Chapter 10
Sectoral Systems of Innovation and Nanotechnology: Challenges Ahead

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Abstract Nanotechnology has emerged as a revolution and is one of the major research initiatives of the 21st century. Several industries are involved in nanotechnology research and invest heavily in R&D in order to create brand new products with functions never imagined before. Breakthrough technologies are expected to change the competitive landscape, across several industries, completely. As there are several scenarios analyzing the future outlook of nanotechnology, as well as how it has been developed in several countries, the aim of this chapter is to analyze nanotechnology from a sectoral innovation perspective and to advance the necessary conditions to implement it.

10.1 Introduction

Nowadays, businesses operate in a very dynamic, uncertain and competitive environment, and try to achieve a competitive advantage in order to obtain a stable market position. As newness attracts new clients, the best way for firms to achieve a competitive advantage is through innovation. According to Fagerberg et al. (2004), innovation has become a factor of development and success for companies and countries, paving the way to economic growth and thus, achieving a leadership position in a specific field for innovative nations. This indicates that producing efficiently is not enough. It is necessary to introduce new features, improvements, or entirely new features *vis-à-vis* existing products (Fagerberg et al. 2004). Innovating involves generating, developing and establishing new ideas or procedures (Dantas and Moreira 2011). As a result, we may have new products or services, new technologies and new administrative structures and systems. Therefore, innovation is the viable alternative for implementing changes in the organization, either to respond to changes in internal or external environments or as an active strategy to

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overcome competitors. Technological advances have underpinned countries, as well as firms, to introduce innovation in economic activity. Every technological innovation affects both the society and the environment. As the world is completely wrapped in technology competition, the evolution of mankind is completely dependent on technology (Gerguri et al. 2013; Lo 2015).

Innovation systems can be defined as a group of private businesses, public research institutes and several innovation facilitators that, by interacting among themselves, can promote the creation and facilitate the diffusion or application of a series of technological innovations (Malerba 2002; Gambardella and McGahan 2010; Beige 1998).

In general, a system of innovation is constituted by its components and the relationships among them. The main constituents of an innovation system are: organizations and institutions. The former are represented by formal structures that are consciously created and have an explicit purpose; they are defined as actors. The latter are sets of common habits, norms, routines, established practices, rules or laws that regulate the relations and interactions between individuals, groups and organizations; these can be regarded as the rules of the game (Freeman 1987; Malerba 2002; Moreira et al. 2008).

According to the system of innovation theory, the key for innovation and technology development is represented by the transfer of knowledge and information among all the actors involved. Moreover, innovation systems can be used to analyze industries from a different perspective not dealt with by the old theories of technological change (Freeman 1987; Moreira et al. 2007; Albuquerque et al. 2012).

Edquist (1997) put forward a more general definition proposing that an innovation system is the group of all important economic, social, political, organizational, institutional, and other factors that influence the development, diffusion and use of innovations.

Innovation and innovation systems are becoming increasingly important for policymakers to achieve their economic and social goals. The "Europe 2020" strategy, a key European Union (EU) program for the current decade, aims to promote a smart, sustainable and inclusive economy. According to the European Commission (2011), innovation has to be placed in the center of the strategy, as it provides the best ways to successfully address key social challenges.

An efficient framework based on connections between all the actors is the key to succeed in achieving innovation and it is represented by the design of a strategic system of innovation.

The notion that certain industries have different needs and technological trajectories was first proposed by Pavitt (1984) who developed a taxonomy about sectoral patterns of innovation according to the sources of technology, user needs and the technology appropriability regimes: supplier dominated sector; scale intensive sector; specialized suppliers and science-based sectors.

Sectoral systems are prone to changes which could be caused by technology, by learning/knowledge practices of the industry, as well as by innovation patterns of the businesses and industries. A change in the knowledge base can lead to consolidation or to significant changes within the industry if a new dominant design brings new results (for example, the iPhone is a clear case of how a dominant design changed competition and industry patterns). Another source of change is the consumer demand structure, which can lead new companies to enter the industry and change it considerably. Generally, these dynamics follow a co-evolutionary nature, leading to changes in terms of technology, knowledge, players and institutions (Pavitt 1984; Freeman 1987; Gambardella and McGahan 2010).

The concept of sectoral systems of innovation (SSI) was developed by Malerba (2002), who claims that a SSI is a set of new and established products developed for a special purpose by a set of agents. Those agents carry out activities and market interactions for the creation, production and sale of these products. Malerba (2002) describes an SSI through three dimensions that are responsible for generating innovation and new technologies: knowledge and technological expertise, players and chains, and institutions. These three dimensions are the main pillars of the concept of sectoral systems of innovation as a result of the interaction of various functional logics, complexity and dynamism which are a result of the generation and diffusion of innovation (Malerba 2002).

In the first dimension, one key issue that is worth mentioning is the focus on knowledge that drives the mastery of a technology as well as the dynamic complementarities and linkages that are the main sources of transformation and growth of sectoral systems, leading towards innovation and change. In the second dimension, an industry is composed of individuals and organizations (agents) at various levels of aggregation with specific learning processes, skills, organizational structure, beliefs, goals and behaviors that interact through communication, exchanges, cooperation and competitive processes. Consequently, heterogeneous structures are formed so that their interactions can enable the exchange of knowledge that generates innovation. Lastly, institutions are a composite of norms, routines, common habits, established practices, rules, laws, and standards that shape the interactions among agents.

