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Mapping nanotechnology across the Atlantic: some (tentative) lessons for the future of nanotechnology in Latin America

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Abstract

This paper is a tentative exploration of the institutionally and discursively distinct invoked forms of nanotechnology that evolved within the United States, Europe and Latin America. In assessing the patterns of nanotechnology on both sides of the Atlantic, it identifies this field as a hybrid category, combining forms of social reflexivity, industrial organization, and the localized histories of research and development. It is argued that such patterns are only understood by rendering nanotechnology as a category used by actors rather than as a solid core of technical and cognitive competencies. Some implications of holding this view are drawn for Latin America.

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1. Introduction

This article explores the spatial configuration of nanotechnology across the Americas and Europe. The purpose of such exploration is to provide a foundation on which to assess the evolution of nanotechnology across numerous political, epistemic and organizational boundaries. In setting these grounds, the following reflections, albeit tentative, seek to highlight the heterogeneous character of nanotechnology, not only in a technical sense (that is, in terms of the many types of projects that are labeled as being 'nanotechnology'), but also in terms of the social hybridity of its constitution.

Two observations motivate this exploration. First, that there is a growing, yet continually changing, perception of nanotechnology as a fundamental component in a novel global form of technoscientific/economic organization. In most of its incarnations, nanotechnology is hailed as the prime element of a new economic wave (Wonglimpiyarat, 2005) with clear societal benefits in the medium and long term (Rocco, 2004; Rocco and Bainbridge, 2001). Numerous estimates exist as to the effects of nanotechnology in our economies, with the sizes of expected markets in 'nano-products' varying from tens of billions to trillions of dollars by the mid 2010s (Bond, 2003). It is hence not surprising that nanotechnology is often presented as a technological fix through which developing countries can escape the environmental and social inequalities associated to 'traditional' modes of industrialization (Annan, 2004; Corbett, McKeown, Peggs, and Whatmore, 2000; El Naschie, 2006; Salamanca-Buentello, Persad, Court, Martin, Daar, and Singer, 2005). Although the degree to which nanotechnology is such a revolutionary innovation remains a matter for further enquiry and debate, a mapping of the status of research, development and innovation activities in nanotechnology in the Americas is a useful reference for future analyses since it allows drawing comparisons between different regulatory, scientific and economic regimes.

The creation of this mapping hinges, however, on a second observation: in claiming nanotechnology as a revolutionary innovation upon which the paradigms of future technological and economic development hinges (see Perez, 2002), this entity became an iconic 'quasi-object': in discourse, it acquired durable and concrete characteristics that allow comparison with successful past technological ventures and the projection of futuristic trends. There are numerous examples of how such discursive concretizations of nanotechnology are adopted, not only by self-identified nanotechnologists, but also by social and economic scholars studying trends within the field. Perhaps the most relevant for the purpose of this discussion is found in the special issue of *Research Policy* on emerging nanotechnologies where the editors set out their program by accepting the broad (and methodologically problematic) definition given by the National Nanotechnology Initiative as "fast becoming the standard" (Bozeman, Laredo, and Mangematin, 2007: 807). Interestingly, the definitions used by the National Nanotechnology Initiative, which serve as a central reference for global scientific and industrial policy communities, have changed over time. Towards 2004, nanotechnology involved "research and technology development at the atomic, molecular or macromolecular levels […], creating and using structures, devices and systems that have novel properties and functions because of their small and/or intermediate size [and the] ability to control or manipulate on the atomic scale". As of 2008, nanotechnology is defined in terms of a very particular division of epistemic labour, connected to a linear model of innovation: nanotechnology is no longer both technology development and 'basic' research. These two groups are differentiated according to their broader significance for industry: "nanoscience involves research to discover new behaviors and properties of materials with dimensions at the nanoscale" while "nanotechnology is the way discoveries made at the nanoscale are put to work". Even with this narrower 'standard' representation, nanotechnology remains too general a term, encompassing diverse and at times disparate fields of research and industrial application, not necessarily linked by practices, developmental trajectories, modes of industrial organization and localized innovation cultures.

The aim of this paper is therefore not merely to describe the organization of nanotechnology in Europe and the Americas. Such description is designed as an exercise through which I seek to answer some basic questions on the character and possible future of nanotechnology as an allegedly emerging technology and/or field of research, development and industrial production. In particular, and by comparing and contrasting the regimes between the United States, Latin America, and the main economies in Europe this article will provide partial, though informative answers, to three questions: first, is nanotechnology an inherently new phenomenon? Second, should nanotechnology be a funding priority for Latin America? And third, should the debates on the ethical, social and legal implications of nanotechnology and the nanosciences that are now so common in Europe and the United States be replicated in Latin America?

This paper proceeds as follows. The following section, section 2, deals with the different provenances and meanings of nanotechnology. In a sense, this section seeks to deconstruct nanotechnology broadly defined in terms of its alleged origins and its historical contextualization. Section 3 presents the discussion of the previous section and renders it in terms of a taxonomy of nanotechnology. The fourth section presents the sources on which an analysis of nanotechnology in Europe and the Americas was conducted. The results of such analysis are presented in section five. Finally, section six contains a discussion of the results and is followed by some brief concluding remarks.

2. The meaning(s) and institutional variations of nanotechnology

The origins of the term nanotechnology lie in what I will refer to as three broad narratives of creation. The first attributes the birth of this field to a lecture delivered by Richard Feynman in 1959 (Feynman, 1992), where the theoretical possibility of extreme forms of miniaturization was emphasized (the archetypical metaphor being the possibility of reducing the Encyclopaedia Britannica to the head of a pin). Although a complete contextualization of Feynman's lecture deserves an exposition of itself, it suffices to note that the notion put forward in it was not a radical departure from previous conceptualizations of a technological future. Rather, it reflected the social conditions surrounding the American scientific community at the time, capturing existing narratives on the nature and future of complex technologies. For instance, the idea of the miniaturization of information storage and computational processing at the quantum level partially followed existing narratives on the reduction of the dimensions of electromechanical systems in general and of computers in particular, an area where Feynman proved to develop some degree of competencies (Feynman, 1985). Furthermore, the mention of biological systems as exemplars of small scale information storage and processing units, and hence as proof of the physical viability of designs at the sub-micron level, was bound to previous long-standing conceptualizations of living organisms, including humans, as machines, a line of thought that had manifestations in other areas of knowledge (see Bensaude-Vincent, 2004 for the use of the metaphor in nanotechnology and Mirowski, 2002 for the role of 'cyborg' metaphors in economics and the physical sciences). Thus, while Feynman's lecture provides a bold and metaphorically rich reference on which several authors could (and indeed have) based their historiographies, it represents a middle point in a longer historical process on the miniaturization of information systems.

