NANOTECHNOLOGY INNOVATION PROCESS FOR ADVANCED MATERIALS

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SUMMARY

Nanotechnology innovation has peculiar characteristics. This paper reviews the methodology and results, drawn from cases analyzed on two EU projects: EULASUR and EULACERMAT. The cases covers both European and Latin American experiences, particularly from countries from Mercosur. We analyze in particular nanotechnology innovation based on new and advanced materials. The main conclusion of this paper is that innovation in advanced materials, based on nanotechnology, relies crucially on networks of cooperative agents. It starts from the validated assumption that innovation is interactive in nature. Therefore, it is needed to co-create through the participation to obtain feasible results. It appeared clearly that innovation in this field is a complex problem, with the same degree as researching (nanoscience), and that the connections between them were not obvious nor simple.

Keywords: nanotechnology innovation, co-operative innovation, co-creation, advanced ceramics.

1. INTRODUCTION

The assessment of the innovation process for Advanced Materials (AM) right now and in the near future is difficult to evaluate. However, there are some characteristics close related to patterns

connected to the innovation process of this type of materials. For instance, they are at the beginning of many value chains. In other words, they have the potential for applying to many sectors: health, energy, environment, car industry, building industry, etc.
Following, we present some results and evidences picked up during two European Projects: EULASUR ("Network in Advanced Materials and Nanomaterials of industrial interest between Europe and Latin American Countries of MERCOSUR"), and EULANETCERMAT ("Ceramic Materials with Environmental and Industrial Applications").

The development of this paper is the following: in the next paragraph, we explain the methodology based on case studies; then, we discuss some case studies from both regions. On this basis, we derive a model for innovation for nanotechnology, particularly related to advanced materials. Finally, in epigraph 5 we tried to drive some conclusions based on the previous topics, taking above all into considerations policy implication from this particularly model of innovation.

2. METHODOLOGY

The contents and results of this paper are drawn from case studies in advanced materials. The cases were collected and researched by the authors in two regions: European Union and Mercosur countries. Comparisons from both regions add some richness to the analysis. Some other cases were taken from the literature, in the same or other regions, showing that the patterns synthetized matched very well.

The case study methodology consists on describing an interesting number of cases, covering different market sectors or segments. Then, we derived from them some stylized facts that cases showed in common[1]. Case-based studies relies on the concept of similarity, and more particularly on the idea that situations recognized as similar in important aspects may be also similar in other respects (Hüllermeier, 2007:5). Thus, our approach is based on a simple instance of analogical or inductive reasoning that will end up with a generalization of an innovation model for nanotechnology-based advanced materials.

Case study is a theory-building rather than a theory-testing research (Eisenhardt and Graebner, 2007:26). "Multiple cases are a powerful means to create theory because they permit replication and extension among individual cases. Replication simply means that individual cases can be used for independent corroboration of specific propositions. This corroboration helps researchers to perceive patterns more easily and to eliminate chance associations. Extension refers to the use of multiple cases to develop more elaborated theory. Different cases often emphasize complementary aspects of a phenomenon. By piecing together the individual patterns, the researcher can draw a more complete theoretical picture" (Eisenhardt, 1991:620).

Recognizing patterns of relationships among constructs within and across cases is a crucial task for coming up with a theory. Case studies are different from lab experiment in the sense they emphasize the rich, real-world context in which the phenomena occur. The theory-building is an emerging process that is based on recursive cycling and puzzling the case data, theoretical

1 The concept of "Stylized Facts" is based on the methodological proposal of Kaldor (1965: 179) for social science. The idea is to characterize a complex surveyed subject posing the main points or facts, as a former approach. Then, these facts are grouped and then connected to introduce a dynamic focus on the subject. Finally, a model could usually appear after these steps.

creation of constructs or models, posing propositions and/or midrange theory from cases, all these based on the empirical evidence (Eisenhardt and Graebner, 2007:26).

Besides, for capturing the interactions and relationships of all stakeholders present in each case, we use the value chain methodology (Kaplinsky and Morris, 2001). The relational character of this methodology allows capturing the interactions, relationships and possible behavior within the value chain, both at micro-economic and meso-economic level.

