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Measuring innovation in the context of emerging and converging technologies: some methodological reflections

Medir la innovación en el contexto de las tecnologías emergentes y convergentes: algunas reflexiones metodológicas

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ABSTRACT

Emerging technologies have been analyzed from the innovation systems theoretical approach. This has meant starting from the premise that the development, use, dissemination and exploitation of technology are similar behaviors that exhibit any other traditional economic sector. However, this omits the fact that emerging technologies have particularities that range from the characteristics of the parties involved, the property rights, the social, technological and institutional dynamics in which they are involved; even the methodological definition of the object of study. This without forgetting the difficulties of access and categorization of information, as in all cases discussed here, emerging technologies cut across many different economic sectors and therefore its use and application diversifies into different process, products and services. This article aims to present a reflection on the possible non-exhaustive methodological alternatives for the study of emerging and/or convergent technologies, such as biotechnology, nanotechnology, information technologies and genomics, among others, as well as to discuss the relevance of using the framework for the analysis of innovation systems. Without this means discarding its application, but rather establishing complementary schemes that help us have a better understanding of the dynamics and evolution of these technologies.

Keywords
Innovation; Emerging technologies; Technological convergence; Science and technology indicators

RESUMEN

Las tecnologías emergentes han sido comúnmente analizadas desde la perspectiva teórica de los sistemas de innovación. Esto ha significado partir de la premisa de que el desarrollo, uso, difusión y explotación de la tecnología son comportamientos similares a los que exhibe cualquier otro sector económico tradicional. Pero esto omite el hecho de que las tecnologías emergentes tienen particularidades que van desde las características de los actores involucrados, los derechos de propiedad, las dinámicas sociales, tecnológicas, económicas e institucionales en las que se ven insertas, hasta la propia definición metodológica del objeto de estudio. Lo anterior sin obviar las dificultades de acceso y categorización de la información, dado que en todos los casos que aquí se tratan, las tecnologías emergentes son transversales a muy distintos sectores económicos y, por tanto, su uso y aplicación se diversifica en diferentes procesos, productos y servicios. Este artículo tiene por objetivo presentar una reflexión acerca de las posibles alternativas metodológicas no exhaustivas para el estudio de las tecnologías emergentes o convergentes, como la biotecnología, la nanotecnología, las tecnologías de la información y la genómica, entre otras, así como discutir la pertinencia de usar el marco de análisis de los sistemas de innovación, sin que esto signifique desechar su aplicación, sino más bien establecer esquemas complementarios que nos ayuden a tener una mejor comprensión de la dinámica y evolución de dichas tecnologías.

Palabras clave
Innovación, tecnologías emergentes, convergencia tecnológica, indicadores de ciencia y tecnología

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Introduction

In economic science, the industrial analysis usually starts with the presentation and collection of macroeconomic variables, which are later broken down until the specific study of industries with traditional variables including the gross value of production, different types of investment, added value, among others is reached. This allows us to move along a methodological way which is already known by economists who can have access to diverse types of information, like census information, indicators and surveys, which allows them to compare periods and industries in several ways.

Nonetheless, when speaking of emerging and converging technological sectors, such as biotechnology, nanotechnology or genomics, there are several challenges in the analysis, because there are no defined data collection systems on the technological and organizational innovation processes, at an industrial or sectorial level. In some cases, characterization of the industry or technological sector implies previous methodological work which allows us to identify variables and the most appropriate methods to approach the phenomenon under study.

Emerging and converging technologies are employed in literature as a term to refer to the appearance (emergence) and to convergence processes of new technologies. These have relevant technical, economic and social potentials that may change full industrial sectors –or even create new sectors–, which have also earned the adjective of disruptive technologies (Foladori & Invernizzi, 2006).

These technologies have an influence on scientific and technological structures as new techniques, approaches, theoretical and methodological frameworks in the production and validation of new knowledge are proposed. Furthermore, over the last decades, we have seen modern dynamics in the production of scientific and technological knowledge which, in turn, imply other ways in the dissemination of knowledge, as well as diverse structures in the organization of scientific and technological work. All of these characteristics and particularities in emerging and converging technologies require of novelty approaches for the study of innovation processes.

Said approaches require correlation of two traditionally separated levels: a quantitative and a qualitative type of research. Moreover, consideration of a multidisciplinary approach enabling the construction of an explanatory scheme as comprehensive as possible is required. This, in turn, requires of a multilevel analysis and of an epistemological discussion on the definition of the research questions.

This text proposes that a reflection be made on the need for non-exhaustive or supplementary methodological strategies to build indicators that may be used in the analysis of innovation of emerging and converging technological sectors. Different examples are mentioned synthetically on how some data may be used and on the analysis levels where work may be done depending on the own nature of the subject of study.

The contents of this article are presented as follows: in the first section, several concepts are resumed on innovation and the severity implied by the use of scientific, technological and innovation indicators proposed by international manuals is discussed. The second section makes a reflection on how to respond to new dynamics, contexts, forms and governance mechanisms in the production of new knowledge.

The third section makes a systematic presentation on what emerging and converging technologies are, with the purpose of understanding what is explained in the fourth section, where the difficulty implied by the analysis of said technologies is outlined and, from the technological convergence approach, several methodological items which may be used for this type of analysis are proposed.