The second narrative of creation of nanotechnology has its origins in an article presented by Norio Taniguchi in 1974 to the Japanese Society of Precision Engineering in which, according to popular wisdom, the term nanotechnology was coined. Rather than focusing on the possibilities of the miniaturization of informational arrangements as was the case with Feynman's metaphor, Taniguchi presented nanotechnology as "the processing of, separation, consolidation, and deformation of materials by one atom or by one molecule" (Taniguchi, 1974). In a sense, this form of nanotechnology is also related to miniaturization via the production of microelectromechanical systems (Frazier, Warrington, and Friedrich, 1995). Here, however, the metaphor is one of directly controlling and manipulating matter at the atomic and molecular levels rather than the development of self-organizing, information-oriented systems. Hence, it is closer to the thrust in microscopy and precision engineering, epitomized by advances in microlithographic techniques as well as by the development of systems such as the atomic force microscope in the early to mid 1980s.

The third and more conservative narrative on the origins of nanotechnology derives from the works of authors broadly seen as located within the field of chemistry, as exemplified by Richard Smalley and Georges Whitesides (Bensaude-Vincent 2004). For these, the challenge in chemistry lies in the creation of materials whose properties depend on their structural, rather than purely chemical, configuration (Rao and Cheetham, 2001; Whitesides, 2008a). In this sense, they focus on understanding, controlling and exploiting so-called emerging properties of materials, which include self-assembly (Whitesides, 2008b), changes in macroscopic behavior due to variations in surface-to-volume ratios (Vayssieres, 2004), and the partial quantization of systems due to sub-micron configurations (Frank, Poncharal, Wang, and de Heer, 1998). Although this narrative emphasizes exploiting 'novel' behaviors as well as the creation of new materials, it tends to frame such developments in the context of existing chemical (and biotechnological) capabilities. Thus, nanotechnology is partly seen as a mere refinement in chemical synthesis capabilities through the creation of tailored and more 'efficient' materials. Since the structure of sub-micron arrangements is a critical factor for this specific conceptualization of nanotechnology, it is thus not surprising to see that it feeds from developments in biotechnology where issues of macromolecular structure and synthesis have been a constant for decades (Bud, 1993).

Though by no means comprehensive, these three historiographic narratives reflect the main disciplinary provenances of nanotechnology. The first, connected to Feynman, and closely associated to condensed matter physics as well as electric and electronic engineering; the second, provided by Taniguchi and related to the development of precision instruments and forms of sub-micron manipulation of matter (e.g. via wafer photo-lithography); and the third, given by Whitesides and Smalley, closely connected to the developmental trajectories of chemistry and, more recently, biotechnology. To a certain extent, other renderings of nanotechnology, such as that of Eric Drexler in which self-assembly, information processing and biological simulation play a central role (Drexler, 1986; Drexler, 1981), are located at the intersection of these three forms. In this sense, to claim that any of these historically bound definitions is incorrect is to miss the point. Each of these contribute to make nanotechnology a concept around which boundary work is performed (Gieryn, 1999), and are hence elements used in negotiating who and what goes into particular research projects, organizations, funding priorities and specialized publications (Selin, 2007).

Nanotechnology is therefore not 'merely' a technical practice that takes place the putatively isolated laboratory benches of universities and industries. These practices co-evolve with a mesh of policies, regulations, public perceptions, and organizational cultures. Recognizing the organizational and discursive environments within which nanotechnology lives is hence necessary in disentangling its many components.

In broad terms, the growth and development of nanotechnology (specifically in the United States) has occurred within the framework of a relatively new mode of knowledge production characterized by three features. First, a reconfigured (though by no means historically disconnected; see Noble, 1979) relation between university-based research centers, governments and industry that prioritizes the comoditization of knowledge and sets innovation and applicability as the ideal outcomes of research (Etzkowitz and Leydesdorff, 2000; Gibbons, 1994). Second, a new regulatory landscape strongly associated to the needs and commercial strategies of transnational corporations (Mirowski and Sent, 2002). (Examples of this brave new world are seen in, but are in no way limited to, the Bayh-Dole Act of 1980 in the United States, which provided an incentive for commercial linkages between universities and industry [Good, 2004]; or the expansion of intellectual property rights given by the ruling in Chakrabarty vs. Diamon). And third, what could be referred to as a restructured hierarchy of science in which large scale, centralized research projects traditionally bound to the physical sciences (e.g. the superconducting supercollider) lost priority and visibility vis-à-vis distributed, multi-scale projects in the biological sciences (e.g. genome sequencing projects). It is important to note that despite claims made in the past, this model of technoscientific knowledge production is by no means uniformly globalized, leaving space for numerous variations in forms and practices between the so-called centers and peripheries of scientific production. Nevertheless, the intricacies of the interactions between the research and development policies and practical realities between developed and developing countries has yet to be explored in all its richness and details.

In addition to its embedding within this relatively novel mode of knowledge production, nanotechnology is characterized by what several authors denote as ELSI-fication (Kearnes and Macnaghten, 2006; Williams, 2006). Namely, the debate around (and potentially the planning of) nanotechnology incorporates a number of discussions on the Ethical, Legal and Social Impacts (ELSI) of this field/practice, similar to those that formed part of the Human Genome Project (Fisher, 2005; Leydesdorff and Etzkowitz, 2003). These include studies on topics such as the public perceptions of nanotechnology (Bainbridge, 2002; Burri and Bellucci, 2008; Keller, 2006), ethical issues (Grunwald, 2005; UNESCO, 2006; Weil, 2003), and its implications for areas such as homeland and international security and risk assessment (Altmann, 2004; Pardo-Guerra and Aguayo, 2005; Ratner and Ratner, 2004; Renn and Rocco, 2006). Although some of these ELSI-type studies are attributable to the veneer of novelty conferred on nanotechnology, many form part of a concerted institutional mandate to investigate the possible future effects of nanotechnology on human life and the environment. Assessments of the effect of these studies on the design and implementation of research projects and industrial policies are still lacking. However, the ELSI-fication of nanotechnology possesses a specific logic if understood as a form of learning upon, or evolutionary adaptation to, the problems faced by other fields in the recent past. An example of this is the debate on genetically modified organisms, where the role of numerous non-expert interest groups within the risk-evaluation and decision-making process was at stake, and which became an issue of controversy in public policy circles. By incorporating ‘societal concerns’ in its institutional configurations, those involved in the management of nanotechnology sought to avoid alleged problems of public participation and social ‘irreflexivity’ that befell some groups and organizations associated to technologies such as GMOs (Rip, 2006).