On this base, we synthetize all the data by constructing a graphic and logic model of nanotechnology-based innovation, trying to apprehend and deploy some specific patterns we found in the field and the nanotechnology cases, above all the regularity of the several applications of advanced materials. Finally, we derive some conclusions in terms of possible policies to apply for the development of nanotechnology innovation, particularly for less developed countries, taking into account different time horizons and different levels of development in this field.

3. DEVELOPMENT: CASES AND MODEL

Nanotechnology-based advanced materials can be considered perfectly as generic technologies; i.e. those that may "yield benefits for a wide range of sectors of the economy and/or society" (Keenan 2003:130). The growth of research in the field of nanotechnology has far exceeded growth in science and technology research in general (Bozeman et al, 2007:807). A whole panoply of applications are emerging from biomedicine to robotics, passing through quite different sectors. Sometimes, the potential for expectations exceed realities, crossing to the field of science fiction. However, in some sectors, like nano-ceramics, there has been real practical progress in applying nanotechnology. This potential of advanced material applications is in contrast with the difficulties of commercializing radical advanced materials technology, due to barriers that were not well studied in the literature.

Over the last 50 years, advanced ceramics was continue evolving. The main front of this evolution came from and was impelled by pre-ceramic polymers, also called as polymer-derived ceramics (PDCs), which were a fundamental material innovation that made possible the fabrication of mainly Silicon-based advanced ceramics. This technological breakthrough gave place to the development of many innovations in advanced ceramics, such as ceramic fibers, coatings, or ceramics stable at ultrahigh temperatures (up to 2000ºC), with significant properties for decomposition, crystallization, phase separation, and creep effect (see Colombo et al, 2010:1805). The trend is to multiply material properties, even designing them on specific demand (pret-a-porter), all of which makes stronger the impact of the material revolution nowadays.

On the other hand, from the specific innovation point of view, the know-how and the explicit knowledge required for innovating in advanced materials (AM) are distributed on a good number of R&D centers, users and firms. Cooperative innovation comes up as the solution because it combines knowledge from different sources to produce process and product innovation within a collaborative network. Then, there is a process of co-creation of a product-service because of this cooperative network, result which is very difficult to obtain by the narrow knowledge of individual agents (Nielsen et al, 2012).

Next, some of the innovation cases analyzed here will be described in terms of stylized facts to highlight common patterns of behavior and identify barrier to innovate. Concerning new entrants and incumbents firms, the prominence of different actors will be outlined, but we can advance that they vary with the sector, and the type of applications involved. Approximately, twenty cases were surveyed in Latin American countries (mainly, Argentina and Brazil)[2], and the same amount for the European Union[3]. Next, we describe some cases for the health sector, for energy sector, and for products that can be applied for more than one.

In the first case, for advanced materials (AM) applied to the health sector, the especial components or products for medical, dentist or other professional utilization show that there are several aspects to be taken into account for innovate. Some are related to the production itself and others related to the way of application, to customer's knowledge for profiting from them and to health regulations. Innovators took these different fronts together for being successful, as it was reported for advanced materials application case in health sector in Brazil.

Some other AMs health products have different behaviors in customer's interactions, following the analysis of the "distance" marked on the diagram (Figure 1). Such distinct behaviors can be observed in some cases, where the same nano-material is applied in different ways. For instance, an anti-microbial material applied on products for medical usages and handled just by highly qualified personal, did not reach the final regular customers (the patients). However, the same material can pass through the different actors of the entire value chain and reach the final customer, when it is applied to manufactured toothbrush or toys as a preventive for contamination.

Another interesting case is the application of advanced materials to the solution of environmental problems. Applications come mainly from the nano-ceramics[4], which are defined as "ceramic materials comprised of particles of a certain size, usually 100 nanometers diameter or less"[5]. Nano-ceramics can be manufactured to have different properties to conventional ceramics, for example, their superior qualities for conduction or insulation that can facilitate new applications in electronics. Besides, their qualities have uses in physics, chemistry, engineering and materials, medicine, biology, agriculture and computer science (Meyer & Persson 1998, Mehta, 2002). However, it is to environmental applications, such as the treatment of drinking water or the filtration of contaminants from hot gasses, that the physical and chemical properties have most successfully been applied and commercialized to date.

