Management Dynamics in the Knowledge Economy
Vol.3 (2015) no.2, pp.213-236; www.managementdynamics.ro
ISSN 2392-8042 (online)

Knowledge-Based Economy in Argentina, Costa Rica and Mexico: A Comparative Analysis from the Bio-Economy Perspective

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Abstract. *The objective of this article is to determine the necessary institutional characteristics of technology and human capital in Argentina, Costa Rica and Mexico in order to evolve towards a knowledge-based economy, addressing the importance of institutions for their development. In particular, the knowledge-based economy is analyzed from the perspective of bioeconomics. Based on the Knowledge Economy Index (KEI) which considers 148 indicators, in the following categories: a) economic performance and institutional regime; b) education and human resources, c) innovation, and d) information and communication technologies, we selected 13 indicators. We aim to identify the strengths and opportunities for these countries in order to meet the challenges that arise from the paradoxes of technological progress and globalization. In this sense, bioeconomy is approached as part of the economy. This analysis shows, among other things, that Argentina has greater potential to compete in an economy sustained in the creation and dissemination of knowledge, while Costa Rica has an institutional and regulatory environment that is more conducive to the development of business activities, and Mexico faces significant challenges regarding its institutional structure, economic performance and human resources.*

Keywords: *knowledge-based economy, bioeconomy, institutions, higher education, human resources, innovation.*

Introduction

The remarkable scientific and technological development that has been observed in recent decades has boosted production growth and economic wealth levels unprecedented in world history. The World Gross Domestic Product (GDP) doubled between 2000 and 2012.

However, this process has been accompanied by paradoxical consequences. While there have been increases in production and wealth, in contrast, income inequality has grown along with a lack of opportunities for individuals and access to basics such as food, health, education and energy resources for production. The gap has increased significantly on global and national scales (Valero, 2002; Milanovic, 2012; UNDP, 2014; Lopez-Leyva, Castillo-Arce Torres Ledezma & Rios-Flores, 2014). In the words of Bourguignon (2015, p.3), “the expansion of international trade, the mobility of capital and labor (notably for the most skilled), and the spread of technological innovation have partially bridged the gap between the wealthiest and the developing countries”.

This research derives from the observation that in the context of global inequality, the increasing demand for natural resources, as a result of rising global production and the search for new sources of energy, has negatively affected other important aspects related to the conservation of the planet. Such as, the increasing levels of environmental pollution, global warming, and change in the production, access and quality of foods (Sachs, 2005). According to the Food and Agricultural Organization (FAO), food production should be increased as much as 70% by 2050 (FAO, 2009).

In order to mitigate the problems, the situation has been addressed through academic research (Dosi, Freeman & Fabiani, 1994; Brooks & Barfoot, 2013), technological developments, policies and new schemes of organizing economic activity (Muñoz, 2001; Trigo & Falck Zepeda, 2010). A relevant example of the above is bioeconomy, which implies a knowledge-based economy that seeks for a better and more sustainable use of resources through technological innovation (Trigo & Villarreal, 2009) and must be accompanied by the participation of government institutions, civil society, academics, research organizations and private enterprises (Pavone, 2012). The Organization for Economic Cooperation and Development (OECD) defines bioeconomy as "the contribution of biotechnology to agriculture, health and industry in order to increase their economic potential" (OECD, 2009, p.19).

Genetic engineering in agricultural production is one of the tools of biotechnology that has caused some controversy, specifically the production of transgenic crops through genetically modified organisms (GMOs). The academic discussion regarding the importance and appropriateness of using biotechnology is increasing and diverse.

On one hand, some authors suggest that the use of GMOs could have negative long term effects on human and animal health (Pavone, Goven & Guarino, 2011; Fernandez, 2009), while others question the independence and confidence of the evaluation studies that expose the risks of using genetically modified organisms when it is known that most of the studies are performed by the same multinational enterprises that produce GMOs (Johnson, Raybould, Hudson, & Poppy, 2007 cited in Pavone et al., 2011). Furthermore, Amartya Sen (1988) notes that the structure of property rights in the food industry has impact on the economic inequality in developing countries.

On the other hand, the supporters of this technology proclaim it as a fundamental key to attend food insecurity and malnutrition in developing countries. They also assure that it counteracts environmental degradation (FAO, 2004). An aspect aside from the ethical discussions argues that countries with more and better performances in terms of their bioeconomy shall have greater productive capacity, which will positively impact the economic growth of the sector (OECD, 2009).

Despite the scientific and technological debate and the political discussions regarding the genetically modified organisms, Trigo et al., (2013, p.2) aptly stated that: “technological agriculture evolves sustainably and slowly, becoming the norm rather than the exception”. Therefore, from our perspective this issue becomes relevant.