3. Of classifications

The above discussion allows defining a space that represents specific projects labeled as examples of ‘nanotechnology’ in terms of two axes: a first related to the perceived provenance (and hence the character of the perceived innovativeness) of the projects, and a second related to their degree of ‘socialization’ (for instance, through their ‘degree’ of ELSI-fication). An elaboration of these two axes, as well as examples of how they may interact, is presented in Table 1. These two axes are linked by the manner in which different conceptualizations of the origins, imagined futures, and assumed intrinsic potentialities of nanotechnology interact to produce distinct narratives on the nature of the field. Each of these narratives serves, in a sense, as a device through which particular communities define specific boundaries. In this sense, this taxonomy is one of expectations and beliefs rather than strictly one of technical provenances.

[INSERT TABLE 1 HERE]

As a rough classification, these two axes differentiate forms of nanotechnology that need not have the same institutional organization. For instance, one could think of two ‘extremes’. On the one hand, one could find a specific instance of a project labeled as being an example of nanotechnology in the area of chemical synthesis (e.g. the mass production of nanocomposites) where the innovations are framed as a continuation of existing trajectories and where there is a perception that technology assessment is essentially unnecessary. If this occurs in the context of an organization in which the meaning of nanotechnology is relatively stable (e.g. a small firm or a small research group), then this case could be identified as an instance occurring at the top-right corner of table 1. However, multi-institutional projects with broad aims can also be identified in which the narratives on nanotechnology are complex, where there is a number of stakeholders participating in decision-making processes, and in which risks and benefits are perceived as highly uncertain. Such would be the case, for instance, of the US National Cancer Institute’s Alliance for Nanotechnology in Cancer. Although this taxonomy by no means indicates whether particular projects will become the sources of 'radical' innovations in the future, it does give insights as to how particular projects might be framed by different actors. Thus, while the first project would likely proceed without hampering from regulations or broad 'societal concerns', it is unlikely that it will draw the same type of funding and from the same sources as the second one.

Since neither of these two dimensions refers to the technical aspects of the project, it is convenient to add a third axis representing specific areas of research within, and potential applications of, nanotechnology. This last dimension is perhaps the most difficult to articulate as the taxonomy of this field a contested issue. For instance, from the perspective of the North American Industrial Classification System (US Census Bureau, 2007), most of the uses of nanotechnology are set by Codes 31 to 33, which include food manufacturing (e.g. use of nanocomposites as additives in foodstuff), textile products (e.g. use of nanomaterials as enhancers of textiles), petroleum and coal products (e.g. use of nanomaterials as additives in fuels), chemical manufacturing (e.g. bulk production of nanocomposites), and pharmaceuticals (e.g. targeted drugs). One could also follow the taxonomy given by the Engineering and Physical Sciences Research Council of the UK (EPSRC, 2006), representing nanotechnology as reducible to eleven different varieties: nanofabrication, nanocharacterization and nanometrology, nanomodelling, fundamental properties of nanomaterials, extreme and molecular nanotechnology, bionanotechnology, nanomedicine, functional nanotechnology devices and machines, nanomanufacturing, nanodesign, and nanotoxicology and the environment. A third taxonomy that shows its industrial origin derives from Siemens, who conceive this field in terms of five areas of application: chemistry/materials, energy/environmental technology, medicine/life sciences, automobile manufacturing, and electronics/information technology (Freise, 2003). Clearly, these categories do not cover the same grounds; further, what is novel for one need not be so for the other. However, these are not merely rhetoric artifacts as they have operational roles within the practices and discourses of particular communities. For the American regulator, they provide a differentiation according to what is known about industrial organization; for the British scientist, they serve as a mechanism for segregating the 'new' from the 'old' and hence for conducting internal evaluations; and for the German industrial analyst, they are a referent for deciding where scarce funds for research and development should be allocated. For simplicity, this paper adopts a relatively narrow taxonomy. The following section describes nanotechnology through this taxonomy as divisible in two broad categories comprised by six sub-categories, shown and explained in table 2. (The categories shown in this table are roughly comparable to the second level of the hierarchical taxonomy presented by Kostoff, Stump, Johnson, Murday, Lau, and Tolles, 2006).

[INSERT TABLE 2 HERE]

4. Mapping the contours of nanotechnology in Europe and the Americas

4.1 Sources

Having provided a brief (and admittedly partial) taxonomy, this article will now proceed to categorize specific countries by locating them within the three axes mentioned above. With this, a series of maps are presented that show the different configurations of nanotechnology across Europe and the Americas.

In methodological terms, the results presented below follow from three different datasets. The first consists of a database created between October 2004 and September 2005 and consisting of 428 entries representing different nanotechnology-related projects and organizations in the United States, Canada, Europe, Japan, China, and India. These entries correspond to five types of actors: universities, non-for profit organizations, governmental or government-sponsored organizations, start-ups and established companies. Each entry contains information on the year on which the project started, its localization (in terms of city and/or country), the type and characteristics of the goods it produces or aims to produce (according to the third axis described in the previous section), and its linkages to other projects, initiatives and organizations. Two characteristics of the entries deserve mention: First, they are based on publicly available prospectuses and descriptions of different organizations and private/public initiatives. In this sense, most of the organizations listed in the database actively promoted and advertised their work as being nanotechnological in nature. In this sense, companies and/or projects that might be considered under ‘standard’ definitions as being nanotechnology but that do not label themselves as such do not form part of this dataset. Second, the database does not cover individual research projects or the work of small groups: the only research projects considered are those that occur under the institutional umbrella of a larger organization designated as being involved in nanotechnology; and in these cases, only the umbrella organization is represented in the database. Although these characteristics of the dataset open the possibility of methodological limitations, the fact that it contains 370 cases of companies involved in nanotechnology is revealing: according to some authors, the worldwide estimate of nanotechnology companies in 2005 was around 550 (Bhat, 2005). The database thus covers nearly two thirds of the companies deemed as being involved in nanotechnology-related activities at the global level.

The second dataset feeds from the literature on nanotechnology in Latin America. Although the number of examinations of the development of nanotechnology in this region is relatively scarce, there are several informative reviews (Delgado Ramos, 2008; Delgado Ramos, 2007; Foladori, 2006; Ulloa, 2002). Of particular import, however, are the surveys conducted by the NanoForum EULA, a project operating under the Sixth EU Framework Programme for Research and Technological Development. The information obtained from these studies, along with that obtained from different ministerial reports, was restructured as a database containing categories similar to those comprising in the first dataset. Here, however, the focus is on specific research programs. Thus, while the first dataset deals mainly with firms involved in nanotechnology, this dataset deals with mainly university-based projects branded as being expressions of nanotechnology.