Other cases in the environmental field use some nano-encapsulated materials for attracting weighted metals, like cobalt, chrome, etc. This product, developed in Brazil, let to perform a cleaning process in a landfill contaminated with these metals. Again, many actors are involved in this case: the product needs particularly a regulation approval, which includes some knowledge

2 In the case of Brazil, the cases were reported by MsC Eng. Eduardo Rovaris Gomes, who is the manager of SENAI Institute for Materials Technology (Instituto SENAI de Tecnología em Materiais). For Argentina, most of the cases were reported by Dr. Eng. Antonio Arciénaga Morales, when he worked for the Ministry of Science, Technology and Productive Innovation. Some well known cases were taken from the literature (see MINCYT, 2009). In both cases, the reports were performed for EULACERMAT Project.

3 These cases were researched by Eaton (2015).

4 This case was researched by Eaton (2015), in the framework of the EULACERMAT Project.

5 See (http://nanoceramics.co.uk/).

for field application, the participation even of the society in the perception of the environmental improvements, among all.

There are some other cases on the nano-encapsulated materials field where the capsule material that was originally developed for the cosmetic industry with the objective to prevent the active principles to oxidize. Then, it starts to be interesting to the chemical industry, where it was applied as an additional process control to the chemical reaction. In this last case, the capsule just breaks in the right time to produce a high quality reaction, which in turn promotes an important increase on the material properties leading to an improved product.

These cases show that even though the developed AMs are already on the market and adjusted to some specific applications, the different actors (of the different value chains) can change the focus when a new application is developed or come up. In this particular case, not just the client of the technology changes but also the regulatory agency, the logistic channels and sometimes even the producer facility must be adjusted to meet these new market criteria and regulations.

It is interesting to note that similar characteristics showed the case of innovation with carbon nanotubes in U.S.A. The pioneer firm involved, Hyperion Catalysis Inc., developed first the raw material and after patenting products and processes, it focused on the search for a partner in different established sector to get the know-how of concrete products. Therefore, the main strategy for innovate was a collaborative scheme with partners already operating in different value chains. The firm also carried out by its own some projects in emerging field, like astronautics. In the former case, Hyperion was quite more successful than in the latter (cfr., Maine and Garnsey, 2005:18-22; Arciénaga and Bacarini, 2011).

Another interesting case is a public firm in Argentina that has developed infrared sensors for satellites produced in Argentina. The scientific background was close connected with the development made by the academia. On the other hand, the public purchase power behind the decision of launching a national satellite and the close relation of the firm with the national contractor were a key trigger to cluster the academia, the developer of the sensor and the national satellite contractor firm.

For summing up these cases, we can point out different facts: the prominence of the actors, of the regulation, of the upstream position or distance of advanced material innovation to the final customers. Besides, the role of logistics and interactions could varied, but there seems that all these co-creating relationships are particularly important for the introduction of innovations within the advanced material sector and for assessing the impacts of such products on markets and society[6].

4. RESULTS: MODELS

The particular upstream position of advanced materials (AM) in the value chain of many applying sectors brings some consequences, which could explain future introduction of new

6 Like Maine and Garnsey (2005: 4) put it: "An innovation creates value for consumers when the products it enables outperform existing substitutes, match substitute performance at lower cost, or meet consumer needs for which there is no existing substitute. Value capture measures the extent to which the originators of an innovation are able to appropriate this newly created value."

products based on these new materials. The following are the main stylized facts or the regularities derived from cases, that constitute a kind of innovation pattern for nanotechnology based new materials:

- The industry that produce raw materials and components based on new advanced materials are usually at the beginning links or upstream of different value chains, usually restricted as providers.
- These links are far from final customer, which can constitute a new limitation for the rate of introduction of these type of materials.
- The "distance" from the suppliers and producers to the customer can vary according different sectors. This distance expressed the level of shared information, confidence, interactions and cooperative behavior. A long distance means a lower level of this variables or necessary conditions for innovating.
- Such distance affect the flow of information between final customers and first suppliers, particularly in terms of requirement and specifications, but it can also influence on both suppliers' behaviors, on their economic and technological stimuli for determining the strategy to innovate, and on the lack of trial spaces for the product.
- A long distance can be considered an internal barrier or a constraint within the value chain for possible applications of advanced materials.
- Some of the links among suppliers and producers (of different kind), located in the middle of the value chain, can also acts as bottleneck or constraints for the introduction of innovative materials within a value chain because they can be affected in their established interests by new advanced materials.
- Therefore, there are additional problems to innovate with advanced materials than with other type of products. Sunk costs of invested capital, commercial contracts, product stocks, power and strategic decisions are some of the constraints that incumbents along the advanced material value chain face to innovate.
- For suppliers, there exists a high specific knowledge in AM production and a low knowledge in the applications. The knowledge for innovate is distributed along the provider-producer-user chain.
- Nanotechnology innovators has two type of uncertainties: one about product value for consumer (translated into product attributes) and second about foreseen costs in the innovation production. Both involve investment on innovation information and a pilot plant, before viability is confirmed (cfr. also Maine and Garnsey, 2005).
- Most of the time, nanotechnology-based advanced material innovations required downstream complementary innovations or changes, which in turn increased downstream barriers to innovation adoption upstream.
- For overcoming all these problems, particularly the latter, innovation in advanced materials, based on nanotechnology, relies crucially on networks of cooperative agents (cfr. Nielsen et al, 2012).
- Solutions required as a necessary condition a process of co-creation by means of the participation of suppliers and producers, and even advanced final customers[7], to obtain feasible results[8].

7 The important positive role of advanced customers for the innovation process was well proved by Erick von Hippel in many publications. See for example von Hippel (1988) and von Hippel (2002).

- In most of the cases, innovation aroused when the chain links that play the role of customers were better educated, more collaborative, and more resourceful for their supplier, than in traditional value chain. This implies an information and interlocked customers-suppliers relationships that were quite profound in terms of value creation and innovation agenda for the value chain under consideration.
- These findings of different forms of cooperation confirm the old assumption that innovation is interactive in nature (cfr. Lundvall, 1992).
- Therefore, nanotechnology innovation can be modeled in first place as an interactive and cooperative innovation process (cfr. Nielsen et al, 2012).
- Innovation based on nanotechnology-advanced materials can be deployed by two typical general strategies: first, by producing new products with new materials, with high uncertainty, and second by producing old products with new materials (with lower risk).
- With regard to the influence of nanotechnology R&D, the interdisciplinary and transdisciplinary character of the research activities in this field (cfr. Meyer & Persson, 1998; Gibbons et al, 1994) is translated to a large extent to the innovation process.
- There are also regulations, closed to customers and closed to the environment, that also can stimulate or inhibit the introduction of this type of products[9]. These regulations are crucial for the development of nanotechnology innovations in any region. Risk analysis and regulations are still an open agenda, even in Europe (see Savolainen et al, 2013:25-26).
- Regulations and a deeper understanding of nanotechnology impacts[10], in a particular environmental field or a socio-economic area, usually led to significant time lags for the development of novel innovations in this field (Owen and Goldberg, 2010). There is an increasing concern for the risks in the utilization of nanotechnology materials that includes not only the regulators, but also consumers and the industries (Savolainen et al, 2013:88).
- Therefore, responsible innovation is almost a sine qua none condition for nanotechnology innovation. Many unintended consequences of human actions, particularly related to global climate change, are modifying the behavior of governments, firms and society because their effects may be so profound that the very future of human society is under serious risks. Nanotechnology innovation is not an exception in this forced evolution. Responsibility seems to be the answer to this survival requirement, to avoid catastrophic consequences. Therefore, the need to innovate is entering in a new phase: to innovate responsibly (cfr. Owen et al, 2009:6902). It is worth to mention that the cases surveyed have in common a responsible preoccupation of the firms for regulations, particularly