Under this latter premise, by building a knowledge economy index, this paper analyzes the biotechnological capabilities of the agriculture sector in three countries: Mexico, Argentina and Costa Rica, which differ in terms of economic, political and social performance, but converge in their degrees of richness and biodiversity. Therefore, it is possible to identify the potentialities and problems that these countries face regarding bioeconomy and the challenges that according to FAO are global challenges: food production and quality.

Knowledge economy and institutions

The increasing rate in the creation, accumulation and use of knowledge has led contemporary societies towards a new paradigm known as knowledge economy (Neștian, 2013; Brătianu, 2013), "a system where knowledge is the true essence of competitiveness and the driving force of long term development." (Borroto, 2007, p.32).

International organizations such as the World Bank and the OECD have stated their own definitions of this term. For the former, this economy is "one in which knowledge is created, acquired, transmitted and used more effectively by individuals, organizations and communities to promote economic and social development." (World Bank, 2012) For the second, it is one based directly on the production, distribution, and use of knowledge and information, and supported by the rapid progress of science and the technology of communication and information (OECD, 2003). Besides, the OECD on "The Bioeconomy to 2013: Designing a policy agenda," clarifies that the foundations of the creation and the improvements to accessing knowledge are increasing efficiency, innovation, quality of goods and services, as well as equity. For this organism, what distinguishes a knowledge-based economy is that knowledge not only is created and transferred quickly, but also by being incorporated into the production of goods and services that transform economic and social processes. This creation of knowledge has taken the leading role in the creation of wealth that is based on the use of ideas rather than physical skills, as well as the application of technology over the transformation of raw materials and cheap labor (OECD, 2009).

According to the World Bank, knowledge must be at the core of an economic strategy, based on four pillars: first, a national training educational foundation, in order to create a qualified and educated workforce able to update and adapt their skills to generate and use knowledge efficiently; second, a telecommunication and information infrastructure that eases communication, diffusion and processing of information and knowledge, as well as information and communication technologies (ICT) including telephone, television, radio and networks; third, an innovation system which consists of institutions, research centers, universities, private enterprises, consultants and organizations that generate new knowledge and technology and take advantage of the existent knowledge created globally, making adaptations to face local needs through its diffusion and public investment in innovation, science and technology; and fourth, institutional frameworks of government and business constituted within the institutional regime of a country and a set of economic incentives that allow the efficient mobilization and allocation of resources, stimulate entrepreneurship, promote the creation, dissemination and efficient use of knowledge, as well as public policies from macroeconomic matters to trade regulations, finance and banking, labor markets and governance (World Bank, 2013).

According to Sebastian (2007), in most of the developed countries there are implicit relations between scientific technological knowledge and governance. The latter understood as the recognition of the strategic role of knowledge and the practice of public policies that prioritize scientific and technological development and encourage innovation. This dynamic is the result of the assimilation and internalization of science and technology in the interaction between society and economy. In this regard, Trigo and Villarreal (2009) conceptualized bioeconomy as an economy which basic components are knowledge and life, as the beginning of an alternative form of development in which is possible to replace the use of non-renewable resources for the use of renewable resources and materials that are widely available and can be exploited without damaging the environment. This scientific and technological convergence enables the use of vegetable material and living organisms that are transformed into energy, other products and new value chains, allowing the protection of the environment without reducing the use of workforce.

Bioeconomy has highly impacted the food, health, transportation and construction sectors. The biotechnology related to plants is known as "green biotechnology". One of the technologies rapidly adopted in the agricultural sector is the use of living organisms derived from biotechnology; this has been used for more than a decade. Nowadays, the novelty is the conjunction of a better understanding of global and local problems, and the maturity of national and international political processes such as the United Nations Conferences on Sustainable Development and the International Panel on Climate Change, which generate political commitments and global actions. An important element is the scientific and technological basis that proposes specific actions to generate changes in production processes (Trigo & Henry, 2011).

To complement this, Rodríguez (2011) widens the conceptual debate by emphasizing the importance of ecological or green economy, which is characterized by the intensive use of knowledge. In the green economy, the emphasis is on reducing the use of carbon in the production process. For this author, bioeconomy complements the green economy; both emphasize the importance of biological resources in production processes that are required for sustainable development; they expect the production processes to be consistent with the objectives of sustainable development, which constitute the essence of bioeconomy and green economy, and suggest a techno-economic change.

At this historic moment, not only are biological sciences associated with bioeconomy, but they are also considered as part of other disciplines' scientific development. The knowledge needed to develop bioeconomy is increasingly complex. It integrates sciences such as genomics, biotechnology, nanotechnology, artificial intelligence, and information and communication technologies (Brambila, 2011). From the perspective of this paper, it is worth noting the importance of an institutional environment that promotes ideal conditions for scientific and technological development within the countries. From the European and American experience as well as some Asian countries, it is observed a determining role of the institutions and public policies to make the transition from conventional economy to a bioeconomy (Trigo et al., 2013).