Dosi et al. (1988) highlighted three features that have influenced the emergence of new technologies: (a) *the knowledge of a technology*, which shapes and constrains the evolution and subsequent rates of technological change, regardless of the market; (b) the stabilization of *the pattern of technical change,* and (c) the *technical change* that is partially influenced by technological changes created within the evolutionary path, which creates an imbalance for new technological changes.

Edquist (1997) has introduced the concept of *innovation systems* based on the following features:

- The innovation, intrinsically connected to learning;
- A holistic and interdisciplinary perspective, involving institutional, organizational, social and political determinants;
- A path-dependent historical perspective;
- An emphasis on the interdependence and non-linearity of the innovation process;
- The main role given to institutions.

The importance of innovation systems stems from the interaction among actors. Heidenreich (2004) argues that the trust-based patterns of cooperation, the local experience-based, context-bound knowledge and the path dependent accumulation of competencies are crucial for an innovation system to prosper. Heidenreich (2004) has also found that the governance structure of an innovation system may, to some degree, limit the innovation process of the region.

Following this systemic approach, the links between businesses and other organizations are portrayed as the result of the technological interdependence of their knowledge (Chang and Chen 2004; Moreira et al. 2007).

Innovation is an interactive process that has the contribution of various economic and social agents, which are characterized by different types of information and knowledge. It can be classified into two categories: incremental and radical (Dantas and Moreira 2011; Fagerberg et al. 2004). The radical innovation emerges when a new product, process or even new organizational solution is developed or introduced onto the market. This type of innovation leads to the destruction of the old technology standards, leading to new industries, sectors and markets that change the economic environment. Incremental innovation may emerge from practice and continuous improvement (Dantas and Moreira 2011).

The impact of innovation on economic growth is not new. Schumpeter (1943) states that economic development and the diffusion of radical innovations are linked with the creative destruction process, which leads to changes in the pace of economic growth and in the production structure.

Schumpeter's (1943) contribution demonstrates that the economic disruption follows when sectors and technologies become obsolete and unprofitable and new industries and technologies make it possible to behave monopolistically, thus creating the creative wave, where there are two points of view for the same process, innovation being the economic transformation agent. Clearly, nanotechnologies will help to make certain technologies obsolete and will generate the Schumpeterian creative destruction process. For countries with scarce natural resources, the need for a strong focus on continuous innovation to achieve the expected international competitiveness level is clear (Souza and Câmara 2009). Human capital and knowledge are two particularly important components of this creative destruction process as it is vital to establish the basis for new technological progress. The theory of endogenous growth has been followed by a controversial debate about the origins of technological progress and its implications on sustainable growth (Ott et al. 2009). However, regardless of the circumstances, nanotechnology will have important social and economic effects (Foley and Wiek 2014; Schulte 2005; Motoyama and Eisler 2011).

Emerging technologies are very important as they underpin the opening up of new markets and pave the way for increased competitiveness of the industry with significant consequences for both public and private sectors (Koh and Wong 2005; Moreira et al. 2007; Moreira et al. 2008).

Nanotechnologies are not only a vivid example of emerging technologies (Bachmann et al. 2001), but also of the pervasive consequences for the societal consequences as there are clear intersections among nanotechnologies, biotechnologies and information technologies (Fleischer et al. 2005). Smadja (2006) states very clearly that there are four possible scenarios involving the levels of nanoscience and nanotechnologies: (a) *undesired*, in which nanotechnology is socially accepted and embraced, yet with an uncertain future; (b) *more of the same*, in which nanotechnology is widespread but involves a very simple technological evolution; (c) nanotechnology is *not accepted*; and (d) *unfulfilled promises*, in which a breakthrough never occurs. Karaca and Öner (2015) found five possible scenarios: (a) *nano-averse*, where no single nanotechnology product is marketed; (b) *go-nano*, the best possible case, where a range of products is expected to be marketed before 2020; (c) *limited nano*, although with the same potential as the go-nano scenario, there are very few nanoproducts that will go to the market before 2020; (d) *low-nano*, in which neither the public nor the private sector is willing to invest in nanotechnologies; (e) *incapable to nano*, in which no product reaches the market.

The objective of this chapter is to show how different nations approached the generation of a national system of innovation for nanotechnologies and to explore the importance of the systemic perspective for the development and growth of nanotechnology innovation.

The chapter is structured into seven sections. After this introduction, the second section briefly refers to the methodology used. The third section addresses nanotechnology. The fourth section addresses nanotech sectoral systems. Section 10.5 presents the structure and evaluation of innovation systems. The sixth section presents a comparative perspective of nanotechnology among several countries. Finally, conclusions are drawn in Sect. 10.7.

10.2 Methodology

The methodology of this chapter was based on a review of existing literature on sectoral systems of innovation involving nanotechnology related studies.

In particular, the cases of the USA, Germany, Sweden, Russia, Iran and South Korea will be described. Information about the way they have approached the innovation system and the generation of strategic plans will be analyzed, taking into account the main features of nanotechnology on a sectoral innovation perspective. Reports on national analyses were also accounted for when writing this chapter.

Indeed companies and countries should be aware that investment in R&D, particularly with regard to nanotechnology and nanoscience is an asset to the long-term success of industries and nations.

10.3 Nanotechnology

In a world where information and communications technologies have pervasive effects across several industries, nanotechnology stands out for its application in various research fields and in almost all scientific disciplines (Islam and Miyazaki 2009; Nikulainen and Palmberg 2010).

