0.39
1998	0.32	0.38	0.37	0.11	0.42
1999	0.37	0.33	0.44	0.15	0.56
2000	0.42	0.42	0.62	0.24	0.39
2001	0.47	0.43	0.64	0.31	0.49
2002	0.49	0.42	0.53	0.38	0.62
2003	0.46	0.40	0.43	0.43	0.57
2004	0.53	0.46	0.67	0.51	0.50
2005	0.55	0.42	0.62	0.61	0.53
2006	0.53	0.48	0.55	0.67	0.40
2007	0.57	0.55	0.61	0.73	0.39
2008	0.59	0.59	0.45	0.79	0.53

Year	Global Index (KEI)	Production	Acquisition	Diffusion	Application
2009	0.67	0.62	0.65	0.89	0.54
2010	0.70	0.71	0.53	0.98	0.59

Source: Author's compilation. The global index was calculated with the average indicator of each activity.

These facts indicate that even in the early 90's, major attention was given to the registration of intellectual property and the sale of incorporated (HTP) and unincorporated knowledge (TBP), although it was neglected for 12 years, then again it has been considered with great interest since about 2005.

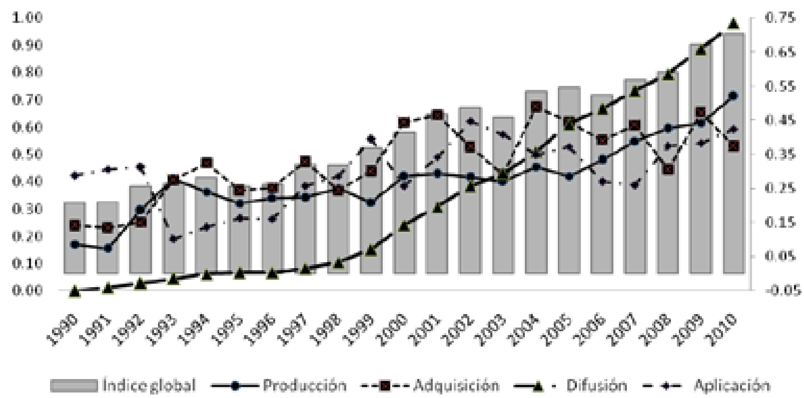

Figure 4. Evolution of knowledge activities in Mexico, 1990-2010 (Standardized Series [0, 1])*

** The standardized values for production, acquisition, diffusion and application of knowledge are presented on the left axis, while the global index of knowledge activities are on the right axis.*

The knowledge acquisition indicator has experienced many ups and downs. In 1990 its value was 0.24, in 2000 it was 0.62, decreasing again in 2010 to 0.53. It shows that the country has not implemented the appropriate policies to achieve an increasing and permanent acquisition of external knowledge. The increasing acquisition of knowledge must also be accompanied by the ability of society and the productive sector (especially firms and workers) to assimilate these imports and also the tacit knowledge that overseas professionals are able to transmit when they return to the country.

It is noteworthy that while the acquisition of knowledge from abroad is necessary in initial stages, the generation of innovations should not be subject to these transfers. However, based on the knowledge produced within the country and supported with the knowledge acquired from other nations, innovations must arise from the dissemination and application themselves. The country should not be dependent on external acquisitions of knowledge; it should be a next exporter.

The major availability of ICTs has increased the capacity of knowledge diffusion, since these tools lead to important network externalities. At the beginning of the period, it was observed that the knowledge diffusion was almost zero, while the indicator went from 0.24 in 2000 to 0.98 in 2010. This is consistent with the ICT's global development and technological improvements, but also their coverage ranges are greater, despite their costs.

The knowledge application indicator shows that, while in the early nineties its average was 0.43, it decreased to 0.19 in 1993, then increased to 0.39 in 2000 and to 0.59 in 2010. The fact that from 1990 to1993 the indicator was around 0.40 is based on the fact that the universities invested in R&D and the National System of Researchers recorded their highest membership numbers. However, both variables have declined since then. From the above, we could make an important point: knowledge application capabilities in Mexico have experienced a lag; the lack of significant efforts in those activities is observable in the stagnation of the indicator with an average value of 0.44 during the last two decades.

KEI shows a growing trend. In the period 1995-1999 the knowledge economy in Mexico improved compared to the values in 1990-1994, with the highest growth rate in the indicator of diffusion. However, the greatest growth performance was observed in 2000-2004, except in knowledge production, which had its peak in 2005-2010. In the last five years that were analyzed, the acquisition and application of knowledge were both weakened, as those activities reported negative growth rates for that period.

In general, over the past two decades, a significant increase in diffusion activities was observed, as a consequence of the global introduction of ICTs, enabling knowledge to be distributed to a larger number of fields. Brătianu and Orzea (2013) develop a set of strategies to promote policies for dissemination of knowledge using social networks. However, the KEI has had a pretty slow growth, less than 5% annual average in the periods of 1995-1999 and 2005-2010, and less than 11% in the period of 2004-2010.