Formal and informal institutions set the rules of the game in a society; they constitute a set of limitations or restrictions that guide the behavior of individuals; their main function is to reduce uncertainty by providing a stable structure for human interactions whether in the political, economic or social areas (North, 1990). A good institutional structure shall generate, for example, incentives to invest and innovate under the protection of property rights, which will impact production and technological development and therefore production costs. Thus, an efficient institution is one that under the existent limitations produces economic growth (Bueno de Mesquita & Root, 2000). This point of view attributes the increases in productivity to the progress in human organization and technological development; it even states that institutional change is critical for a solid and a steady progress of the economy.

Furthermore, authors such as Acemoglu, Johnson and Robinson (2001), Acemoglu and Robinson (2012), and Easterly and Levine (2002) support North's thesis regarding the leading role of institutions in economic development. For them, the origin of institutions has an impact on their own performance, therefore geographical, climate and cultural factors are determinants in the emergence of institutions and have an indirect impact on economic development. For example, Easterly and Levine (2002) state that the main impact of the environment on economic development depends on the role of strong institutions. The authors describe how environments where crops are effectively produced using large extensions of land have political and legal institutions that protect the landowner´s property rights. In this investigation it is concluded that political institutions that promote good governance are the key factor for developing economies.

A National System of Innovation formed by different groups of actors depends on national institutions and is embedded in a national economic structure. Also the countries in a regional level include regional systems of innovation "based on institutions embedded in a local and regional socio-economic context should rather be the perspective for understanding processes of knowledge creation and innovation" (Hansen & Lars, 2012, p.20). The National System of innovation is an institutional framework for designing public policies in science, technology and innovation.

For the neo institutional vision, the successful economic performance of a society is determined by the ability to establish an institutional framework that reduces transaction and production costs, and protects property rights and contracts. It also must promote mutual confidence among its members, guarantee competition and force the government to respect its policies and agreements. Thus, efficient institutions generate positive externalities and public goods for the population. Contrary, low quality institutions and instability diminish social efficiency because they reduce the possibilities of production and exchange (Valdivieso, 2004).

Agricultural biotechnology in the world

The increasing use of biotechnology in agriculture in the world was noticeable between 1996 and 2012, a period in which farmers from 30 countries made the decision to grow a thousand five hundred million hectares with these techniques (James, 2012). The use of biotechnology in the global agricultural sector peaked in 2012 when a land surface of 170.3 million hectares were biologically cultivated representing an increase of 6% (10.3 million has.) compared to 2011; the crops mainly included wheat, cotton and soybeans (James, 2012).

It is relevant to mention that 20 out of 28 countries producing biotech crops in 2012 were developing countries where more than half of the world's population live, however these countries only concentrate 50% of the agro-biotech production, which is consistent with their development level. This fact reveals the potential for this type of production, when it is observed that in 2011 the growth rate was higher in developing countries than in developed countries, 11% and 3% respectively. According to James (2012), these changes in the structure of global agricultural production are somehow due to environmental and socio-economic advantages, but also to the growing confidence of farmers in these technologies which reduce production costs and increase the possibility of a second cycle of crops in the same season, though it also leads to the abandonment of conventional agriculture (Brookes & Barfoot, 2013).

Globally, the top five agro-biotechnological producers among developing countries are China, India, Brazil, Argentina and South Africa, who cultivate 45% of the total global production and concentrate 40% of the world population. According to Trigo and Villarreal (2009), biotechnology has had a global impact in the fight against hunger, so that, for the first time in 2009 the number of small and poor farmers in developing countries benefited from this technology reached 12 million, of which 90% produced genetically modified crops. In this regard/matter, it is observed that 50% of the world's poorest people are small farmers with limited resources, and 20% are rural workers whose only livelihood is agriculture, hence the importance of using these technologies that directly contribute to improve their income and thus contribute to reduce the levels of inequality in the world.

Furthermore, Brookes and Barfoot (2006), cited in Trigo and Villareal (2009), reported that until 2004 the application of pesticides and agrochemicals to biotechnological crops was reduced by 6%, decreasing fuel consumption and the emission of carbon dioxide into the atmosphere in more than one billion kilograms. Additionally, it promoted a conservation tillage that allowed a greater incorporation of organic matter into the soil and saved 9.4 million carbon dioxide emissions, this is another advantage of using biotechnology regarding environmental conservation.