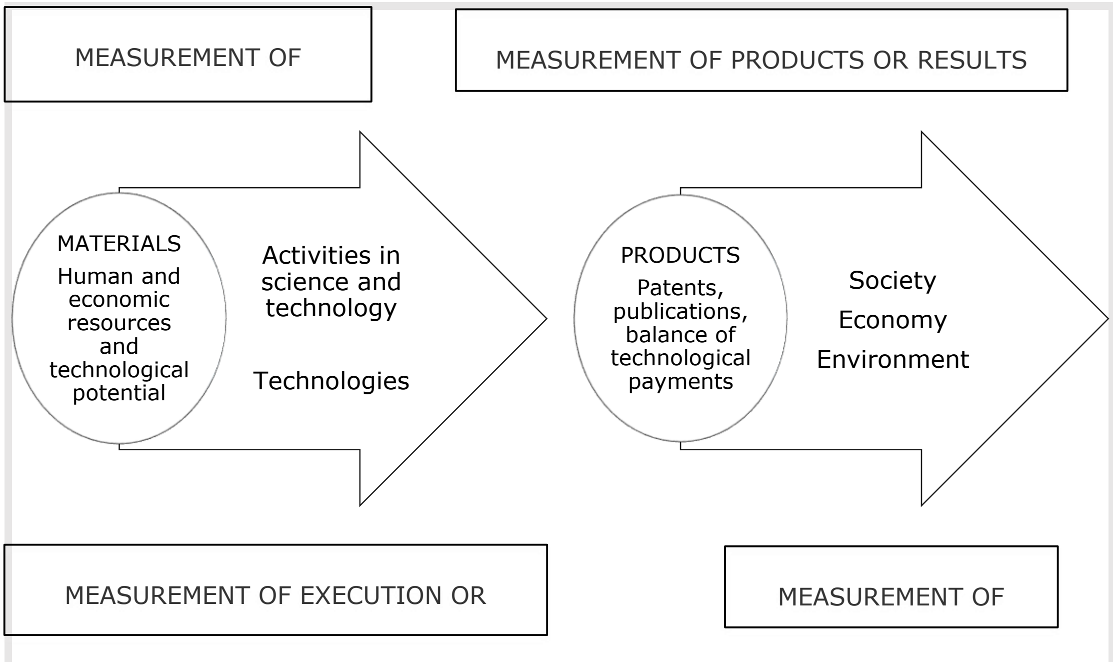
Innovation and indicators

Science, technology and innovation have been considered as determining factors for economic and social development (CEPAL, 2001). Assuming these three elements as drivers of change and progress has implied that public policies are designed to foster them at diverse levels, such as the instruction of human resources, installation of infrastructure, and the promotion of community outreach, cooperation and entrepreneurship.

In the case of Mexico, designing public policies has been based, above all, on the use of indicators as the supply for the formulation of said policies; with this, special emphasis has been made on variables such as the expenditure on research and experimental development (GIDE, by its acronym in Spanish), the percentage of the gross internal product (GIP), the federal expenditure on science and technology (GFCyT, by its acronym in Spanish), the whole personnel of researchers engaged in scientific and technological activities, as well as the number of items and patents.

However, these added data will not allow us to become aware of the dynamics of the innovation process, but of inputs and outputs; therefore, there is no information about what is happening during the process itself. This is the result of thinking science, technology and innovation as de-contextualized elements from their environment and to leave out the dynamics; although it must be emphasized that there are some reflections such as that of CEPAL (2001), which propose the integration of several measuring phases in a scheme like that in Figure 1.

Figure 1. Science, technology and innovation measuring phases



Source: modified from ECLAC (2001).

In view of the above, it is necessary to reconsider the manner in which innovation is studied and analyzed, and even to contextualize the same concept depending on the characteristics of the phenomenon and of historical, social and economic particularities, among others.

The concept of innovation has been defined from different perspectives; Amaro & Gortari state that the approach of evolutionary economy defines innovation "as the application and use of new ideas, concepts, products, services and practices, intended to be useful in increasing productivity, and it mainly takes place in the company" (Amaro & De Gortari, 2016, p. 89); therefore, it is only materialized by means of monetary gain.

The above notwithstanding, this is a highly narrow and insufficient vision to analyze the innovation process, for there are elements such as learning, interactive processes, cooperation and coordination among actors and levels that are highly important (Lundvall, 1992; Edquist & Björn, 1997; Dosi, 1994). In accordance with Cimoli (2000), innovation is a social process evolving with greater success if inserted in a network of intensive interactions between suppliers and buyers of goods, services, knowledge and technology, as well as universities and governmental organizations that promote the infrastructure of knowledge.

Innovation is continually associated to activities done in the technological borderline, therefore, a very important role is given to what is happening in the scientific, technological and the research and development process (Mytelka, 2000); nonetheless, this leaves imitative innovation or incremental innovation in the margin. Undoubtedly, these elements are important to underdeveloped countries, as there are different characteristics in the innovation process from the dynamics of developed countries, where national policies, technology transfer processes, the organizational process, incentives and the establishment of cooperation relations play a major role for innovation.

Moreover, innovation, seen from a continuing learning process, with consecutively organizational changes, requires of a concept to consider companies and organizations that contribute to changes in the production chains of goods and services, regardless of whether these contributions are not necessarily new to their competitors (Mytelka, 2000).