Nanotechnology emerged in the 1960s, when its concept was introduced by Richard P. Feynman, Nobel Prize in physics in 1965, the pioneer in the field of quantum computing. Nanotechnology is mentioned as a set of emerging tools that enables us to generate and manipulate materials and structures at molecular and atomic level. As nanotechnologies, one can consider the technologies with structures between one and a thousand nanometers (Schulte 2005). One cannot forget that science is capable of creating new products and tools at high speed in our daily lives, and the term encompasses different non-specific technologies, which are extensively described in various technical documents that show great potential for incremental and innovative applications (European Commission 2011; Kostoff et al. 2007; Allarakhia and Walsh 2012).

Nanotechnology comes as a worldwide revolution and is the first major research initiative of the 21st century (Marques 2008; Gkanas et al. 2013). Many authors believe that, in the future, nanotechnology will dominate generic technologies (Ott et al. 2009).

The brand new properties that nanostructured materials present, make scientists believe that nanotechnology may represent the answer for the development and production of components potentially able to benefit society. In fact, those materials may find application in numerous fields such as health, electronics, energy saving and production, automotive industry, pollution treatment and environmental industry (Miyazaki and Islam 2007; Islam and Miyazaki 2009; Zhao et al. 2003).

Nanotechnology comes as a revolution in the world and is the first major research initiative of the eleventh century worldwide. Several industries have heavily invested in R&D to create products with unimagined functions. This new technology has changed the competitive conditions in many sectors of the economy (Marques 2008; Gkanas et al. 2013). It mirrors a new dimension of solving problems by creating brand new solutions and driving new technological developments with strong impact on the wealth of humanity. This wealth is subject to the realm of new opportunities that are emerging through research based on micro systems technology (Souza and Câmara 2009).

The pervasive effects of nanotechnology are quite widespread and incorporated into production lines or in products developed for several industries, such as energy, health, pharmacy, water, petrochemical, agribusiness, electronics, fine chemicals, military, aerospace, automotive, among others (Islam and Miyazaki 2009; Allarakhia and Walsh 2012; Maine et al. 2014). Having a strong economic and social future potential to meet global challenges, nanotechnology has been considered the basis of the next industrial revolution (ObservatoryNANO, 2011).

Nanotechnology-related innovations may be of added value to the environment. For instance, in the production of clean energy, it is expected that the nano-wires and nano structured materials can create cheaper and more efficient solar cells. Nanotechnology may also lead to higher energy content batteries and enable manufacturers to improve the environmental performance of products, allowing them to reduce toxicity, increase durability and improve energy performance (European Commission 2011).

Economy-wise, the importance of nanoscience is growing as a result of enhanced labor and technology productivity. As nanoscience and nanotechnology might radically transform the economy environment, developed countries stimulate and apply many resources in these areas in order not to lose their position to other countries with more innovative technology (Andersen 2006). This is a result of the neoschumpeterian theory emphasizing the link between economic and technological development and discontinuity generated by radical innovations.

In order to highlight the opportunities that innovations in nanotechnology can bring to the economy, in the recent Government Accountability Office report (GAO 2014), many industry experts, government and academia expressed that those opportunities could exceed the economic and social impact the digital revolution had on society. The market for nanomedicine alone, for example, was estimated at about 20–40 % of the global nanotechnology market, valued at 78,540 million dollars in 2012, with a growth forecast of 117.60 billion in 2019, according to a new market report published by Transparency Market Research (2014). Various social benefits are also facilitated by nanotechnological innovations. For instance, there are several pilot projects using nanometal particles to remove chemical and biological contaminants from water in rural and underdeveloped regions of the world (Kaiser et al. 2014).

Today's market nanoproducts have been improved gradually in order to better meet the consumers' needs based on the evolutionary nanotechnology pull. Based on its importance in all economic areas (from agriculture to medicine), the number of companies that manufacture nanoproducts will grow exponentially, seeking to improve existing products by creating smaller components with more effective performances, at a lower cost. This evolutionary nanotechnology should therefore be seen as a process that will gradually affect most businesses and industries, with enormous social and economic consequences. Innovations might take place involving the increase in miniaturization of the development of whole new products, processes or services. Innovations in the field of nanotechnology not only affect productivity in downstream supply chain, but can also induce continuous innovation circles (Ott et al. 2009).

10.4 Nanotec Sectoral Systems

Academics agree that the heart of most government policies is the achievement of growth through innovation and technological development. At the same time, nanotechnology is seen by many national and international stakeholders as a fast growing area that can affect and improve technologies in different sectors (Flament 2013).

Islam and Miyazaki (2009) and Schulte (2005) claim that nanoscience is very difficult to follow as it is not a discrete field but has pervasive influences across different lines of scientific disciplines and crosses several industries. However, one common characteristic of nanotechnology is the size of the materials being developed and used, which characterizes nanotechnology as a common technology with super-functional properties at nano-scale for several technology sectors (Bresnahan and Tajtenberg 1995; Islam and Miyazaki 2009). As a result of this specificity, Islam and Miyazaki (2009) analyze the nanotechnological system based on the relationship of four different poles: finance, science, technology and market.

There are great expectations regarding the potentialities of nanotechnology leading various governments to invest billions of dollars in its development. Particularly since 1990s, around 30 countries have designed strategies and created policy initiatives for the development of nanotechnologies (Perez and Sandgren 2008). These initiatives are categorized in what is called a system of innovation, which can be defined as the network of institutions in the public and private sectors whose activities and interactions initiate, import, modify, and diffuse new technologies (Freeman 1987).