Agrobiotechnology in Argentina, Mexico and Costa Rica

A country's biodiversity wealth is a fundamental factor for the development of a bioeconomy (Trigo et al. 2013), since the application of biotechnology implies the crucial existence of genetic biodiversity within a given location (Abarza, Cabrera & Katz, 2011), therefore in this research we used the National Biodiversity Index (NBI) developed by the Convention on Biological Diversity, which estimates the natural wealth and the endemism of countries regarding four classes of terrestrial vertebrates and vascular plants, in a scale between 1 as a maximum and 0 as a minimum (CBD, 2014). These resources offer comparative advantages in terms of opportunities to generate aggregated value and a sustainable exploitation using new biotechnological tools, an opportunity that has been underlined by the dynamism of the global market for natural products, which has increased by more than 170% between 2002 and 2008 (Trigo et al. 2013); in this regard, even though Argentina, Mexico and Costa Rica are dissimilar in some aspects, their biodiversity indexes are similar and above the global average.

These three economies belong to a group of developing countries that according to the OECD are major long-term markets for biotechnology within the agri-food industry because of their great biodiversity. Mexico is one of the 17 countries called "mega diverse," its national biodiversity index is 0.928 from a maximum of one. Costa Rica's index is 0.820 and 25% of its national territory are protected areas. Argentina's index is 0.615 (Trigo & Villarreal, 2009), furthermore, this country has been named the world´s breakfast due to the increment of agricultural exports in the last thirty years.

Moreover, these countries share a key element for the present analysis: the institutional efforts to increase the use of various biotechnological tools. Certainly in Latin America, biotechnology represents the possibility of increasing the competitiveness of the agricultural sector, at least that is observed in its growing dynamism within these countries (Trigo & Villarreal, 2009).

For example, Mexico was one of the first countries worldwide that started commercial cultivation of genetically modified crops. Since 1996, the cultivation of genetically modified cotton was allowed in the northern side of this country, in an area considered as the main producer of cotton where transgenic soy is also cultivated. In the country there is a big concern regarding the integrity of the indigenous species of corn, as this crop is a symbol of Mexican heritage, therefore the use of biotechnology should allow the protection of native plants (IICA, 2008). In 2009, after a moratorium of 11 years, the Mexican government approved field tests with transgenic corn tolerant to herbicides, in four northern states. The tests were applied in 2010 showing that this crop is as safe as conventional corn, despite these results Mexican law still does not allow the release of genetically modified corn into the environment (AgroBioMexico, 2013). The acreage of cotton and soybeans genetically cultivated in 2011 increased 100% compared to 2010, having an effect on the producers' income and the environment with a smaller amount of insecticides being used (James, 2012). Mexican biotechnology infrastructure includes researchers, research institutes and internationally recognized universities, also has a committee that coordinates the national bio-safety activities and an organized and active private sector that foster the adoption of biotechnology. Public institutions do most of the research in this area and the results are not commercialized, mainly due to a poor communication with the companies, lack of resources and management, transfers and commercialization policies. The reality in the country is that foreign biotech companies have the rights over the genetically modified crops that are currently being released into the environment. The Mexican regulatory framework related to bio-safety is designed to prevent and control the risks from the use and application of biotechnology products on human health, to protect animals, plants and the environment (IICA, 2008).

Biotechnology has led Argentina's development since the eighties, specifically in the agricultural, food, human health and some industrial sectors. Since its adoption in 1996, the cultivation of soybean and cotton genetically modified have increased steadily, making this country the third largest producer of transgenic soybean, having a positive impact on employment within the sector and the income of producers (ArgenBio, 2013). To a large extent this situation is the result of an appropriate regulatory environment, promotion policies and the economic benefits of this activity (Trigo & Henry, 2011). Clearly the strengths of this country are: the availability of high quality human capital, productive and innovative resources, versatility and innovation. The biotechnology industry has significant support from the public sector through various institutions, programs and policies that facilitate and promote basic research and technological development (IICA, 2008). The country has the largest number of researchers in relation to the economically active population in Latin America, of which about 10% are biologists (MRECIC, 2012).

Costa Rica has made strategic decisions in the areas of biotechnology, bio-safety and biodiversity in order to develop its infrastructure and high quality human resources. The effects of joint efforts in education, environmental care and biodiversity are reflected in an increase of the forested area. By 2012 protected areas represented 25% of the national territory. The bio-safety activities consider the implementation of a national bio-safety framework, and as part of this project, the "Strategy on Communication and Education of Biotechnology" was launched. By using biotechnology, state research institutes have contributed to genetic improvements in crops of agricultural importance and to the study of biodiversity. Moreover, in cooperation with the private sector, activities to generate genetic improvements in crops such as rice, banana and pineapple have been implemented. In the last ten years, several companies dedicated to produce and export genetic cotton and soybean seeds have emerged. Even though Costa Rican society has shown clear opposition to the use of some biotechnological tools in the production processes aimed for domestic consumption. Costa Rica as host country of the Tropical Agronomic Center for Research and Education has an important advantage for training specialized human resources and conducting research in biotechnology. The phytosanitary authorities conduct the management of genetically modified organisms following the current international standards on environmental bio-safety (IICA, 2008).