Extending the innovation concept makes us think about it as a possible answer to the solution of social problems; although, from our perspective, it is important to place innovation not as a goal *per se*, but as a possible answer to some problems of the society. The solution of local problems ought to be in the center of the innovation logic (Antonelly, 2001), as the construction of results arises from problems of the market, of science and technology, and they become relevant as they are related to a social need.

It is necessary to remember that the global context defines a large part of the interactions of some countries with others, and that, above all, there are unavoidable forces that determine the performance parameters of national actors involved in innovation processes (Metcalfe & Ramlogan, 2008). The innovation process is a complex one, therefore it is important to consider different levels: the market, the knowledge production dynamics and the transfer of knowledge, technological production, innovation barriers, cultural and social aspects, public policies, even regional, national and international contexts.

In the definitions on innovation, it is interesting to recover its concept as a social system: "Innovation systems may be considered as sets of different institutions and social actors who, both by their individual action and by their interrelations, contribute to the creation, development and dissemination of new productive practices" (Albornoz, 2009, p. 14). This is due to the fact that innovation processes are considered to be non-linear, they acknowledge the dynamic character and see interrelations between institutions and actors who participate; in addition, they take specific contexts into account where innovation is taking place.

From the above premises, classical indicators to measure innovation limit our understanding and explanatory abilities of these processes. It is true that these indicators enable the assessment of innovation systems and that, as they become standardized and proposed by international entities, and adopted by national entities, comparisons may be made. However, as mentioned above, these indicators only show part of the innovation processes and leave aside the new elements of emerging and converging sciences and technologies. To overcome these limitations, it is necessary to set other elements into action to account for the dynamics in new sciences and technologies found in the foundations of innovation.

New dynamics in the production of science, technology and innovation

Over the last decades, the appearance of new sciences and technologies as well as the convergence of several disciplines, has implied amendments in the traditional way of production, use and dissemination of new knowledge. These changes have attracted the attention of several scholars in social sciences, who have proposed different approaches for their study, such as innovation systems, the triple helix, the new production of knowledge (mode 1 and mode 2), to mention the most popular ones.

In order to account for the new dynamics, there has been the need to move different indicators on the scientific, technological and innovation advance. These do not only concern to academic studies, since different governmental agencies, both national and international, have made efforts to propose methodologies for the production of indicators on science, technology and innovation. It is the cases of the Oslo and Bogota manuals that seek indicators to be normalized on technological innovation, and whose proposals of indicators have limits as new production forms and spaces of said knowledge are not considered.

The recent dynamics on emerging sciences and technologies concern to different elements which we may see in different levels and dimensions. Regarding levels, when we look at global, regional, national and institutional sociotechnical contexts, we may see important differences in the interrelations among several actors partaking in scientific, technological and innovation processes. On the other hand, regarding scientific, technological and market dimensions we see different dynamics where the participation of actors and the relationship between them change.

The configurations are structured from the participation of actors and the relationships they establish as a function of spatial and temporary contexts. When the structures of these sociotechnical processes are seen closer, we notice that the actions of the actors reflect their interests and positions, as well as the mobilization and involvement of other actors in the search for specific applications of knowledge, that may result in innovations.

Studies of new sciences and technologies –such as nanoscience and nanotechnologies, biotechnology, cognitive sciences, information technologies and genomic sciences– have shown the relevance of seeking modern ways of seeing them in their relationship with society. In the scientific dimension we see renewed configurations in the organization of the scientific and technological work, such as the organization in scientific networks that are gradually more multidisciplinary and interdisciplinary; this is with the purpose of rationalizing the use of the scientific and technological infrastructure, as well as to prevent duplicity, because access to these infrastructures has been a central point in the development of emerging technologies and in the creation of scientific cooperation networks.

The technological dimension, the development of prototypes, of patents and other technical objects, has been the focus of debate in scientific communities, and they are each time more accepted in the academic and scientific space. Transfer of this technological knowledge towards the industry has required both amendment of regulations governing institutions and new organizational arrangements.

In the development of these new technologies, technical industrial and market potentialities (market dimension) are each time more centralized in their promotion speech. Similarly, announced potentialities by the emergence of these sciences and technologies have attracted the attention of several actors from different areas of the academy, who partake in the different stages in the development of technologies, which range from defining research agendas to debate on the regulations. In fact, new sciences and technologies have raised questions on the ethical and social aspects, as well as the likely environmental consequences.

In view of the characteristics of emerging or converging technologies, and in spite of methodological difficulties implied thereby, these have been studied as innovation sectors, for they are technologies of crosswise use in several productive sectors, such as the pharmaceutical, food, farming, environmental, manufacturing, among others (Amaro & Morales, 2016; Castañeda, León, Robles-Belmont & Záyago, 2017; Foladori *et al*., 2017).

An interesting perspective to analyze the difficulties arising in the study of emerging and converging technologies from innovation systems is to recognize the arrangements of the relationships between the agents and the set of policies and institutions with an influence on the introduction of new technologies (Dahlman *et al.*, 1993). Furthermore, Carlsson (2006) describes the innovation process as a system of institutions for the creation and transference of knowledge, skills and artifacts within the framework of the development of new technologies.