The third dataset concerns scholarly articles in the social sciences and humanities that discuss the so-called social, economic and political dimensions of nanotechnology. For the United States and Europe, these were obtained from the social sciences and arts and humanities citation indices of Thompson Scientific’s ISI Web of Knowledge which represent the bulk of the peer-reviewed literature in established scientific journals. For Latin America, most of the scholarly articles were obtained from three databases: the Red de Revistas Cientificas de America Latina, el Caribe, España y

Portugal (Redalyc) of the Universidad Autonoma del Estado de Mexico; the São Paulo based Scientific Electronic Library Online (SciELO); and the virtual library of the Consejo Latinoamericano de Ciencias Sociales (CLACSO).

4.2 Results – Europe and the world-at-large

Before presenting the specific results for the Americas, it is convenient to provide supplementary findings from the first dataset that show some of the major trends in nanotechnology in the northern hemisphere. The first derives from an expected recognition of nanotechnology as an activity predominantly based in industrialized countries. Figure 1 shows the distribution of nanotechnology-related companies across 21 countries (Australia, Belgium, Canada, China, Denmark, Finland, France, Germany, Hungary, India, Ireland, Italy, Japan, the Netherlands, Korea, Spain, Sweden, Taiwan, the United Kingdom and the United States). Of the countries represented in this first dataset, the United States dominates the landscape with 132 companies, followed by Germany (59), the United Kingdom (39), Japan (24) and Korea (20). These five countries concentrate more than two thirds of the companies dedicated to research, development and commercialization of nanotechnology.

[INSERT FIGURE 1 HERE]

An indication of the accuracy of this map is provided by cross-reference to the distribution of nanotechnology-related patents. Whilst the relation between patents, innovation and industrial activity is far from being trivial and little if any generalizations can be made, it is possible to establish a partial causal nexus between these parameters. Bearing this in mind, and making use of other studies that feed from the databases of the United States Patent and Trademark Office (Xin, Yiling, Hsinchun, and Rocco, 2007) a map of the global distribution of patents deemed as being of a nanotechnological character was produced and is presented as figure 2. As this figure shows, the distribution of patents follows the distribution of companies in nanotechnology with the United States (3,450), Japan (517), Germany (204), France (156) and Korea (131) concentrating more than four fifths of the 5363 patents at the global level.

[INSERT FIGURE 2 HERE]

Additional information is provided by the types of commercial projects taking place within nanotechnology at the global level. Based on the first dataset and on the third axis of the taxonomy described in table 2, it is possible to classify corporate entries in different countries in terms of the type of activities in which they are involved. Figure 3 shows such the result of this categorization. To understand these results, it is convenient to provide some brief examples of the type of companies and activities that fall under each category. The category 'sensors and nano-arrays' includes firms such as the Immunicon Corporation (USA), providing ferrofluids (magnetic nanoparticles) and specific devices for cell isolation, and Integrated BioDiagnostics (Germany) offering customer specific biochips. Therefore, this category mainly consists of companies elsewhere deemed as involved in bio-nanotechnology. The category of 'bio-interfaces', on the other hand, includes companies involved in the production of biocompatible implants. Such is the case of GfE Medizintechnik (Germany) which commercializes covalent titanium nano-coating for reducing bodily reactions to implants. The category of ‘pharmaceuticals and cosmetics’ includes companies ranging from L’Oreal (France) and SkyePharma Plc (UK, providers of dried powder inhalers for drug delivery) to the Elan Corporation (Ireland, offering nanocrystal technology for the delivery of insoluble drugs) and LiPlasome Pharma A/S (Denmark, producers of anticancer drug delivery systems). Contrary to the firms grouped under the heading of ‘sensors and nano-arrays’, those included in this category are involved in the therapeutic applications of nanotechnology rather than in the development imaging and testing systems. The category of ‘nanomaterials and nanocomposites’ is somewhat self-descriptive as it encompasses companies involved in the production and commercialization of materials. These include, but are not limited to, carbon nanotubes (Shenzhen Nanotech Port Co Ltd, China), biocomposites (SusTech, Germany), quantum dots (Evident technologies, USA), nanostructures for gas storage (BASF, Germany), and nanopowders (Tetronics Ltd, UK). The fifth category, ‘thin films and surface technologies’, includes companies such as Altair Nanotechnology Inc (USA) and Nanofilm Technologies International Ltd (Singapore), providers of coating services for industry. Finally, the category of ‘measurement and fine control’ refers to companies such as Triple-O Microscopy (Germany) which offer cantilevers and probes for scanning probe microscopy. From this graph, it is clear that companies involved in the production of nanomaterials and nanocomposites represent more than a third of the sample. Indeed, companies related to the second type of nanotechnology as presented in table 2 (namely, those involved in a form of nanotechnology that is closer in practice, institutional organization and technical details to research in condensed matter/solid state physics) represent more than two thirds of the global sample. Companies involved in the first form of nanotechnology (namely, that connected to biological applications and similar in form and institutionalization to biotechnology and the pharmaceutical industry) are roughly equally divided in terms of the development and commercialization of sensors and of therapeutic systems.

[INSERT FIGURE 3 HERE]

A closer look at the regional organization of these companies shows that the patterns observed in figure 1 are preserved, to a certain extent, at lower scales. Figure 4 presents the distribution of nanotechnology-related companies for Europe, showing that general patterns of industrial organization are replicated by the self-denominated emerging industry in nanotechnology: not only are companies located in areas with strong pre-existing industrial activity (e.g. South-East England), but there is some evidence of clustering of companies according to their ‘type’ (e.g. South-West and North-West Germany).

[INSERT FIGURE 4 HERE]

The spatial organization of firms described above is coupled to a complex of policies, regulations and public perceptions on the nature of nanotechnology as an emerging field of research and development. In particular, the environments where these firms exist can be decomposed in terms of the manner in which nanotechnology is presented as requiring various levels of social engagement and public reflection. For the purpose of analysis, in this paper it is assumed that the literature on the ‘social dimensions’ and/or implications of nanotechnology provides a proxy for this broader discursive environment: for instance, if nanotechnology is not seen as controversial and hence as requiring little 'social' input, then the literature on the social impacts of nanotechnology will be scare. Bearing this in mind, and using the taxonomy provided in table 1, a categorization of the articles on nanotechnology, produced in Europe and listed in the database of ISI Web of Knowledge in the areas of social sciences and arts and humanities, generates the distribution shown in figure 5. From this figure, it is possible to observe that perceptions on the degree of innovativeness of nanotechnology are not constant across countries. In the United Kingdom, for instance, the early literature on nanotechnology predominantly rendered this field as a potentially disruptive innovation requiring new analytical techniques and a new understanding of the relations between science, technology and society. The literature in the Netherlands, on the other hand, contains a higher percentage of texts conceiving nanotechnology as a radical departure from the past, but largely as an activity that can be understood and managed with existing techniques.