These three countries show differences in the development of their agricultural biotechnology, largely as a result of the different processes when using biotechnology which have shown different degrees of complexity depending on their economic situation, the state of their scientific and technological capabilities, and their institutional context. These countries face the challenge to be part of a new logic and economic dynamic in which knowledge and scientific and technological development are the basis of progress.

Defining a knowledge-based economy and its development implies the combination of certain elements (Sanchez & Rios, 2011):
1) Skilled human capital and knowledge intensive production processes.
2) Level of competitiveness and export orientation.
3) Institutional framework and social capital that reduce uncertainty among the stakeholders building confidence and reducing transaction costs.
4) Innovation systems and entrepreneurial abilities.
5) Communication, information and technology infrastructure.

Methods and data

Comparing innovation processes among regions represents several problems due to the heterogeneity of the factors involved in them. Capello and Lenzi (2014, 2013) developed the concept of territorial patterns of innovation, which suggests that both important internal and external factors drive creation and innovation. Camagni and Capello (2013) point out two key concepts that should be taken into account in the design of policies of innovation for regions and countries; there are “embeddedness” and “connectedness.”

Recognizing the factors that define a knowledge-based economy allows determining the indicators that make possible to perceive the degree of integration of a country in the dynamics of a knowledge economy. The

World Bank (2012) built the Knowledge Economy Index (KEI) through the program "Knowledge for Development," which serves to establish the level of expertise that countries have to compete in an economy based on the creation and dissemination of knowledge in order to identify the strengths, challenges and opportunities within the four pillars of a knowledge-based economy, Figure 1.

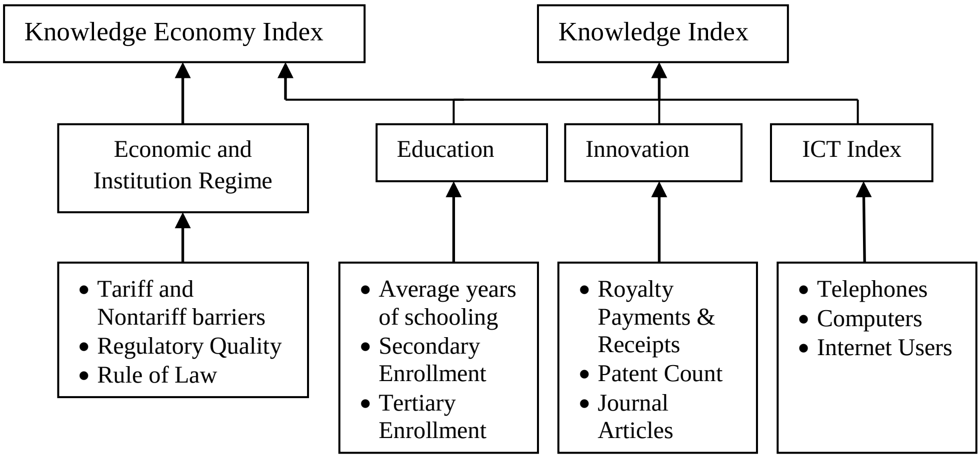

Figure 1. World Bank knowledge-based economy indices
Source: World Bank (2012)

These factors determine if the environment is conducive for knowledge, so it can be effectively used to generate the necessary technological innovation to foster economic development. It is an aggregate index that represents the overall level of development within a country in relation to the knowledge economy. The indicator values are on a scale of 0-10, where 0 indicates weakness to compete in a knowledge economy and 10 represents a high potential.

The components of the indicator are:
1) Economic performance and institutional regime.
2) Education and human resources.
3) Innovation system.
4) Information technologies (ICT).

To measure the components, this methodology uses 148 indicators that allow making comparisons among the 128 countries that are part of the sample, starting with the calculation of each country's KEI. Normalization is performed based on absolute values, so that:

$U = 10 * (1- Nh / Nc)$, where:

(U) = Normalized value
(Nh) = Place in the sample
(Nc) = Total number of countries in the sample

For this work, we created a simplified and adapted version of this methodology, which includes 13 indicators taking into account the availability of data for the three countries between 2007 and 2010. We used the most recent available data from formal institutions of each country. In addition, we found that these indicators were representative of the four KEI components, Table 1.