The concept of innovation systems takes contributions from previous concepts including industrial districts, the innovating media and learning regions (Doloreux, 2002). In addition, it resumes elements from the discussion on the evolutionary economic theory, institutional economy, new regional economy, learning economy, innovation economy and the networks theory, crucial elements for the analysis of learning mechanisms, of the production of knowledge, of diverse proximity types and social integration.

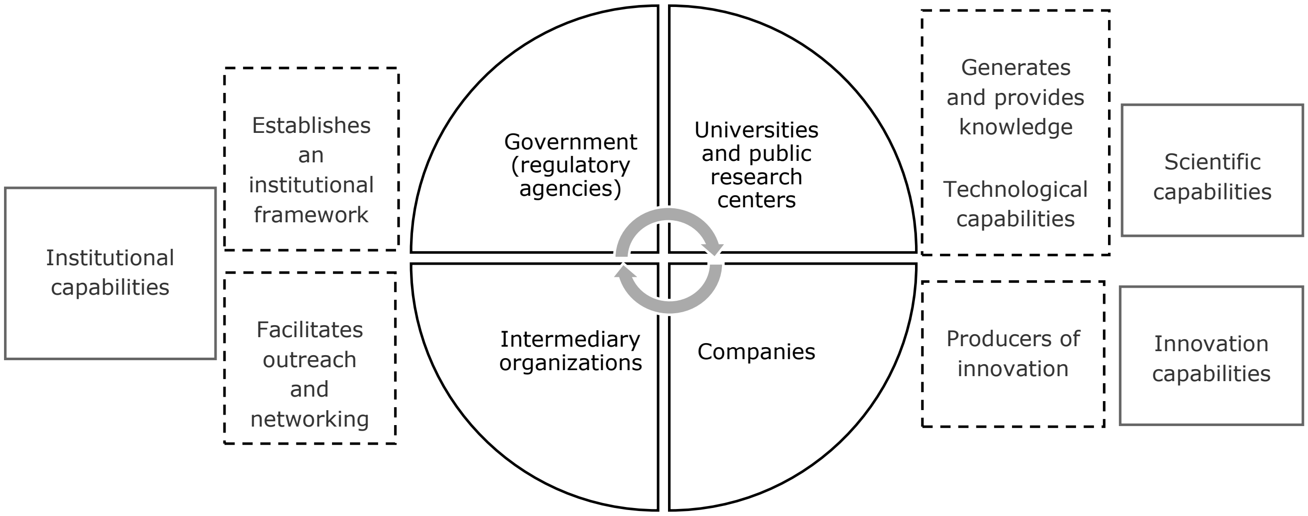
To Nelson (1993) the innovation system is centered on the interaction between the production system and the innovation process, which primarily considers the role of institutional actors who have an influence on the process and on supporting mechanisms. This vision has been classified as the institutional perspective (Doloreux, 2002), as it makes an emphasis on the relationships between companies and the institutional environment, and considers that the different institutional configurations and their different roles in generating innovation capacities comprise the crucial factor to understand the process.

In view of the above, the evolutionary and economic theory has hypothesized that the appearance of and the development of technological problems entailed by the emergency of productive and organizational innovations take place within a specific interaction regime, that have been dubbed as innovation system. Although the company is in a central position within the system, as this is the organization where the largest number of innovations are produced, it is accepted that incidence of other collective actors is crucial for technological progress to have a positive impact on economic development.

The diverse analyses on the configuration, structure and development of emerging or converging technologies (Casalet, 2017; Roco, Bainbridge, Tonn & Whitesides, 2013; Adeoti & Adeoti, 2005; Gittelman, 2006; Dohse, 2000; Niosi & Banik, 2005, Van der Valk *et al.,* 2009) agree on the fact that there is a series of variables –public policies of science, technology and innovation, the creation or amendment of incentives at different levels, the educational system, laws, regulations and rights of ownership, among others– that perform very relevant roles in the promotion and growth of analyzed technologies, which in some cases has led them to turn into an important economic sector in their countries.

Most of the studies mentioned above resume the theoretical framework of the innovation systems, therefore, indicators related to scientific capacities are analyzed, such as the number of students and graduates in the technology analyzed or related areas, the number of researchers, research projects with public financing done in universities or public research centers, published articles and academic cooperation networks. Figure 2 shows a scheme to synthesize the traditional analysis of emerging technologies from innovation systems.

Figure 2. Traditional analysis scheme of emerging and converging technologies from innovation systems



Regarding technological and innovation capabilities, it is common to resume indicators such as the number and types of companies that produce, manufacture and use technology in question, investment and the number of R+D projects done by companies and patents applied for and granted. Finally, variables are also resumed that may be called institutional capabilities, which include regulations, laws, controlling bodies and the type of public policies.