Newness provoked by nanotechnology, as it is in an emerging stage, is probably the hardest difficulty that policy makers usually face when planning an innovation system. In fact, as nanotechnology is a relatively "young" branch of science, there are still many unsolved uncertainties and ambiguities related to how scientific knowledge will lead to the potential application of some nanostructured products. Those aspects make the development of a nanotechnology innovation system a very challenging task.

As a result of the controversial nature of this technology, the consumers' attitude towards the risk may really affect the demand, which can either stimulate or hinder innovation (Ott et al. 2009).

In 2006, William K. Reilly, a former administrator of the US Environmental Protection Agency, with reference to the report on Managing the Effects of Nanotechnology, claimed that nanotechnology can only flourish if industry and government are committed to identifying and managing the possible risks of this technology for workers, consumers and the environment alike. There must be a dialogue between business, government and citizens on how to move forward and develop this technology (Davies 2006). This is a clear indication of the challenging task ahead.

Davies (2006) also admits that reaching a consensus on the regulation of nanotechnology, which encourages economic innovation and environmental management, will not be easy, but it is a challenge we cannot ignore, involving public participation, foresight capability, international harmonization, regulatory incentives, tax breaks and research and innovation programs (Davies 2006). These regulatory issues are extremely important to provide security for businesses, investment and even to convince shareholders of the opportunities of this new industrial platform.

The German Federal Environment Agency (UBA) published a document (Hermann et al., 2014) stating that, based on the uncertainties regarding the assessment of the possible risks, nanomaterials can trigger certain risks on human health and on the environment. The Agency supports, as a preventive measure, the establishment of a European registration support entity for nanomaterials-based products. The creation of this registry is intended to provide a general overview of the products that are in the manufacturing process or already in the market. According to Hermann et al. (2014), this measure would allow public authorities to delimit the priorities for implementation and monitoring, to determine the exposure to humans and to the environment and, in the case of adverse effects, to guarantee the screening. According to Hermann et al. (2014), this measure will take place in a centralized way in the European Union in order to avoid a product from a certain country overriding the EU legislation, meaning not only loss of control of the process, but also an increase of costs for the authorities.

In March 2014, the European Chemicals Agency published a report stating that the requirements applied to the registration of nanomaterials are the same as any other chemical product (Hankin and Caballero 2014), which gives a clear indication that the situation is far from solved.

The perception of the territorial character of the innovation and production has led to the formulation and implementation of policies for the development of local arrangements of production and innovation systems. Paradoxically, with a few exceptions, policies aimed at production have been designed without any regard for the territory (Cook and Memedovic 2003).

Both the OECD countries and the emerging economies seek new ways of implementing green innovation in order to increase their competitiveness, based on the application of new technology (OECD 2013). Nanotechnology attracts a particular attention within the group of new technologies (OECD 2013).

As nanostructures have constituted the driving force that has led to the emergence of new materials for the twenty-first century industries, nanotechnologies are of fundamental interest to the disruption capability that may affect the production sector. According to the Brazilian Agency for Industrial Development (2011), another aspect to consider is the configuration of economic activity in nanotechnology, whose prediction for 2015, according to new economic analysis, a worldwide market, is of about $3.1 billion for products based on nanomaterials.

10.5 Structure and Evaluation of Innovation Systems

To create a national nanotechnology system of innovation it is important to first identify partners among the scientific community, the business world and government institutions. As seen before, the realization of a system of innovation depends on the interrelations between all actors involved.

In order to create a systemic perspective, it is important to establish centers of competence in specific subjects and network them in clusters. This allows for the assessing of the implications of nanotechnology on health, environment and economy, and for fostering public information campaigns. Several technology management activities can be divided into four types of activities (Zweck et al. 2008; Zhao et al. 2003; Allarakhia and Walsh 2012):

- technological forecasting (both general and for specific innovation fields);
- market assessment and applications;
- innovation and technology analysis;
- communication.

Technological forecasting consists in the continuous monitoring of technological developments leading to an early identification of promising future applications and to an assessment of their potentials with literature and patent analyses, expert surveys, interviews, and questionnaires. The aim is to provide a global view of the technology, its prospects for possible applications and their related deficits, impediments, and recommendations.

This is very important for keeping strong connections among all of the actors.

Market assessment and applications involves the systematic analysis of possible markets and applications for nanotechnology. Market surveys combined with market studies, patent analyses, and interviews with scientists and technology suppliers are important mechanisms of market assessment (Zweck et al. 2008). It is important to have a broad view of market assessment. As such, the economic potential needs to be assessed in some of the most important leading markets.

As experienced in Germany, technology analysis was carried out to investigate and weigh the positive and negative effects of new technologies on society, the economy, and the environment with the aim of using the opportunities they offer while minimizing the hazards (Zweck et al. 2008). This concept might use a broad range of qualitative and quantitative methods to foresee potential risks and technologies in the development process of a new technology as early as possible.

Communication involves public discussion by means of newspapers and televisions in order to give as much information as possible about nanotechnology to people.

As can be seen, the four components are very important for keeping a strong interconnectedness among all stakeholders of the innovation system (Zweck et al. 2008). Each of the mentioned activities represents a particular phase in the evolution of the innovation system. All of the phases are strictly related to each other and in some cases they overlap. The timing of their execution is important for the achievement of the final goal of the innovation system.