Table 1. Components and Indicators of the Knowledge Assessment Methodology for Argentina, Costa Rica and Mexico, 2013

Economic Performance and Institutional Regime
1. GDP average annual growth (%)
2. Human Development Index
3. Property Rights
4. Regulation
Education and Human Resources
1. Percentage of the literate population older than 15 years
2. Rate of college enrollment
3. Public expenditure in education as a percentage of GDP
Innovation
1. Expenditure on R & D as a percentage of GDP
2. Number of scientific articles per million inhabitants
3. Number of patents approved by WIPO per million inhabitants
Information and Communication Technologies
1. Total number of telephones per 1000 inhabitants
2. Computers per 1000 inhabitants
3. Users of Internet per 1000 inhabitants

Source: Own elaboration with information from the Knowledge Assessment Methodology, World Bank (2013).

Once we have normalized the values for each selected indicator, we used the simple average with two purposes: first, to calculate the four components values and, second, to obtain the KEI for each country.

Furthermore, this methodology was adapted to assess the agro-biotechnology component considering the surface (million/hectare) of biotechnological crops with data from the report "Global Status of biotech crops in 2009, ISAAA". This sample only includes biotechnological crop producers from Latin American countries. Table 2 shows the surface of biotechnological cultivations in the three countries for 2009.

Table 2. Agro-biotechnological Cultivations in Argentina, Costa Rica y México in 2009 (million hectare)

Position	Country	Surface (million of has.)	Biotechnological crops
1st	Argentina *	21.3	Soybean, corn and cotton
2nd	México *	0.1	Cotton and soybean
3rd	Costa Rica	<0.1	Cotton and soybean

**Countries with at least 50,000 hectare biotechnologically cultivated*
Source: James (2009, p.5)

To strengthen the analysis, we checked whether there is consistency between the results of the KEI and other international indices, such as the International Index of Property Rights, an annual study whose purpose is to compare the protection of physical and intellectual property rights among countries (IPRI, 2014).

Results

Table 3 shows the results obtained from current and normalized data. It is observed that Costa Rica obtained the highest values in the indicators of economic performance and institutional regime, Argentina's highest indicators are in education and human resources, innovation and ICT, and Mexico obtained intermediate values in the four components.

Table 3. KEI components with current and normalized values with their respective indicators for Argentina, Mexico y Costa Rica

Component	Indicator	ARGENTINA		MEXICO		COSTA RICA	
		Current	Normalized	Current	Normalized	Current	Normalized
1. Economic performance and Institution Regime Index	GDP average annual growth (%), 2005-2009	6.8	8.33	1	0.83	5	7.08
	Human Development Index, 2010	0.78	8.4	0.75	7.2	0.73	6.4
	Private property rights, 2009	-0.9	1.92	0.35	6.15	0.53	8.85
	Regulation, 2009	-0.66	4.23	-0.57	5.77	0.56	8.08
2. Education and human	Percentage of the literate population older	97.73	7.69	93.44	5.38	96.06	6.92

resources	than 15 years, 2007						
	Rate of college enrollment, 2009	69.38	9.2	27.87	4	25.34	3.6
	Public expenditure in education as a percentage of GDP, 2009	5	7.89	5	7.89	6	9.47
3. Innovation	Expenditure on R & D as a percentage of GDP, 2009	0.52	8.46	0.37	6.15	0.4	6.92
	Number of scientific articles per million inhabitants, 2007	85.19	9.62	40.12	7.69	22.46	6.54
	Number of patents approved by WIPO per million inhabitants, average 2005-2009	1.12	8.85	0.82	7.69	3.91	9.62
4. ICT	Total number of telephones per 1000 inhabitants, 2009	1530.00	8	960	3.6	760	1.6
	Computers per 1000 inhabitants, 2008	260	6.92	140	5.38	340	8.46
	Users of Internet per 1000 inhabitants, 2009	300	6.4	260	4.4	340	7.6

Source: Own elaboration with data from: Knowledge Assessment Methodology (KAM), World Bank (2013).

The results obtained by integrating KEI components with agro-biotechnology show that Argentina has the highest KEI with 7.61 points which means that in relative terms the country has a greater potential to compete in an economy based on the creation and diffusion of knowledge, followed by Costa Rica and Mexico that obtained 5.57 and 4.95 points, respectively. See table 4.

Table 4. Estimation of Knowledge Economy Index considering the component of agro-biotechnology for the countries of Argentina, Mexico and Costa Rica

KEI Components						
Country	1. Economic performance and Institution Regimen Index	2. Education and human resources	3. Innovation	4. ICT	5.Agro-biotechnology	**KEI**
Argentina	5.72	**8.26**	**8.98**	**7.11**	**8.00**	**7.61**
Mexico	4.99	5.76	5.56	4.46	4	4.95
Costa Rica	**7.6**	6.66	7.69	5.89	0	5.57

Source: Own elaboration with information from: James (2009, p.5)

Although Costa Rica's KEI is 5.57, the components of economic performance and institutional regime obtained a value of 7.61 points which means that the institutional and regulatory framework of this country is more conducive for business activities. Meanwhile, Argentina and Mexico ranked in lower levels with 5.72 and 4.99 points respectively.