8 Collaboration and co-creation imply to deal with a new type of customer along the value chain. Old customers are passive consumers of value instead of active collaborators and co-producers of value. They emphasize transaction-based relationships instead of interactions and experience-based relationships. They prefer to be a fixed and invisible link at one point of a long value chain instead of being an adaptive and very visible link, anytime, and anywhere. Finally, in old customers the concept of value is related to what companies offer (one size fits all) and not to the criteria that customer determines and tailor a unique solutions and a customized experience (cfr. Bhalla, 2011:4-5). The cooperation or collaboration could be extended even to rival firms (von Hippel, 1987).

9 Regulations for environment impact assessment are far more developed in Europe than in Latin America, even though there appeared in the last 10 years some important decisions in national government agendas.

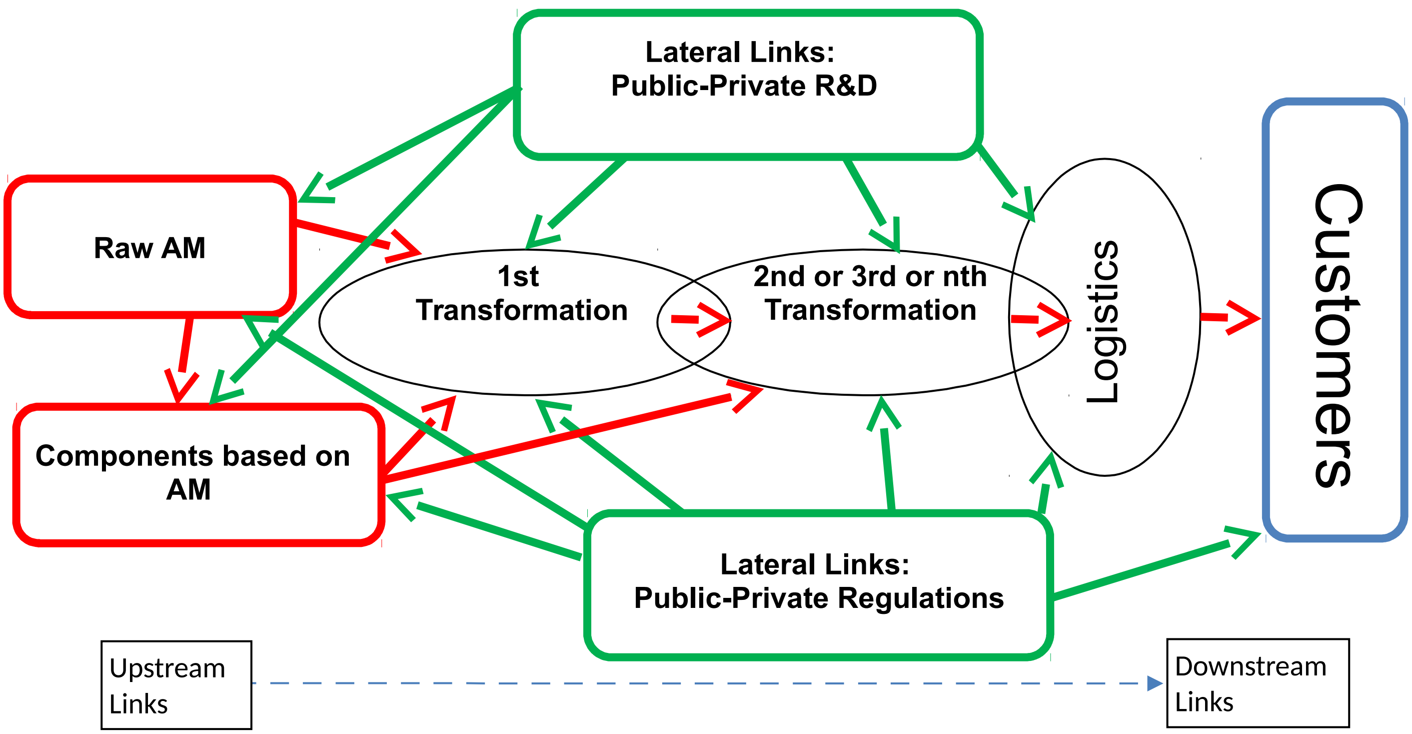
10 Environmental impact is fundamentally assessed on the basis of *in vivo*/*in vitro* toxicological studies and surveying of physical/chemical properties of nanomaterials released into the environment. Besides, other risk analysis include also the integration of safe-by-design, closed production-to-product and green nanotechnology approaches into the development stages of new nanomaterials and their applications (Savolainen et al, 2013:24).