The next step was to apply a co-integration[1] analysis in order to assess the relationship and the intensity of the compound indicators for each knowledge activity and the economic performance of Mexico. First, we propose a model where KEI is an independent variable and then a model that contains the four knowledge activities, both to explain economic performance as shown in the following table.

Table 4. Estimations for knowledge activities and GDP per capita in Mexico, 1990-2010

Variables	Model 1 Log (GDPpc)	Model 2 Log (GDPpc)
C (intercept)	9.752	9.935
Log (global index)	0.653* (0.046)	
Log (production)		0.544* (0.134)
Log (acquisition)		0.074 (0.144)
Log (diffusion)		-0.001 (0.001)
Log (application)		0.278* (0.088)
R2	0.91	0.82

Note: The standard errors are in parenthesis. The (*) corresponds to significant coefficients of 5%.

According to Model 1, the relationship between the KEI and Mexico's economic performance is positive and significant which coincides with the theory. From the table above, the KEI coefficient means that a 1% increase in this variable produces a 0.65% increase in GDP per capita. Both models cointegrate in the sense of Engle and Granger (1987).

Model 2 shows that the acquisition and dissemination of knowledge activities are not significant in explaining the variations in GDP per capita, while production and application are.

The results of the second model indicate that the production of knowledge has a major role in the knowledge-based economy of Mexico. A positive aspect of this is that the evolution of knowledge production in Mexico has picked up in recent years, regaining the importance that it should have according to the

[1] Prior to the analysis, we ran the unit root tests (see appendix) and all the integrated variables resulted in order one, ensuring the effectiveness of the method. In this sense, the co-integration test estimates the regression residuals and verifies that they are integrated in order zero.

results. On the other hand, it is also worth directing efforts toward application, which renews the virtuous cycle of research, invention, and innovation.

Conclusions

The hypothesis that knowledge activities are positive and significant to economic performance is partially accepted. While the production and application performed as expected, the values of acquisition and diffusion activities are not significant. The global knowledge economy index is positive and significant and the degree of explanation is superior to the disaggregate model of knowledge activities, possibly explained by the systemic effect of the activities together, which are not reflected individually. According to Antonelli (2009), activities related to knowledge integrate a complex system such it can be studied from theories of complexity.

The activities that were significant seem to show higher productivity, that is, the sector that produces knowledge is more productive than the industrial sector where knowledge is applied; this could explain the non-significance of acquisition. In the case of diffusion, its exponential growth in recent years has not been accompanied by a higher productive application of knowledge. The fact of having increasing diffusion activities does not guarantee that knowledge will bring benefits to the society. Economic benefits of a growing knowledge base economy are achieved when they are adapted and applied to the industrial system and then disseminated to the entire production network. Even though the conduits for diffusing knowledge are the same in the country's producers the assimilation and application are different in each country and region (Lall, 1992; Stoneman & Battisti, 2010). Brătianu & Orzea (2013) based on previous reviews propose a set of strategies to promote policies for dissemination of knowledge, they suggests the application of social networks.

One of the limitations of this research is the measurement itself. The implementation and measurement of knowledge activities have complex dynamics. While the production of knowledge is considered a measurable item, there is an amount of tacit knowledge in everyday life that is not measurable or registered. The application of knowledge varies depending on its complexity and the different skills of those who implement it. The acquisition of knowledge has different unregistered elements, such as the informal acquisition, the different qualities of the acquired knowledge and the characteristics of who acquires the knowledge. Perhaps, the most complex indicator is the diffusion of knowledge, which mainly occurs through invisible channels, from person to person, linking tacit knowledge, this phenomenon is hard to quantify. In this dynamics the countries have their own development imitating strategies in the first stages, where they have a good chance for illegal imitation which only takes pace during a transitional period (Richter & Streb, 2011)

In this paper we presented some evidence of the systemic view of knowledge and the possible effects that each activity generates individually. Therefore, in future research, it would be interesting to do an in-depth study of the different types and qualities of knowledge activities.

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Appendix

Summary of unit root tests applied to the time series

Variables	Dickey-Fuller		Phillips-Perron		KPSS		Integration Order
	Level	1st difference	Level	1st difference	Level	1st difference	
GDP	-2.37	-3.49*	-2.05	-3.96*	0.13	0.06	I(1)
KEI	-2.81	-5.42*	-2.81*	-5.60*	0.08	0.16*	I(1)
Production	-2.89	-4.36*	-2.88	-4.36*	0.12**	0.16*	I(1)
Acquisition	-3.07	-5.43*	-2.84	-11.47*	0.16*	0.30*	I(1)
Diffusion	-2.89	-4.36*	-2.88	-4.36*	0.12**	0.16*	I(1)
Application	-2.67	-4.93*	-2.62	-4.98*	0.08	0.12**	I(1)
Resid1	-2.19*	-	-2.27*	-	0.14	-	I(0)
Resid2	-3.22*	-	-2.35*	-	0.21*	-	I(0)

Source: Author's compilation.

** 5% of significance to reject the hypothesis of non-stationarity.*

*** 10% of significance to reject the hypothesis of non-stationarity.*

All variables are expressed in logarithms.