As such, it is clear why nanotechnology is considered a future emerging technology and why scientific world publications related to this multidisciplinary field grew exponentially during the last two decades (Miyazaki and Islam 2007; Kostoff et al. 2007; Motoyama and Eisler 2007).

In fact, the lack of investment in research reduces the level of security when launching a new product on the market. This is often associated with dangerous products being widespread in the market. These can be so bad that incredibly good products are not launched on the market due to a lack of certainty regarding their risks (Schulz 2009).

The number of patent applications can be seen as a well-known and valuable indicator for evaluating trends and developments in this area. Patenting is driven by commercial interests and focuses mainly on assessing economic potential. Statistical analyses on nanotechnology related patent activities are of increasing interest to many researchers as they allow for a close follow up of what is occurring worldwide. With the introduction of specific systems of nanotechnology classification such as The United States Patent Trademark Office (USPTO), the Japan Patent Office (JPO) and the European Patent Office (EPO), the ObservatoryNANO (2011) is a base for in-depth analysis of the patenting activities.

10.6 Comparative Perspective

It is not by chance that the discourse on nanotechnology is prevalent in the United States of America (USA). Early in the 1990s several pushes emerged on nanotechnology in the USA. This is a period characterized by a scientific policy increasingly emphasized and supported by the government and where the belief in basic science is seen as the leading economic engine of the USA (National Science and Technology Council 2011).

The strategic plan, entitled the National Nanotechnology Initiative (NNI) had, as its main function, the coordination of goals, priorities and strategies between federal agencies as well as the promotion of interdisciplinary research and critical development of the infrastructure needed for this important technology.

Its initial structure was represented by eight federal agencies that grew to a set of 25 in ten years of program. These agencies implemented nanotechnology related activities in different degrees and were responsible for a series of research papers and regulatory responsibilities that led to the implementation of similar assumptions in several other countries (National Science and Technology Council 2011; Mowery 2011).

Meanwhile, in Russia, SSI involving nanotechnology emerged as a result of actions taken by public authorities. It is important to take into account that government actions over several decades were focused mainly on supporting sectoral systems and scientific infrastructures for development (Gaponenko 2007).

In Iran, the need for developing this technology was also considered by the authorities about a decade ago. The beginning of the research on nanotechnology has led to the formation of the Nanotechnology Development Special Committee (NDSC), which develops and launches 10-year development plans for the development of nanotechnology (Mohammadi et al. 2012).

Germany is one of the leading nations of the nanotechnology industry in Europe. This country has shown interest in this emerging technology since the beginning of the 1990s when the German Ministry of Education and Research (BMBF) recognized this area as a promising field of innovation (Zweck et al. 2008).

The Swedish government also recognized nanotechnology as a field with industrial potential and strategic importance in the long run. However, Sweden has failed to articulate a coordinated national strategy to strengthen the research and development activities in nanotechnology. Only in 2006 did the Royal Swedish Academy of Engineering Sciences presented a plan for a national innovation system involving nanotechnology, influenced by the presentation of a European Commission communication entitled "Towards a European nanotechnology strategy." This communication stressed the need for interdisciplinary procedures, the intensification and coordination of research at national and European level, the need for building a world-class R&D infrastructure, the need for basic and continuous training of human capital and the development of marketing capabilities by means of appropriate standards and intellectual property rights structures (Perez and Sandgren 2008).

In Asia, South Korea stands out as the leader of research and technological development in nanotechnology. The main feature of the South Korean approach in building a national innovation system is represented by the change of vision of this country in this area. This is because, until 1990, its position before nanotechnology was limited to the knowledge and imitation of foreign technologies. Only around the beginning of the century did the government decide to change its strategy toward an active innovation approach (Song et al. 2007).

Clearly, several nations have set their own innovation system in order to promote the growth of nanotechnology. However, actions and plans differ from country to country. The objective, which is common to all innovation systems of different countries, is to transform new discoveries in both new products for immediate commercial profit and in licensable intellectual property. A general perspective of each individual innovation system of the countries mentioned earlier will be exposed subsequently.

10.6.1 The USA

The National Nanotechnology Initiative (NNI) articulates corporate goals and specific objectives. It also describes collaborative activities between the various stakeholders and demonstrates a country focused on renewable energy, sustainable production and next-generation electronics (National Science and Technology Council 2014).

The NNI has a subcommittee that provides investment in all agencies to address the critical elements and to support the development and use of nanotechnologies. In addition, the program states that the subcommittee should interact with academia, industry, local government groups and international organizations. The subcommittee is also responsible for evaluating the progress and reviewing the strategic plan every three years.

In particular, the main objectives of the NNI strategic plan represent the concrete measures to be taken to collectively achieve the vision and NNI goals. The main areas of the program established in 2004 set a description of the main areas of the program components which were established in 2004. That is, to ensure the success of the initiative, to support research in interdisciplinary nanotechnology, to sustain and expand critical infrastructure, to train and inspire the next generation of scientists and engineers, and to support the responsible development and the nanotechnology transfer to commercial applications that benefit the American economy and society.

In detail, the first goal was to advance nanotechnology R&D programs. The second one aimed at promoting the transfer of new technologies into products for commercial and public benefit. The third objective was to develop and sustain educational resources, a skilled workforce and infrastructure and tools to advance the nanotechnology field. Finally, attention was also given to the development of sustainable-related innovation.