[INSERT FIGURE 5 HERE]

4.3 Results – the United States and Latin America

The patterns of what is broadly labeled as 'nanotechnology' in the Americas are clearly dominated by the industrial and scientific dynamics of the United States. For instance, whilst the first dataset contains no entries for Latin America, there are 141 firms in the United States self-identified as involved in nanotechnology. Likewise, while the literature on the ethical, social and legal aspects of nanotechnology in the United States is extensive and comparable in size and characteristics to what exists in Europe, it is less common in southern regions of the American continent. In this sense, and taking Canada and the United States out of the account for the time being, the results for the Americas are reduced to research and development activities in three countries, Mexico, Brazil and Argentina, which concentrate most of the activities labeled as nanotechnology in the region.

Given that nanotechnology in Latin America is tied to the research and development activities of universities and other non-for-profit institutions, the spatial distribution of this field is somewhat predictable. Indeed, figure 6 shows that activities in nanotechnology in Latin America follow the general patterns of the region, whereby research centers are located near, or are highly connected to, centers of economic activity. In Brazil, where research in nanotechnology occurs within networks established under the auspices of the Ministry of Science and Technology, the projects are concentrated in the Atlantic coast, along the established centers of economic and intellectual activity. The same pattern occurs in Mexico and Argentina, where research and development in nanotechnology takes place in areas that harbor institutions with a long tradition of research in the chemical and physical sciences; such are the cases of the Universidad National Autonoma de Mexico in Mexico City, Mexico, and the Centro Nacional de Energia Atomica in Bariloche, Argentina. Here, it is important to note that, of all the countries in the region, only Brazil and Argentina have federally-sponsored and federally-funded nanotechnology programs comparable to the United State's National Nanotechnology Initiative.

[INSERT FIGURE 6 HERE]

The type of activities pursued in the region are also indicative of previous developmental trajectories. As represented in figure 7, research in nanomaterials represents 40% of the region's projects in nanotechnology, followed by research in thin films and surface technologies (27%), pharmaceuticals and cosmetics (23%) and measurement, control and simulation (10%). Established local research communities in the areas of chemistry, condensed matter and solid state physics serves as the explanation for this distribution. Whereas these fields were the 'natural' predecessors for research in nanomaterials and were widely distributed across the university systems of the subcontinent, biotechnology and biomedicine – the ideal predecessors for so-called bio-nanotechnology – were until recently less dispersed and less frequent (partly due to the entry costs of research in recombinant biotechnology as well as the costs associated with the temporally long processes of pharmaceutical development and commercialization). Intra-regional differences are likewise accountable in terms of the interaction of local institutional realities and policies of science and technology. In Brazil, for instance, the ten research networks established by the Ministry of Science and Technology (Ministerio da Ciencia e Tecnologia, 2006) included projects such as the simulation and modeling of nanostructures, the development of nanocosmetics, and nano-glyco-biotechnology (involved in exploiting naturally occurring polysaccharides for the preparation of nanostrucutred materials). In Mexico, on the other hand, the projects covered under the rubric of nanotechnology are more narrowly defined in terms of research on nanomaterials such as carbon nanotubes, as made evident by the projects of the Advanced Materials Group of the Instituto Potosino de Investigación Científica y Tecnológica (see (Foladori 2006; Ulloa 2002)). This variation occurs despite the fact that research in the area of the commercial applications of bio-polysaccharides also exists in Mexico, although not under the label of nanotechnology (in particular such research is located at the Escuela Nacional de Ciencias Biologicas of the Instituto Nacional Politecnico in Mexico City, Mexico).

[INSERT FIGURE 7 HERE]

The ELSI-fication of nanotechnology in Latin America is also a matter of regional and institutional variation. Here, a series of observations must be made. First, and as mentioned by (Foladori 2006), nanotechnology in Latin America is often presented as necessary for guaranteeing the competitiveness of countries in the region. However, in its different institutional incarnations (be they the Argentinean Nanotechnology Foundation, the Colombian Center for Science and Technology at the Nanoscale, or the several research networks in Brazil), nanotechnology is strictly limited to a 'technical' sense. Research into the social and ethical dimensions of this field do not form part of the mandates of the projects and networks of Latin American countries, less so of the ministries in charge of planning research and development. And the rhetoric surrounding these projects seems to suggest that the prevailing perception in the science and technology policy circles in the region is one of nanotechnology as a radical innovation, rather than a disruptive technology, in which investment must be made.

Second, it should be noted that the general meaning of nanotechnology in the region is derived from metaphors of miniaturization and improved chemical synthesis. Biological metaphors are hence not so prominent as in Europe and the United States, where so-called bio-nanotechnology is considered an important area of the field. The possible exception for this is Brazil, where the array of projects under the rubric of nanotechnology incorporates several lines of research in the bio-sciences.

Third, and finally, the ELSI-fication of nanotechnology in Latin America has only recently emerged as a novel trend. In Brazil, the beginning of such trend is arguably located, between 2002 and 2004, when a number of researchers in the social sciences redefined nanotechnology as an area of both economic and social interest. Concerns started in the form of inquiries on the impact of nanotechnology on human health and the environment (Martins, 2006; Martins, 2005; Quina, 2004) but have been gradually extending to discourses on convergence and disruptive innovations (Cavalhiero, 2007). In Hispanic Latin America, research on the implications of nanotechnology has been largely confined to a handful of authors. These, however, seem to have followed a path similar to that of their Brazilian counterparts: an interest initially located in the economics of nanotechnology and its environmental impacts was transformed into a wider concern on the broader social aspects of this field (see, for instance, the articles listed by the Latin American Nanotechnology and Society Network, RedLANS). An important factor for this transformation has been the involvement of several transnational non-governmental organizations, which carry similar social agendas across borders, enrolling local social scientists in particular debates.

5. Discussion and conclusions

The landscapes presented in the previous section render nanotechnology in its broadest definition as an inherently heterogeneous field. In practice, the organizations deemed as involved in nanotechnology carry out activities in a number of disciplinary and technical areas (from computer simulations of inorganic molecular structures to environmental remediation technologies), feed from a range of narratives, and are embedded in locales structured by different approaches to the social, economic and political dynamics of science and technology. In this sense, nanotechnology is not a strictly delimited unit of practice, knowledge or technique. There is, in a sense, no such thing as a token ‘nanotechnologist’ with competencies in ‘nanotechnology’. The contours of nanotechnology and its definitional scope are produced at the intersection of local historical experiences in research and development and global narratives of revolutionary and disruptive innovations. And, in this sense, nanotechnology exists mainly as a category used by different actors to negotiate their position within a wider sea of technoscientific innovation activities.

From this perspective, the mapping(s) of nanotechnology presented above should be read not as snapshots of the dynamic evolution of an emerging field or of a solid and finite type of practices, but rather as expressions of the different forms of mobilization and use of nanotechnology as a category applied on particular projects, groups, institutions and programs. In a sense, the taxonomies described towards the beginning of this article should be read not as categorizations of what ‘is’ nanotechnology in a strict realist sense; they are categories that refer to the manner in which nanotechnology can, and often is, presented in different spheres.