Regarding economic performance, considering the GDP annual percentage growth from 2005 to 2009, Argentina ranked at the top with 8.33 points, Costa Rica in the intermediate level with 7.08 points and Mexico ranked in a very low level with 0.83 points.

These results demonstrate the relationship between a solid institutional regime and the productivity of a country; both are determinants of economic growth. Costa Rica's economic performance and institutional regime ranked over the average, showing a positive relationship between the indicators involved, not being so in the cases of Mexico and Argentina.

The indicator value regarding the GDP annual growth of Mexico was very low, that is 0.83 points; similarly the regulation indicator value was low with 5.77 points. From this information it is possible to identify a very important area of opportunity for the country's development, which is the generation of a regulation framework that foster business activities.

According to the data in Argentina there is a lack of appropriate regulations for entrepreneurship, however, it obtained the highest score in the GDP average annual growth, which may be the consequence of the relatively better results in education, human resources and innovation that reflect the existence of a favorable environment for the creation, dissemination and use of knowledge.

It also has been found consistency between these results and those obtained in the 2013 report of the International Property Rights Index (IPRI) that states that Costa Rica has a better political and legal environment for the protection of property rights, which suggests a relatively stronger institutional structure, see Table 5.

Table 5. International Property Rights Index for Argentina, Mexico and Costa Rica

	Argentina	Costa Rica	Mexico
Legal and political environment	4.2	6.3	4.2
Physical property rights	4.7	6.2	5.8
Intellectual property rights	4.8	5.1	5.7
Total	**4.6**	**5.9**	**5.2**

Source: Own elaboration with information from the International Property Rights Index (2013).

IPRI was developed to serve as a barometer of the global situation of property rights. Its components are political and legal environment, physical and intellectual property rights. As stated by the Institutional School (North, 1990; Acemoglu et al., 2001), political and legal environment have a significant impact on the forms of property rights, which are vital for the economic development of a country. In this sense, the results of our analysis are consistent between the levels of knowledge economy, institutional performance and economic growth rate. Therefore the premise is satisfied, since an economy with a solid institutional framework in the area of property rights creates confidence for the protection of private property rights and there is certainty and incentives for innovation (Bueno de Mesquita & Root, 2000).

Regarding education, which is a decisive factor in shifting towards a knowledge-based economy, Mexico and Costa Rica recorded intermediate levels in the percentage of the literate population older than 15 years according to 2007 data, and Argentina is located above the intermediate level. With information from 2009, the college enrollment rate in Argentina obtained a high score with 9.2 points, and Costa Rica and Mexico scored below the intermediate level with 3.6 and 4 points respectively. Same year, the three countries recorded relatively high scores regarding public spending on education as a percentage of the GDP, Costa Rica achieved the highest score with 9.47 points and Argentina and Mexico obtained 7.89 points each.

In conclusion, concerning the education and human resources component, Argentina obtained a high score with 8.26 points, unlike Mexico that scored in the lowest level with 5.76 points, and Costa Rica is at an intermediate level with 6.66 points. These results are consistent with the premise that in a knowledge-based economy to have a national educational foundation that generates a workforce of educated and skilled workers is essential. From the results, we could also state that Mexico and Costa Rica have large areas of opportunity regarding the coverage and quality of higher education, since they only obtained 4 and 3.6 points respectively.

The first indicator chosen to evaluate the innovation component was the expenditure on R&D as a percentage of GDP in 2009. Argentina obtained a high score of 8.46 points; Mexico and Costa Rica are at an intermediate level with 6.15 and 6.92 points respectively. It is important to note that these three countries invest less than 0.5% of their GDP in research and development, which is very low considering that the most advanced economies invest between 2% and 4%. The second indicator is the number of scientific articles produced for every million of inhabitants in 2007. Argentina obtained the highest score with 9.62 points, while Mexico and Costa Rica are at an intermediate level with 7.69 and 6.54 points respectively.

Patents are the third indicator of the component, and it is very relevant because they protect the inventions, industrial designs and trade secrets, and they also stimulate and protect innovation, invention and technology creation. The indicator represents the number of patents approved by the World Intellectual Property Organization (WIPO) per million inhabitants for 2005-2009. The three countries obtained scores above the intermediate level. Costa Rica obtained the highest with 9.62 points, secondly Argentina obtained 8.85 points and Mexico is in third place with 7.69 points. A common feature shared by the three economies is that the vast majority of patents that are approved by WIPO take the form of patents granted to foreigners within the national territory. This could be a result of the low investment in research and development, which indicates technological dependency.