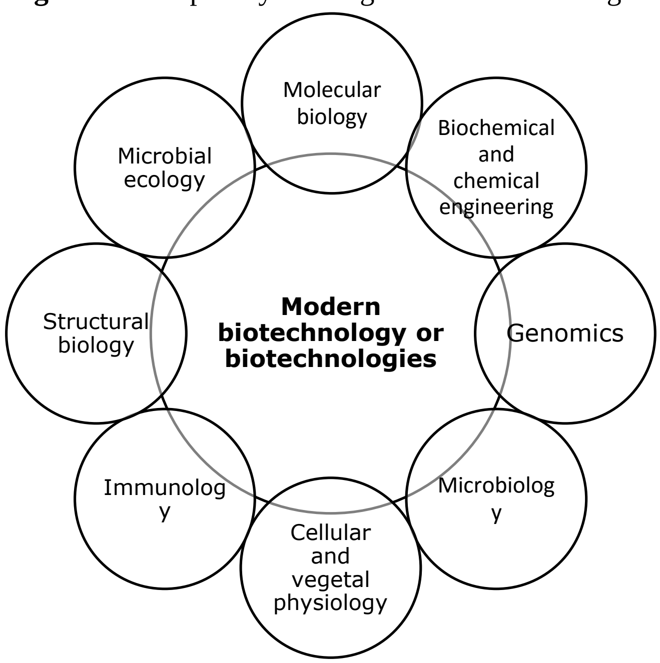
In most of cases the quality of institutional capacities is not analyzed, but it starts from the hypothesis that its existence enables the development of another type of capacities, as it is assumed that the own development of emerging and converging technologies represents opportunities to solve several scientific and technological problems with a high impact on economy and society.

What are emerging and converging technologies?

As mentioned, there is a special feature in the so-called emerging technologies which implies "convergence" of diverse scientific and technological disciplines. In the best interest of this work, a decision was made to call them converging technologies because of the multidisciplinary and interdisciplinary characteristics that shape the manner in which knowledge, technology and solutions provided thereby are constructed. Although new converging technologies are not so new, they now have special characteristics. For example, the diversity of actors partaking, such as universities, companies, research centers, society and the state, as well as the speed or the purpose in the construction of scientific and technological knowledge.

In accordance with Perez (2004), there is a set of technologies that may be considered as a new socio-economical paradigm worldwide thanks to its likely transforming characteristics of the productive system; nanotechnology, biotechnology, information technologies, robotics, cognitive sciences, artificial intelligence and genomics currently are mostly representative of this process. Some of them are consistent with the detachment of the scientific-technological paradigm based on the study of life and the great revolution which meant one of the most relevant facts to humankind: the discovery of the sequence of the deoxyribonucleic acid (DNA), which has had an impact in the development of biotechnology and genomics (Figure 3).

Figure 3. Disciplinary convergence of biotechnologies

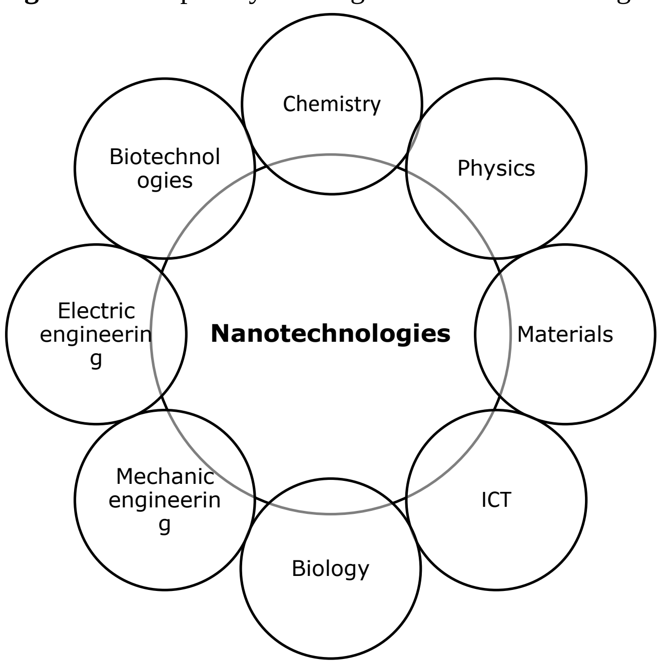


In the specific case of biotechnology, it is based on the scientific and technological convergence of disciplines such as molecular biology, biochemical engineering, microbiology, genomics and immunology, among others. Its characteristics allow it to have applications in several sectors, as there is a productive use of living matter which enables processes and items to be improved, above all, those based on biological products (OECD, 1989). Currently, and from the DNA sequencing, biotechnology has had, in many ways, a technological revolution that has permeated in diverse scientific and productive levels and meant a faster rate in its development and an expansion in the use and applications.

In addition to DNA sequencing, another very important fact was the invention of the scanning tunneling microscope and the discovery of fullerene in the 1980s, which allowed identification and characterization of nanoparticles, giving rise to the possibility of developing and managing matter at a nanometric scale, a level in which matter has special properties, not appearing in any other scale (Poole & Owens, 2007). This discovery has had an impact on information technologies, robotics, et cetera.