To say that nanotechnology is best understood as a category used by actors in different arenas does not imply that it is merely a rhetorical ploy; it does not mean that nanotechnology is simply the season’s collection of the emperor’s new (and invisibly inexistent) clothes. Although at the global level it is nearly impossible, indeed analytically undesirable, to identify a unique and correct form of nanotechnology, at the smaller scale it is possible to observe how, in use, the concept of nanotechnology becomes more bounded, solidified and pragmatic. Take the cases of nanotechnology interpreted as either a global or local phenomenon. If one thinks of this field as a global phenomenon, the issue of definitions and categorizations becomes somewhat of a paradox. As figures 1 and 2 show, the distribution of firms and projects self-described as connected to nanotechnology is overall wide, both in a spatial and thematic sense, making a unique definition problematic: if one defines nanotechnology broadly, for instance, as the study and manipulation of matter at the scaled of 1 to 100 nanometers in order to accommodate the community-at-large, then ‘too many things’ become nanotechnology and drawing boundaries becomes a laborious task since the technical competencies for being a nanotechnologist exist in a number of non-overlapping fields. On the other hand, if too narrow a definition is given, one faces the danger of leaving out of the account groups and projects with relevant competencies and which can potentially be sources of institutional, political, financial and technical support. At the local level, however, the danger of giving narrower definitions of nanotechnology is reduced. Such is visible in Mexico and Argentina, where the definition of nanotechnology is strongly influenced by physicists rather than by biotechnologists (in Mexico the example is particularly relevant since the lack of a national nanotechnology initiative implies that being labeled ‘nanotechnology’ does not have direct consequences on access to federal funding). In Brazil, on the other hand, the construction of a broad definition of nanotechnology served as mechanism for rallying funds and generating networks based on the experience and activities of pre-existing research groups.

Returning to the first question presented at the outset of this article, nanotechnology is hence not a novel phenomenon in and of itself, insofar as the bulk of nanotechnological research, development and innovation follows established technological trajectories (e.g. in continuing the increase in transistor density in microcircuits) and technoscientific practices and institutions. The novelty of nanotechnology derives from the manner in which this term has been used to build new networks of collaboration, to project specific images to the market (and to create the market), to redefine the boundaries of existing and new research communities, to obtain support for funding, and to generate a scaffolding of policies and their associated bureaucracies that guarantee the life of this amorphous field in the medium term. The differences highlighted by the mapping of the previous section are therefore differences in the provenance, institutionalization, and strategic planning of scientific and industrial communities in different regions of the world: being labeled a nanotechnology firm in the United States might have some benefits; however, the same is not necessarily applicable to a firm in Costa Rica or Argentina. And in this sense, such variations are exemplifications of the different modes of production of science across the world: whereas practices in the United States and, to a lesser degree Europe, seek to link industry to universities, the same is not true in Latin America.

In this sense, the answer to the second question posed at the beginning of this article is not to be found looking at nanotechnology as a localized technological unit, invariantly transportable across time and space, and for which generic investments can be made. Nanotechnology should be viewed as a priority only if properly defined, domesticated, and institutionalized. Investing in the label alone is a policy fraught with potential disasters. What is required are not overall policies for ‘nanotechnology’ as a generic field, but rather sectorial policies for finite areas and projects in which the short and medium term applications are visible and for which there is local support in the form of established structures for research and development. Some instances of so-called nanomaterials are a prime example of this. As the demand for tailored nano-materials increases (e.g. carbon nanotubes), investments directed towards increases in the efficiency of production of such materials becomes profitable in the medium term. Yet investing in this area as such is not necessarily the same as investing in nanotechnology *per se.*

Following this line of thought, the types and degrees of ELSI-fication of nanotechnology can, and indeed should, be understood as reflections of local(ized) interests. It is not odd, for instance, that four out of the six social sciences articles produced on nanotechnology in Switzerland and included in the social sciences citation index of ISI Web of Knowledge refer to, or are in some manner connected, to the issues of risk, insurance and emerging technologies: the most cited, though by no means the first, report on insurance in nanotechnology was produced by the re-insurers Swiss Re in 2004 (Hett, 2004), explaining the particular approach to the topic (Bucher, Birkenmeier, Brodbeck, and Escher, 2003; Coomber, 2006; Hett and Herold, 2005; Siegrist, Keller, Kastenholz, Frey, and Wiek, 2007). In a sense, the ELSI-fication of nanotechnology serves not only an evolutionary logic, as an adaptation to previous technological controversies (such is the case of the United States and Europe, where issues of risk and social participation in the debate on genetically modified organisms led to the institutionalization of ELSI-type projects at the level of the National Nanotechnology Initiative and the European Commission). The ELSI-fication of nanotechnology is also a mean by which contested futures are negotiated, deconstructed and packaged for re-distribution. The literature in the Netherlands, for instance, has largely become an effort to 'domesticate' nanotechnology into a tractable field (see, for instance, the role played by technology assessment in the NanoNed (2006) program). In the same way, work on the social, ethical and legal impacts of nanotechnology in the United Sates has largely worked within the institutional boundaries and priorities of nanotechnology as conceived by the National Nanotechnology Initiative. Consider, for instance, the International Council on Nanotechnology, ICON, based at Rice University, and that seeks to foster risk reduction 'while maximizing societal benefit' as well as the Project on Emerging Nanotechnologies endeavored by the Woodrow Wilson Center for International Scholars which follows a similar rationale. The character and approach of these two organizations contrasts with the initial strategies of the Foresight Institute, where much of the discourse on radical futuristic scenarios originated (Wood, Geldart, and Jones, 2008).

The locally contingent nature of the ELSI-fication of nanotechnology can be rendered in terms of two lessons for Latin America. First, that although awareness of social, economic and ethical studies of nanotechnology generated in the United States and Europe is important, these must be framed in the appropriate context. In this sense, the replication of narratives about radical and/or disruptive innovations, or about untamed futuristic risks, are ineffective as they are intrinsically tied to particular (often external) conceptualizations the nature of the social order (e.g. of the social 'role' of technology, of the organization of the polity or of the planning of science and technology). Second, that studies on the social dimensions of nanotechnology in the region should take into account the historicity of the different practices, communities, and institutions that are said to be involved in the consolidation of this field. The literature in Latin America has, in a sense, replicated some of the methodological pitfalls of the literature in the United States and Europe by assuming (or accepting) nanotechnology as a novel form of technoscientific life, devoid of any historical continuities or technical entanglements. Rather than pursuing this path, research on the social dimensions of nanotechnology should seek to deconstruct and re-assemble the local meanings and histories behind what is referred to as nanotechnology in order to produce an analytical frame that captures the technical, political and organizational realities of existing institutions. By tracing such continuities, the limits and potentials of particular lines of research and development will become clearer, as the different motors and bottlenecks of existing trajectories are differentiated.