We could say that Argentina has an efficient innovation system since its indicator value was 8.98 points; Costa Rica shows a fairly efficient innovation system with 7.69 points, and Mexico obtained the lowest score of them with 5.56 points, this represents an area of opportunity for Mexico to improve its innovation system.

The fourth component to measure KEI is the ICT, which may facilitate an effective communication, the transmission, dissemination and process of information in a knowledge-based economy. Mexico had the lowest score with 4.46 points followed by Costa Rica with 5.89 points, placing these two countries at an intermediate level. Argentina scored 7.11 points, slightly above the intermediate level. ICTs are the essential infrastructure of an economy based on information. ICT's include telephone, television, radio and networks. In this regard, the increasing public access to telephony and networks is an area of opportunity for the development of these three economies in their transition to a knowledge–based economy.

Argentina is the second most important Latin American country in biotechnological production, which coincides with the results of our calculations, where this country obtained 8 points regarding this component, placing it in the highest position. Mexico is at an intermediate level with 4 points and Costa Rica with zero points appears in last place, reflecting its smaller territorial capacity for agricultural use and the opposition of society to use some biotechnological tools in the production processes for domestic consumption.

Overall, Argentina has the highest KEI, although if we modify its calculation and eliminate the agro biotechnology component, the results change and Costa Rica would obtain 5.57 points which is very close to Argentina with 6.01 points. What that tells us is the relevance of this last component. This finding emphasizes the importance of the institutional context, property rights and certainty for a knowledge-based economy. It has also been observed that there is a big difference when comparing the indicators of economic growth between Mexico and Argentina, despite the small difference among their institutional performance indicators, which could indicate that relatively small changes in this indicator have significant multiplier effects on innovation and thus on economic growth.

Conclusions

For Argentina, Costa Rica and Mexico, bioeconomy is the expression of a knowledge-based economy that cares for a better and more sustainable use of resources through technological innovation; it is the result of their performance achieved planned or not by different agents in the public and private sectors. Theoretically, countries with a higher and better performance in terms of their bio-economy will be better able to meet the challenge of the paradoxes of technological progress and globalization.

Each of these countries has public and private institutions that contribute to the crops genetic improvement, giving importance to their agricultural sector. Furthermore, they stimulate the development of qualified human resources and technology. Likewise, the three countries have directed their efforts toward international harmonization of their respective regulations regarding bio-safety and intellectual property. The aim is to ensure the public good over private, involving the participation of diverse social agents.

It is also worth to mention that Argentina has a better institutional context to pursue the generation of human capital in a knowledge-based economy. Costa Rica and Argentina have stronger institutions regarding innovation systems to expand technology within a knowledge-based economy. And, as for the necessary means to facilitate the effective communication, dissemination and processing of information in a knowledge-based economy, Mexico and Costa Rica have an area of opportunity.

Beyond the findings of this investigation, where the erratic behavior of some indicators related to the institutional, economic and human factors within these countries, it is useful to identify their weaknesses and strengths to face the challenges of moving from a conventional economy to a knowledge-based economy, in particular the development of agricultural biotechnology.

The main challenges of these economies are related to the generation of human capital capable to tackle the technological progress; coordinated work for the creation and dissemination of knowledge generated through technology transfers between higher education institutions, public and private research centers and the productive sector; and strengthening institutions that facilitate innovation processes, generate certainty for stakeholders and promote economic development. According to Lopez Leyva (2014), connections and relationships within the society are a process not a spontaneous event, which is being developed just as the productive and academic structures change; this requires a certain degree of institutional development. Among the countries studied, Mexico has a major disadvantage regarding these factors and it can be observed in its low KEI. Costa Rica and Argentina have advantages and disadvantages in some of the KEI components; the first one has a better institutional and regulatory environment conducive for the development of business activities, the latter has better indicators regarding human capital formation.

The use and application of biotechnology in the agriculture sector of these economies may allow them to generate the tools to face what Ohmae (2008) points out as the challenges of a global technology-driven economy where knowledge is the most valuable factor that emerging nations should use to boost economic growth. Growth that can be seen in the improvement of the producers' quality life, the acquisition of new skills and their empowerment as being involved in the dynamics of global markets.

Another measure of success for these countries is the expansion of knowledge creation in basic scientific research, which has a central role in the application of biotechnology to agriculture.

While this work shows important findings for understanding the dynamics that lead to knowledge-based economies, it is important to add other countries to the analysis to weigh and contextualize the results in the Latin American context in order to get more and better elements for public policy decisions.

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