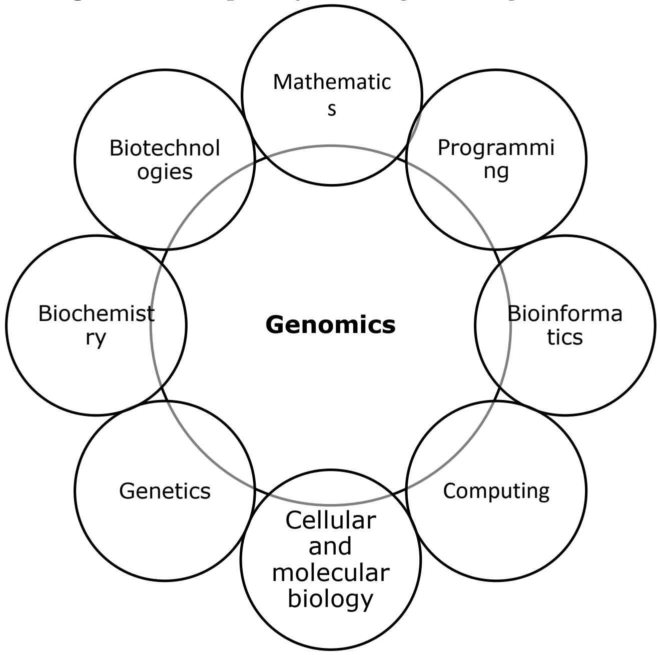
Just as in nanotechnology and biotechnology, there have been accomplishments that enable new research and development areas, this is happening in genomics and in information technologies (Figure 4). For example, the former studies living organisms by means of the structure of their genetic materials, aimed to analyze the operation, contents, evolution and origin of genomes and to predict the function of genes from their sequencing or interactions with other genes (Cevallos, 2008).

Figure 4. Disciplinary convergence of nanotechnologies



Genomics allows us to identify the genetic risk, predisposition of individuals to develop particular diseases and to establish preventive measures to avoid or delay their appearance (Jimenez & Silva-Zolezzi, 2003). Just as in biotechnology and nanotechnology, genomics is a science and technology applicable to several areas (Figure 5); in fact, to some specialists we cannot speak of a biotechnology or nanotechnology, in singular, because they are made of several types of biotechnologies or nanotechnologies. In the case of genomics, there are developments in areas such as nutrigenomics, which identifies the effects of diet on genomics, proteins and metabolites, to design food based on the genetic profile of each population; or *pharmagenomics*, which analyzes the reactions of people to certain medications and doses, with the purpose of designing more specific, efficient and safe drugs aimed to population groups.

Figure 5. Disciplinary convergence of genomics



In the case of information technologies, robotics and cognitive sciences, an assortment of disciplines are also seen which interact and contribute with its scientific and technological development. Once the multidisciplinary characteristic of technologies is presented and an example on why they are called converging is given, a reflection is made about how these technologies may be analyzed.

Theoretical and methodological approaches in the face of emerging technologies

Emergent technologies are frequently employed as synonyms of converging technologies. Without going into too much discussion on the proximity of both notions, and with the purpose of focusing on theoretical and methodological difficulties we may find in the study of these technologies, the approach of technological convergence was selected for the reasons presented below.

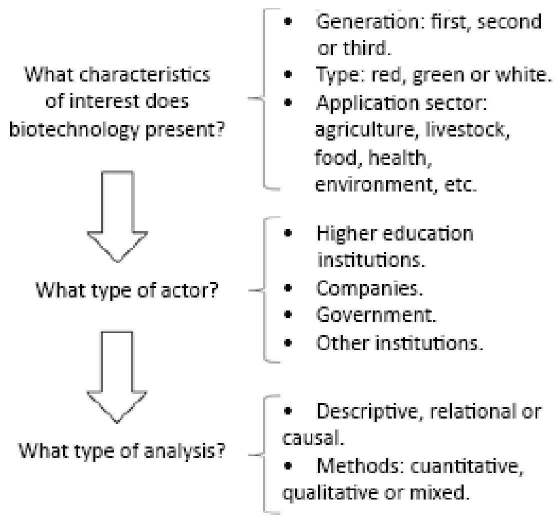
Technological convergence, or converging technologies, is a relatively recent notion used to design new technologies with a high degree of convergence. This syntagm has permeated in the discourse of politics on science and technology, and on the processes that are behind are not so evident to be studied or give an account of (Miège & Vinck, 2012). A feature of these technologies, as has been mentioned, is its heterogeneity, because in its production, use and dissemination dynamics the presence of diverse disciplines of knowledge and actors from different fields (academics, university, government, society and non-governmental organism) is observed.

Furthermore, the definition of converging technology is quite extensive and seeks the integration of complexity of socioeconomic and technological problems several disciplines currently face (Jeong, Kim & Choi, 2015). Indeed, when making reference to technological convergence it is interesting to conceptualize it as a set of processes which imply mobilization of diverse disciplines, technological resources, industries and markets. It is necessary to emphasize that these technologies cannot be considered as traditional analysis sectors, since they are rather seen as transverse technologies to different sectors. For example, when performing the study on the development of nanotechnologies in the health sector, its convergence is seen with biotechnologies, as well as with other emerging sciences and technologies.

Biotechnology has very diverse applications in sectors like health, agriculture, the environment, food, et cetera. This variety of sectors of application has diverse methodological problems to measure the development of this technology. The first one implies defining what technology is; subsequently, knowing the dynamics in production, use and dissemination –which is highly relevant– in addition to identifying the patterns of appropriability and exploitation, or the rights of industrial property, to identify the institutional structure that is the interest of analysis, and, finally, the application sector. The foregoing is not exhaustive nor is it the only way to organize the investigation, which depends on the level wanted for the analysis, whether from a microanalytic perspective, of the study of behaviors and the making of decisions of actors; the meso level, with the formation of networks and interactions; or the macro level, which involves actions in the national governmental arena or international organizations.