The NNI Strategic Plan promoted the transfer of technology, facilitating the engagement among agencies with key industries by providing public access to the results of nanotechnology research funded by the federal government, and helping to support the creation of a business environment conducive to the responsible development of nanotechnologies.

Funding is fundamental to the success of further nanotechnology development. The NNI has promoted educational programs that develop scientists, engineers, technicians, production assistants and laboratory personnel (including academic students and trainees) through multidisciplinary academic programs, industrial partnerships and R&D systems funded by the federal government. Infrastructural capacity, including the centers and research support facilities in nanomanufacture, nanoscale characterization, synthesis, simulation and modeling, has been developed through the NNI over the past 10 years.

The USA NNI strategic plan was well designed and allowed this nation to play an important role in the development of nanotechnological innovations worldwide. However, analysis of available sources do not reveal the US effort in the communication process with the public to gain public trust and thus promote the actual positioning of nanotechnology related products on the market. The analysis also indicates that the development of new policies for regulating and licensing intellectual property rights is necessary in order to promote knowledge transfer between universities and businesses.

10.6.2 Germany

In Germany, the measures adopted by the BMBF, from 1990 to 2006 in its nanotechnology innovation system, led to the development of a funding and support strategy for nanotechnology, considered essential for Germany to be competitive in the global market and solve future challenges in issues related to health, the environment and safety. Therefore, the BMBF has focused its funding in collaborative projects between partners from the scientific community and the business world. In order to achieve the above objectives, BMBF also funds some "accompanying measures" to support the industrial development of nanotechnology applications, and to fully exploit the potential of nanotechnology so as to benefit society.

The main goals of the system of innovation designed by BMBF were the following:

- achieve deeper scientific and technological knowledge in the field of nanotechnology;
- investigate the real potential of applications of specific nanotechnology-related products;
- organize clustering of resources and networking;
- inform people to enhance public understanding of nanotechnology;
- investigate societal implications and side effects/potential risks of nanotechnology;
- establish adequate education and training possibilities;
- arouse the fascination of young people for nanotechnology.

Germany is a good example of a proper implementation of the measures needed to create a good innovation system. The integrated approach followed by the German Ministry of Education and Research has resulted in achieving a high level of participation of companies in the research programs. The development was supported by an analysis of the market and of the patents granted and by the accompanying measures of the research programs and activities. The strengths of the German innovation system led to a very important aspect: sustainability. The sustainability of a product or a process is one of the keys for achieving public trust and credibility. This statement is even truer when the subject of interest is represented by a technology that is still in its emerging phase as is the case of nanotechnology.

Indeed, a well-designed strategic innovation plan underpins the leading position that Germany acquired in the field of nanotechnology over the last decade.

10.6.3 Russia

Meanwhile in Russia, nanotechnology-related systems of innovation emerged as a result of actions taken by public authorities. The institutional map consists of six layers, each with different functions. The top layer includes the general political bodies that develop a key role in determining the general political guidelines. The second layer involves institutions that formulate and implement science, technology and innovation policy. The third layer comprises the public sector, foundations and private investors that, along with federal and regional authorities, support the production and implementation of innovations financially (Gaponenko 2007).

One of the characteristics of the innovation system is that Russian companies were quite passive in fields related to nanotechnology (Gaponenko 2007). However, the creation of the private foundation by the ONEXIM[1] group led to some changes in expectations in the private sector as well as their beliefs and behaviors. The ONEXIM Group invests specifically in nano-energy. As such, certain trends can already be observed in the energy sector. Space and aircraft technologies will certainly be shaken by nanotechnology as Russia has a very strong position in those sectors where public and private investors have already expressed interest for nanotechnology. The fourth layer includes R&D oriented organizations, that are concentrated mainly in the public sector (about 90 %), in the Russian Academy of Sciences (RAS). The fifth layer includes organizations that facilitate the diffusion of technology, while the sixth layer encompasses companies in the Russian nanomarket. Gaponenko (2007) concludes that the nanotechnology sectoral system of innovation in Russia is unbalanced. For many years, special attention was paid to the development of infrastructure, but the nanoscience remains underdeveloped. The Russian nanoscience is funded by different sources involving the Ministry of

[1] ONEXIM group is one of the largest private equity funds in Russia. It has a diversified portfolio of investment in several industries comprising mining banking, real estate, media, energy and high tech.

Science and Education, the Ministry of Industry and Energy, the Ministry of Defense, the Ministry of Public Health, the Russian Academy of Sciences, the Russian Academy of Medical Sciences and the Russian Foundation for Basic Research. It was estimated that in 2006, the budget allocations in the field of nanoscience was about $350,000 (Gaponenko 2007).

At the beginning of 2006, two national nanotechnology development programs were launched to coordinate actions and resources and to face the challenges of the area. In 2007, President Putin announced that the Russian Federation Government would allocate about $7 billion in the development of nanotechnology. However, future trends and the impact of nanotechnology on the economy and competitiveness of Russian companies are going to be dependent not only on the allocated budget but also on how the money is spent within the sectoral system (Gaponenko 2007).

10.6.4 Iran

In Iran, the need to develop nanotechnologies and nanoscience was considered by the authorities a decade ago. The most important event since the beginning of research in nanotechnology was the formation of Nanotechnology Committee and Special Development (NDSC), which develops and launches 10-year development plans for the nanotechnology sector. Simultaneously, the government mobilized special financial resources for the NDSC to invest in the development of nanotechnology. The budget allocated to the NDSC has grown in recent years, but this funding is not sufficient to meet the industry's growing needs (Mohammadi et al. 2012).