This article is but a tentative approximation to the analysis of nanotechnology as a hybrid field of research, development and innovation. Highlighting the heterogeneity of nanotechnology in both Europe and the Americas through different mappings and taxonomies, it sets the grounds for a reassessment of nanotechnology not as a coherent technical unit generically based on the manipulation of matter at sub-micron scales but rather as a label applied by actors across the world to different activities and organizations. Adopting such perspective renders nanotechnology as a phenomenon built at local levels integrating (and indeed reinterpreting) existing trajectories of technoscientific development in different fields. This observation thus calls for analysts to engage in critical (and perhaps more conservative) re-examination of nanotechnology, seeking continuities rather than disruptive change. Such re-examination is particularly relevant in countries that show interest in nanotechnology as a promissory area of investments but where the industrial and technoscientific organization if structurally different from the United States and Europe.

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<table>
<tr><th>Narratives of creation

Degree of ELSI-fication</th><th>Miniaturization with a focus on information and the simulation of biological systems (Feynman)</th><th>Miniaturization with a focus on design and manipulation at sub-micron levels (Taniguchi)</th><th>Enhanced chemical synthesis (Whitesides and Smalley)</th></tr>
<tr><td>Incremental innovation
‘Nanotechnology’ as uncontroversial and requiring no special treatment or research on its social/economic implications</td><td colspan="3">(I.1, I.2 & I.3) The specific meaning of nanotechnology is defined by relatively small research groups that do not find it either controversial or ambiguous. Particular narratives become predominant and are used to show nanotechnology as the next logical step in a chain of progressive advancements. Overall, an instrumental view dominates the attitudes towards nanotechnology.</td></tr>
<tr><td rowspan="2">Radical technology
Nanotechnology poses no societal problems. However, it is economically relevant, therefore calling for research on its market impact. Little or no institutionalization of social/economic research.</td><td colspan="3">There are several meanings of nanotechnology dictated by different research groups that compete for funding. However, nanotechnology is presented as a concrete ‘thing’ with potentially radical implications for production. There is hence a closer focus on its economic impacts and recourse is made of linear models of innovation in organizing funding of nanotechnology, with an underlying instrumental interpretation of technology and innovation. Further, distinctions are made, for instance, between nano-technology and nano-science. Regulation, in this sense, is seen merely as an inhibitor/stimulant for industrial applications.</td></tr>
<tr><td colspan="2">(II.1 & II.2) Nanotechnology is considered as a source of breakthroughs on the miniaturization of systems (e.g. by continuing Moore’s law in the semiconductors industry). The effects of nanotechnology are thus seen as consisting of a reduction in prices and increase in efficiency of commercially available products.</td><td>(II.3) Nanotechnology is seen as providing materials that increase the efficiency of conventional systems (e.g. pharmaceuticals). Existing risk assessment techniques (e.g. toxicology) are deemed adequate.</td></tr>
<tr><td>Disruptive technology
Nanotechnology is a radical innovation. There is an intense ESLI-fication of</td><td colspan="3">Nanotechnology acquires a wide multiplicity of meanings and becomes a publicly contested topic. Several narratives on the origins of nanotechnology co-exist. Since it is perceived as a disruptive technology, efforts are focused on exploring not only its impacts on the market but also on human life and the environment in general. Debates on regulation, trends, and promised futures are framed in ethical and societal terms</td></tr>
</table>

nanotechnology. ELSI-type studies are institutionalized.	therefore leading to the institutionalization of ELSI-type programs.		
	(III.1) Nanotechnology is seen as the source of sub-micron designs inspired on biological systems. The scenarios of future uses, however, vary widely, from those of grey-goo to those of domesticated in-vivo sensors.	(III.2) Nanotechnology becomes the source of breakthroughs in miniaturization and the production of microsystems and interfaces. However, it is seen as posing risks in terms potential mis-uses.	(III.3) Nanotechnology is seen as a source of compounds with novel properties and a wide spectrum of application. However, such compounds are considered potential sources of risk, not accounted for in current assessment techniques.

TABLE 1. A taxonomy of instances of nanotechnology projects based on their perceived levels of innovation and their perceived origin.

	Subcategories	Description	Disciplinary and industrial precedents	Promises (examples)
'Bio-nanotechnology'	***Sensors and nano-arrays***	Development of high efficiency sensors for in-vivo assays and of portable sensors for environmental analysis 'in the field'	Biomedicine, physiology, chemistry and pharmacology	Real-time early detection of multiple genetic disorders; dangerous substance detection for uses in toxicology and homeland security
	Bio-interfaces	Development of versatile immunologically non-reactive substances for uses in medicine and of imaging and contrast materials	Biomedicine, physiology, material sciences	High resolution imaging through magnetic Nano-particles
	Pharmaceuticals and cosmetics	Development of targeted delivery systems for pharmaceuticals and of trans-dermal and pulmonary delivery mechanisms	Biomedicine, chemistry, pharmacology	Effective delivery of drugs with increased combined efficiency and reduced side-effects (for instance, in chemotherapy)
'Physico-chemical-nanotechnology'	***Nano-materials and nano-composites***	Development of materials exploiting size/volume ratio and/or behaviors derived from the quantum properties of complex molecular structures	Material sciences, chemistry	Use of carbon nanotubes for their use as energy-efficient electrical devices in new generations of microcircuits
	Thin films and surface technologies	Development of systems based on the optical, physical and catalytic	Material sciences	Low cost diamond coating, high

		properties of thin films		efficiency energy and photovoltaic cells
	Measurement and fine control	Development of systems for the manipulation and analysis of matter at small scales	Material sciences, precision engineering	Ultra-precision lithography for new generation silicon wafers

TABLE 2. Taxonomy of nanotechnologies according to their technical characteristics