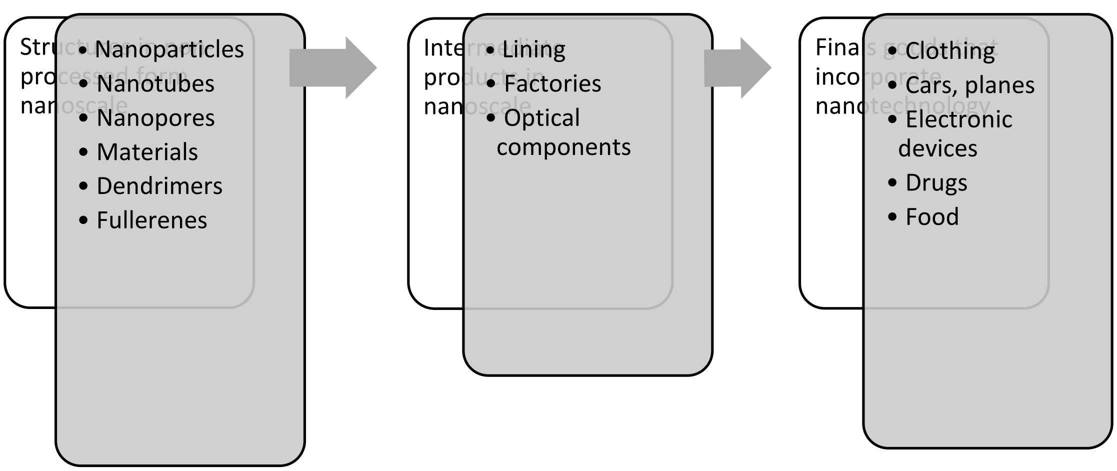
Below are two examples on how the study may be centered in converging technologies; the former is the case of biotechnology and the latter, of nanotechnology. Figure 6 shows a synthetic manner of different methodologies that may be applied which include the definition of the object of study and, therefore, its characterization; this allows us to know the dynamics of particular technological production, the type of application sector and whether it is also important to know the type of actors and the dynamics in a combined manner (technology and sector). In the case of the type of actor which is of interest, for example, it may be relevant to analyze all the actors, as is the case of innovation systems, and hence to define whether it is better to do this by regions, sectors or at a national level; or to study each group in separate and see the dynamics, networks, controversies, cooperation, among other peculiarities of the action groups. Once all of this has been defined, we can determine the method, whether quantitative or qualitative, as well as analysis tools. Usually, in the case of converging technologies there are no information systems to do the follow up in time and space. Therefore, it is necessary to build information, where the preparation of surveys, interviews, patents and publications may be used.

Figure 6. Possible methodological route for the study of biotechnology



Another methodological option is the analysis from the value chain. Note that what is interesting here is to identify dominant actors, relations and the ability of actors comprising it to change its position. Figure 7 shows the example of nanotechnologies from the approach of value chain analysis.

Figure 7. Analysis of nanotechnology through the value chain



Source: adapted from Holman, 2007; Lux Research, 2004 and Foladori *et al*., 2016.

It is currently difficult to conceive the development of an emerging technology in isolation from other technologies. Another interesting characteristic of emerging technologies is that, when it converges in other technologies, they have the potentiality to transform sectors or industries already existing, as well as to create new industries or markets.

Within this framework, Roco & Bainbridge have published several studies where they propose nanotechnologies, biotechnologies, information technologies and cognitive sciences as converging technologies (Roco & Bainbridge, 2002), whose acronym is NBIC. All of these technologies have been equally classified as emerging technologies.

In addition, the development of converging technologies has brought a series of social, economic, ethical implications, among others, that have been the subject of debate and to highlight the need to have regulation and governance schemes (Bainbridge & Roco, 2016; Invernizzi *et al*., 2015; Roco, 2008; Roco, Bainbridge, Tonn & Whitesides, 2013). These works, which have discussed the promotion of technological convergence of NBIC may be considered as a point of reference of studies on converging technologies; studies which have, by the way, shown convergence as a necessary and irreversible process which is taking place from scientific laboratories to industries and markets.

In accordance with Roco's (2007) proposal, technological convergence would imply a higher analysis level where several technologies interact which at the same time are converging. The context where these technologies develop likewise has an important place in these studies. Social, economic, industrial and cultural trajectories play major roles in the creation of favorable contexts for these projects to take place. This may result in asymmetries in the development of convergences, because not all the countries or regions have favorable environments.

Nonetheless, proper formulation of policies in sciences and technologies, as well as their relationship with other policies, may favor and cause change of contexts for the development of emerging technologies. This, of course, would imply several mapping and evaluation exercises of local capabilities and needs for the development of emerging technologies. Furthermore, it is important to consider global capabilities and needs, as the local-global relationship has been equally pointed out as one of the characteristics of the development of emerging technologies (Perez-Martelo & Vinck, 2009).

So far, heterogeneity and mobility of resources and actors, new dynamics which require modern regulation and governance schemes, as well as the complexity of problems faced by emerging technologies have been stated. From the new configurations seen in socio-technical relations and from the dynamics of changes shown by these technologies, as well as the mainstreaming of NBIC in several sectors, levels and dimensions, several questions arise around the theoretical and methodological difficulty to study and to account for these socio-technical processes. An interesting alternative to study these new technologies is the approach of complex systems, because the characteristics mentioned above are equally found in this approach from the social sciences.