Soon afterwards, the government strengthened the NDSC through: the creation of working groups on nanotechnology and infrastructure development in various ministries; the creation of the network of nanotechnology laboratories and the network of nanotechnology companies; the launch of the nanotechnology standardization committee; the creation of a network of incubators and technology parks; the creation of universities, research centers and centers of intellectual property services; and the allocation of financial resources to support theses and research in nanotechnology areas.

Following the strengthening of the NDSC, there has been an exponential growth of international publications of Iranian researchers in the field of nanotechnology, an increase in the number of theses and research related to nanotechnology and an increase in the number of international patents registered by Iranian residents. At the same time, this has led to changes involving an increasing number of active students and of specialized human resources in the field of nanoscience. The number of companies has also increased, which has led to a more specialized value chain. A reinforcement of nanoscience is expected to occur to stabilize and promote the institutionalization and legitimization (Mohammadi et al. 2012).

10.6.5 Sweden

Participants of the Swedish nanotechnology innovation system were identified in research groups from universities, nanotechnology related companies, funding bodies and governments.

In the year 2000 many nanotechnology related industries and companies were born in Sweden. In just 4 years there were 85 firms. Due to their novelty factor, many of them lacked customers.

During the same time period, research groups at universities also recorded remarkable growth, many of them changing their research line to topics related to nanotechnology and nanoscience.

A large number of financing bodies, both public and private agencies, are keenly interested in nanotechnology. They are characterized by having programs focusing on nanotechnology. What emerged from further analysis of the innovation system is mainly that there are no clear guidelines, defined rules or practical measures in order to promote effective collaboration and transfer of knowledge and technology between the various partners of the initiative.

Even with the existence of a systemic perspective and with high expectations regarding its performance in promoting the interaction among all actors, no effort was made to make fruitful collaborations. Moreover, despite the pressure on academia and industry, no concrete measure has been taken.

Although nanotechnology emerged as a potential growth area for the Swedish industry and even though the innovation system has had the opportunity to thrive, so far there are clear signs of it being at an early stage of development.

Unlike the German and American approaches to generate a successful innovation system, the Swedish strategy did not lead to the same results obtained in those countries. The main weakness is the lack of a national political interest that represents one of the main driving forces for creating innovations systems from emerging technologies. In addition, although scientific knowledge is strong, the technical knowledge is weak and a low collaboration among all stakeholders, including universities and industry, jeopardizes the diffusion of interdisciplinary knowledge.

10.6.6 South Korea

It was the desire to become an advanced nation in the world that led South Korea to an emerging position in nanotechnology. This new way of thinking was imperative to plan a national innovation system that would allow for the achievement of creative and decisive new technological discoveries. Such a system was used for the organization and management of innovative R&D projects and defining the role of all key actors involved (Song et al. 2007).

As a characteristic of the field of nanotechnology (still in its emerging phase) and the relatively new research model and market, the main task of designing a development strategy was represented by the uncertainties related to the technology and its market.

The Ministry of Science and Education (MOSE) was accused of planning, systematically, the technological development of South Korea, providing intensive support (for over more than five years) for strategic technologies with strong industrial applications. Therefore, the main objective of the MOSE program was to identify the specific areas in which South Korea would be prepared to achieve technological leadership, including high definition TV, medical technology, alternative energy sources and energy production processes. After that, a management system was introduced and a leader for each program was chosen and charged with overseeing all activities related to the R&D cycle (Song et al. 2007).

The ultimate goal set by the government aimed at achieving new technologies that enable to generate industries, jobs and new products. Unfortunately, the development of such a technology-driven approach to innovation has been slow and complicated as a result of the lack of technological expertise combined with a lack of field experts in the development process of many projects of emerging technologies.

Due to the relatively recent approach, oriented not to imitation but rather to creating new technological innovation, and to the lack of technological knowledge to perform the project plan, the South Korean system encountered some obstacles that slowed down the creation of innovations. The study of this nation is relevant because it shows that, in spite of all obstacles, it has a strong potential to succeed in creating nanotechnology innovations (Song et al. 2007).

10.7 Conclusion

One can conclude from Karaca and Öner's (2015) study that although the demand for nanoproducts may be latent, it is clear that systems of innovation will only emerge if the necessary conditions are met so that public and private sectors work in tandem.

Nowadays, it is possible to describe the general characteristics of nanotechnology systems. The current embryonic stage of nanotechnology SSI is marked by institutional shortcomings, the creation of new institutional infrastructures (companies and organizations), the emergence of networks, the existence of a learning system and the consolidation of the technological base. The knowledge base is of fundamental importance as a "training engine" in nanotechnology. Malerba (2002) pointed out that the SSI base differs among sectors, strongly affects innovative activities, the organization and the behavior of companies, as well as other agents within the sector (Malerba 2002; Gaponenko 2007).

Then, what are the specific features of the nanotechnology knowledge base?

First of all, nanotechnology encompasses a multidisciplinary and intersectoral challenge. It is characterized by a huge thematic range where the most important sub-disciplines are applied physics, material sciences, physical chemistry, condensed matter physics and molecular chemistry and biology. It is already possible to witness some trends and common actions on the formation of nanotechnology sectoral systems: the creation of interdisciplinary nanotechnology research centers and centers of excellence. Moreover, nanoresearch requires specific and expensive scientific equipment, which can only be provided with the involvement of the state and public bodies so that public and private research organizations can have up to date equipment and instruments required for demanding R&D in this area (Gaponenko 2007; Zweck et al. 2008; Zhao et al. 2003).