those related to environment. However, in the markets many products do not declare explicitly the content of nano-compounds, perhaps to avoid customers' rejection, lack of acceptance or the tendency to prefer natural products.

- Particularly in Latin American cases, but also in many European ones[11], governmental support for research and innovation is crucial in nanotechnology. Most of the time, the knowledge is researched in a public R&D center, and there exists several spin-off or incumbent firms that take advantage from this public investment in nanotechnology. These supports interact with all the links or firms along the value chain. Therefore, public and private R&D centers are a kind of lateral link interacting with all the central links.

The following diagram synthetize the model on which we had applied largely the above ideas and facts, presented by the considered cases.

Figure 1: Dynamics of Innovation on Nanotechnology.



Source: own elaboration.

The innovation process is in the graphical model extended in both directions of the supply chain (upstream and downstream). The model combines process and product innovation within a cooperative or collaborative network. Then, the management of suppliers, producers and users relationships are fundamental for characterize nanotechnology innovation process. Neither suppliers or producers nor users can independently create this collaborative network using its own resources. This network is a key part in the innovation process to meet market requirements or performance for product and/or service at a competitive cost. Besides, the model highlights

11 Nanotechnology activities and innovations are a significant output of commercial companies in Japan and USA. In contrast, in Europe, the relevant scientific activities are dominated by academia and government research institutions (Miyazaki and Islam, 2007).

that advanced materials are at the beginning of many value chains (health, energy, environment, car industry, building industry, etc.).

The introduction and acceptance of products based on AM (advanced materials) will depend on the different solutions and trajectories that can be adopted for this pattern of nanotechnology innovation. New material applications are required to outperform existing substitutes, or match substitute performance at lower cost, or meet consumer needs for which there is no existing substitute (Maine and Garnsey, 2005). Next, we tried to drive some conclusions based on the previous topics.

5. CONCLUSIONS

The reviewing of the cases throw as a main result the interactive and cooperative model, reflected in Figure 1. It synthetize the main characteristics of the innovation process in the nanotechnology field. Therefore, based on this model, one of the main conclusions of this paper is that innovation process in advanced materials, based on nanotechnology, relies crucially on networks of cooperative agents. The rationale of the model starts from the validated assumption that innovation is interactive in nature, but it is also due to the nature of nanotechnology interdisciplinarity (Meyer & Persson, 1998) and even transdisciplinarity (Novotnik, 2001)[12].