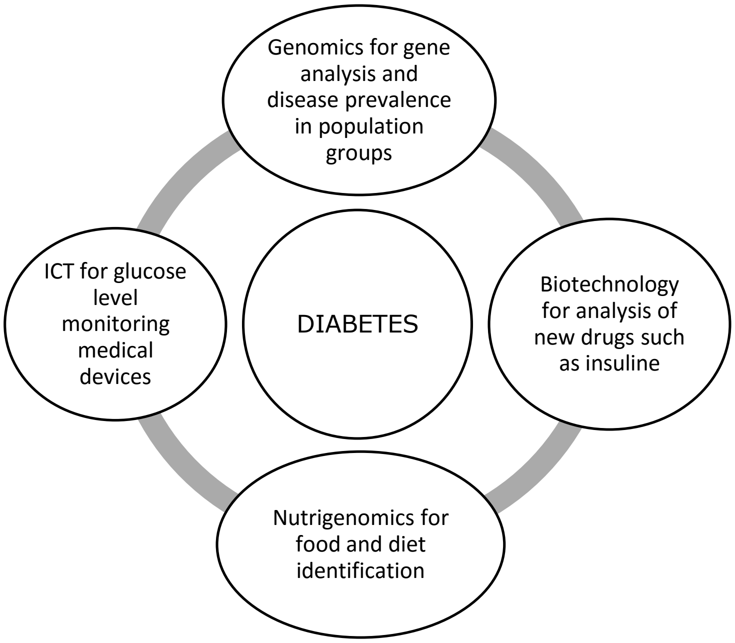
In order to analyze emerging technologies and to overcome the limits of classical schemes of indicators on sciences and technology mentioned in the previous sections, it is required that *ad hoc* methodologies allow that the particularities of contexts and study technologies be sifted through. In addition, we must remember the dynamic character of these technologies, because the concern of analyzing and grading the development of emerging technologies as they take place is each time more frequent. Regarding the task of measuring and evaluating technological convergences, there have been proposals made from bibliometric and scientometric studies (Robles-Belmont & Sigueiros-Garcia, 2017).

This is an interesting proposal, as the perspective of network analysis and dynamic analysis approach of these (both close to the approach of complex systems) show cognitive and social structures of convergences from the scientific dimension, as well as change of these structures in time. However, from the networks approach, most of these studies only cover the scientific dimension, and the technological and market dimensions are currently pending, which indeed may be studied by this type of approach using market patents and data, even if there still are challenges to obtain this type of information.

Finally, the need to make qualitative approaches that allow us to account for the socio-technical contents of the dynamics on cognitive and social structures presented by studies based on network analyses is widely known. For this purpose, there are several tools and methodological approaches in social sciences that may contribute to the analysis of emerging technologies. The actor-network theory, the laboratory ethnography, the socio-technical scenario approach, and the constructive technology assessment are some of these tools and approaches.

So far, we have explained the term of convergence by considering that each technology in itself represents an interrelation system of actors and disciplines; however, a methodological scheme where it is considered that, from the complexity of problems faced, it is necessary to resort to a convergence scheme may also be proposed. If the innovation proposal is resumed as a problem-resolution process, convergence may result from the specific nature of the subject of analysis. When taking the problem of diabetes and seeing it as a complex problem, for example, we may think of the methodological route described in Figure 8. In this scheme we show that addressing the problem of diabetes requires of scientific and technological convergence, without forgetting that it is inserted in the social and cultural framework.

Figure 8. Methodological route to measure convergence based on a specific problem



Conclusions

This article shows elements concerning the construction of indicators for innovation in new sciences and technologies. Reflection has been centered in some limits within the framework of the concept of innovation, on the one hand, and in the nature of emerging sciences and technologies on the other.

Indicators to measure innovation have been centered on supplies and on results of scientific and technological activities, and on the standardization of these indicators that have allowed their use in the comparison of different levels. These indicators respond to the economic concept of innovation, which is mainly focused on the company. The review of innovation in this text confirms that studies on this concept have progressed and recognize the diversity of dynamics taking place in socio-technical processes, both in the industry and on the government and the academy. Nonetheless, the methodological proposals of indicators seem to not have followed these advances, and there currently are several limits upon assessing innovations in the development of emerging and converging technologies.

On studies on emerging and converging technologies, such as nanotechnologies, biotechnologies and genomic sciences, the importance to consider the particularities of these technologies, as well as the contexts where they are developed, used and reproduced has been stated. This is reflected on the schemes shown in this work about the likely research routes of these emerging and converging technologies ranging from the definition of the subject of study, the analysis of the value chain or the identification of a complex problem where different technologies take part. The schemes presented are not the only ones, but they only are examples of how a methodological route may be operated; this does not imply a formula but a proposal so that within the framework of each subject of study it is amended or adapted.

Lastly, it is relevant to highlight the need to constantly reflect on the relevance of the methodologies employed for innovation indicators, above all, when it is about emerging and converging technologies. In fact, in addition to the importance of keeping the concepts of emergence and convergence in mind, as well as the innovation concept, on studies of new technologies it is necessary to establish mixed methodologies that enable the identification of and, if possible, to quantify the different elements and factors in the development of these technologies.

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