The multidisciplinary knowledge base leads to multidisciplinary and overlapping networks within the sectoral system, which might lead to a diverse and unfocused technology conglomerate as a result of the diverse paths of all the involved players. There is a clear interest in nanosciences involving researchers of many different sciences, creating new grounds for a multidisciplinary approach, combining scientific paradigms. Despite the large and ongoing investment, the development of nanotechnology is a recent theme and is in its experimental phase (Gaponenko 2007; Islam and Miyazaki 2009; Lo 2015).

It is not possible yet to determine exactly how the nanotechnology "platform" would be consolidated in the future. According to Heidenreich (2004), one might argue that it is still in its dirigiste perspective. Nanotechnology is in accordance with a science-based innovation pattern where scientific investments play an intertwined world between science and technology. The initial development of tools and instrumentation precedes and facilitates the scientific developments which, in turn, stimulate the technological development and commercial applications. Nanotechnology is thus marked by the emergence of certain non-core organizations, such as financial institutions, government agencies and technology transfer organizations. Moreover, risk funds and technological incubators also play a key role if the innovation system is to attain a networked perspective, according to Heidenreich (2004).

Nowadays, the market for nanotechnology is at an early stage but is expected to grow rapidly. Looking at recent trends we can highlight some peculiarities: spin-offs and micro and small enterprises will have a special role in this market—the creation of business relationships between companies and research centers and universities. Some regional differences may arise in the future: in the USA the role of small and micro enterprises is the most relevant, while in Europe research centers and universities are more prevalent (Gaponenko 2007; Kostoff 2012; Zweck et al. 2008).

Advances in emerging technologies play an indispensable role in the development of all sectors (Maine et al. 2014). Developed countries have succeeded in muddling through the intricacies of driving new technologies to the market developing appropriate opportunity-driven innovation policies. Funding nanotechnology projects increases each year. Moreover, mastering the knowledge and the experience gained involving nanotechnology projects is important to define the strategic direction of nanotechnology funding policies, as well as the results of ongoing research. For example new challenges are expected to flourish as the sustainability of nanotechnology, understood as the impact on the environment and on human health.

The experience of the Grenoble micro-nanotechnology cluster is very important from the innovation system point view (Potter 2009). As one can conclude, based on Potter's (2009) work, the following topics are very important for a sectoral system of innovation to work properly:

- The support by national administration for continuing and broadening R&D infrastructure and products so that social and economic benefits can be maintained in the nanotechnology long-term perspective.
- In order to respond to increased international competition, firms and R&D institutions from the nanotechnology industry must work in partnership. As nanotechnology involves massive public investments, in order to maintain a favorable investment firms and R&D institutions need to work together to achieve sufficient scale to be able to compete internationally.
- From the cluster perspective it is important to focus on the balance between diversity and specialization, as well as between exploitation and exploration. As such, the governance of the innovation system needs to take into account that too much investment on exploitation of current innovation / R&D activities might be important for the short-run, but will surely jeopardize the long-term perspective. On the other hand, too much focus on new / uncompetitive technologies may halt short-term research profitability. The diversity / specialization balance is also very important as nanotechnology might have pervasive effects across several industries, which might be jeopardized if the specialization is too narrow. These two important balances will certainly influence the international competitiveness of all players involved.
- Although most of the above mentioned studies refer to patenting and R&D activities quite exhaustively, the promotion of start-ups and new SMEs is very important as they involve the creation of a buffer of cooperative activities within the innovation system, as well as the dissemination of innovation across the system. If SMEs are able to perform adequately throughout the value chain, larger firms and R&D institution will be allowed to focus on their core activities, which enhances the cooperative dynamics throughout the whole innovation system.
- If start-ups and SMEs are to be competitive players, they need to overcome early financial barriers so that they achieve a proper scale to generate long-term revenues. As such, seed capital, business angles, among other private sources, need to be mobilized so that public funding can reach all players and technological complementarities among them are achieved.
- If financial support is imperative, entrepreneurship support activities are also important so that new start-ups have streamlined support underpinning exploration/diversity of the innovation system. Education, training, incubators and coordinating bodies need to be deployed so that entrepreneurship intentions are not hindered.

Based on Heidenreich's (2004) regional innovation dilemmas, the governance structure of dirigiste regions must be avoided because of the highly fragile institutional order threatened not only by companies' individualistic behavior, but also by the lack of technology widespread knowledge. A network perspective is needed, for example as shown by Moreira et al. (2007), so that governance structure maintains an entrepreneurial interest matching R&D infrastructure, the promotion of new ventures and innovative economic policy, so that nanotechnology may evolve towards a knowledge-base economy, in which all industry players achieve long-term, growth-based dynamic complementarities.

Despite being a radical innovation with economic and social pervasive effects, Smadja (2006) and Karaca and Öner (2015) found possible scenarios in which nanotechnology is doomed. As a consequence, one must seriously take into account the governance of the nanotechnology innovation system so that the go-nano perspective really takes place in the future. One thing is certain, more of the same perspective is not an option. As a result, an entrepreneurial outward looking perspective needs to be deployed so that new opportunities are embraced.

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