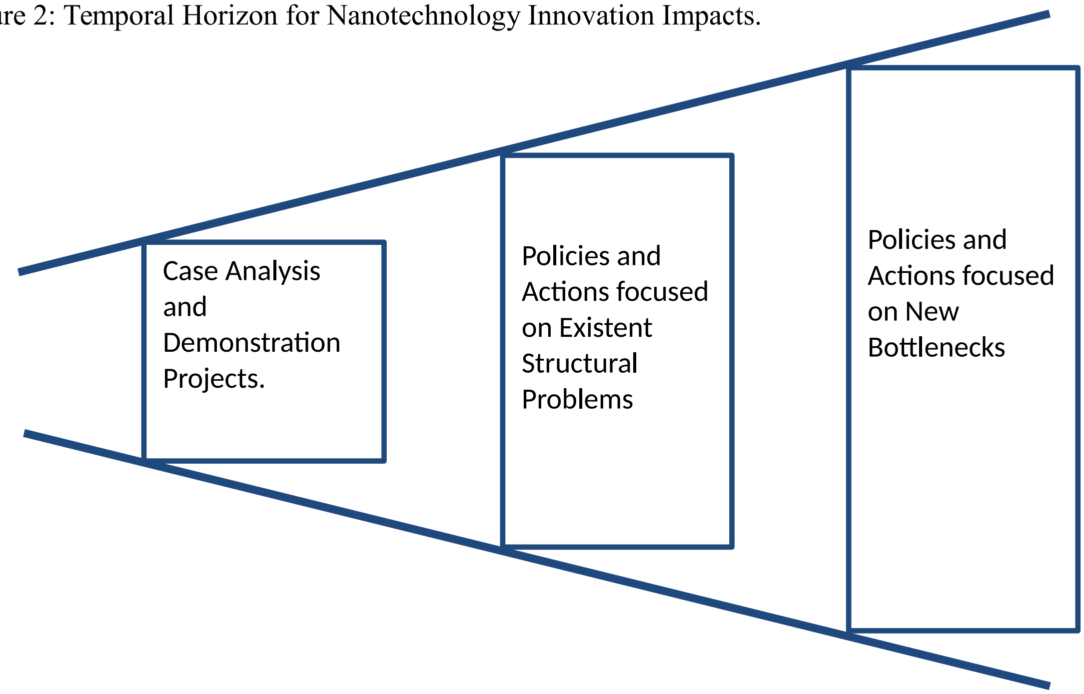
Therefore, it is required to co-create within the innovation process through the participation of different stakeholders to obtain feasible results. It appeared clearly that innovation in this field is a complex problem, with the same degree as researching (nanoscience), and that the connections between them (nanotechnology and innovative applications) were not obvious nor simple. The model here suggested needs further validation through empirical data analysis in appropriate network settings. On this basis, the paper offers a network viewpoint to be considered by innovation management, particularly the requirements for public-private partnerships because of the importance of public R&D centers and public regulations.

However, we can also derive some other results by discussing quite different policies implications from this particular model of innovation, complementing the analysis at meso-economic level. In first place, the model seems also able to address the impacts of nano and advanced ceramics on the markets and the society. In this case, it is useful to discriminate them in terms of the temporal horizon of nanotechnology innovation to be carried out, for ensuring that the impacts of AM will be suitable for the society.

The following diagram (Figure 2) describes the different policies and measures that are needed from a time perspective.

12 Transdisciplinarity means here that participation of different stakeholders in the value chain, the consumers' feedback get a better technical solution if these views are brought in the innovation process. In Helga Nowotny (2001:73) words: "It implies that more involvement on the part of society means not a better social solution, or a better adapted solution, or one that brings social tranquility to a community, but a better technical solution".

Figure 2: Temporal Horizon for Nanotechnology Innovation Impacts.



Source: Own elaboration.

The first type of nanotechnology innovation affects society and markets in the short term. The outcomes of this measure are particularly focused on generating awareness and demonstration effects about this new technology and its applications. It is particularly important when we talk about new products with new materials, given the higher risks and uncertainties involved. The other option is to develop old products with AM. This latter type of innovation is an interesting platform for less developed countries to start with nanotechnology-based innovation process, because they involves lower risks.

In the second cases, the foreseen impacts of nanotechnology are on the structural problems of the society, like energy, environment and health solutions (in a 5 to 10 years horizon). It is necessary a much longer time to produce the desired effects based on these new materials for today and future solutions. In parallel, the regulation acts as a support to develop the solutions for structural problems, minimizing or eliminating non-desired collateral impacts. In this sense, the regulation related to the assessment of nanotechnology impact is of utmost importance. In this long term, the significant time lags for the development of novel innovations due to regulations in this field is not a constraint for solving structural problems.

Finally, there are impacts in the very long term (in a 20 years horizon) that are more difficult to forecast. For sure, if the new technology (like nano-materials) pretend to be sustainable, it will need to address new bottlenecks and problems of future society. Therefore, this new knowledge base probably will solve new problems yet not known.

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