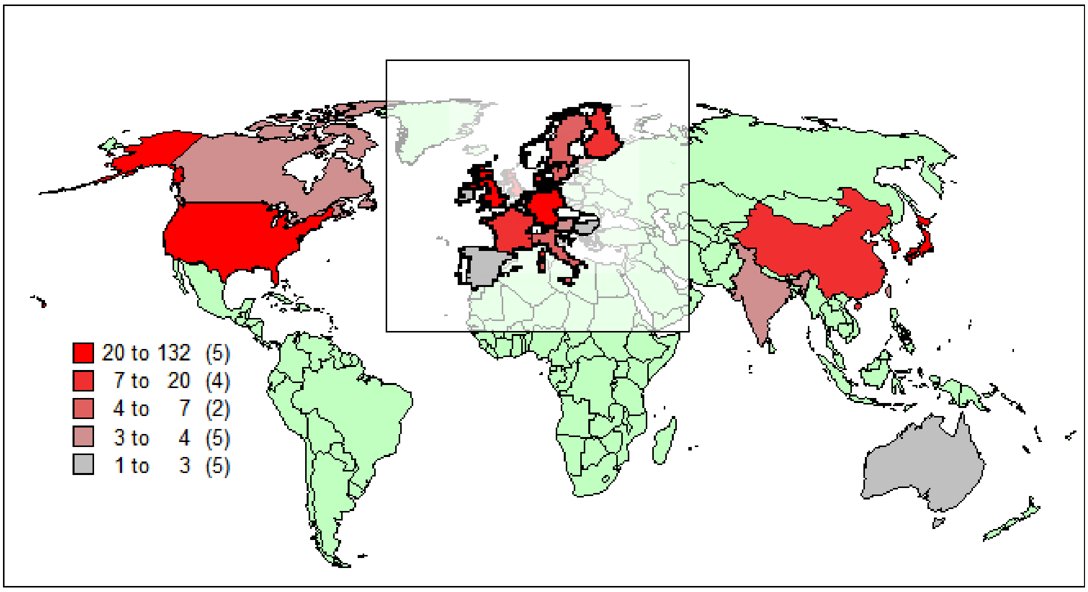

FIGURE 1. Distribution of companies self-identified as engaged in research and development in nanotechnology.

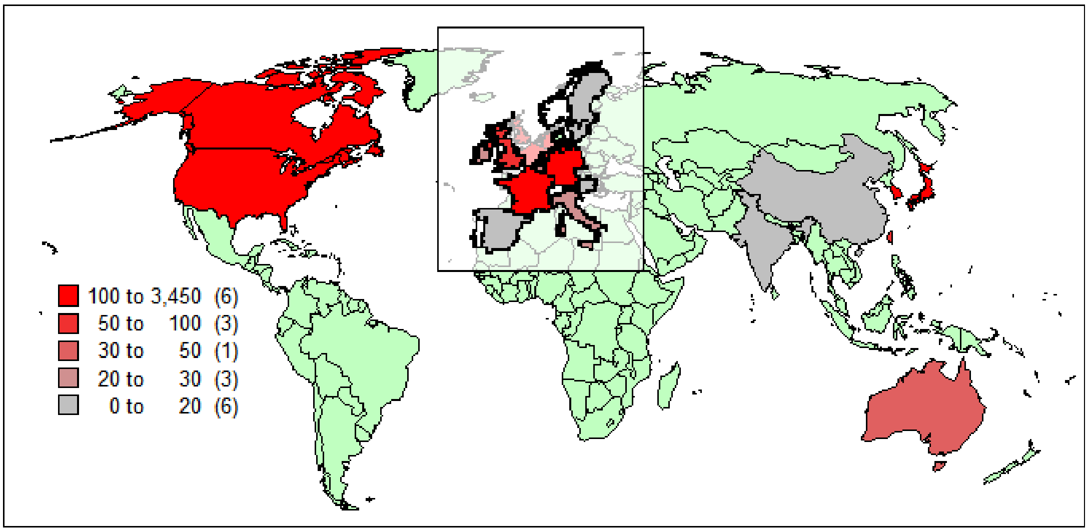

FIGURE 2. The global distribution of patents in nanotechnology according to the USPTO as obtained by Xin et al, 2007.

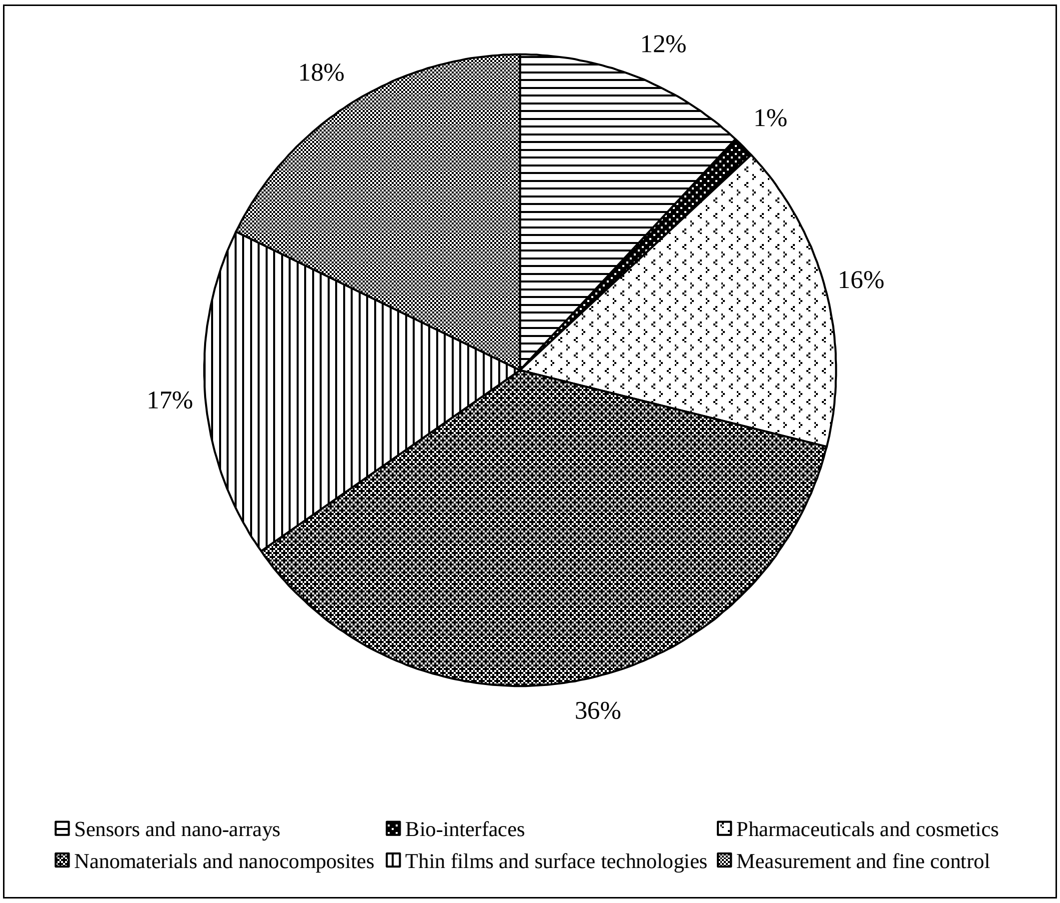

FIGURE 3. The commercial landscape of nanotechnology in terms of the types of activities in which companies are involved

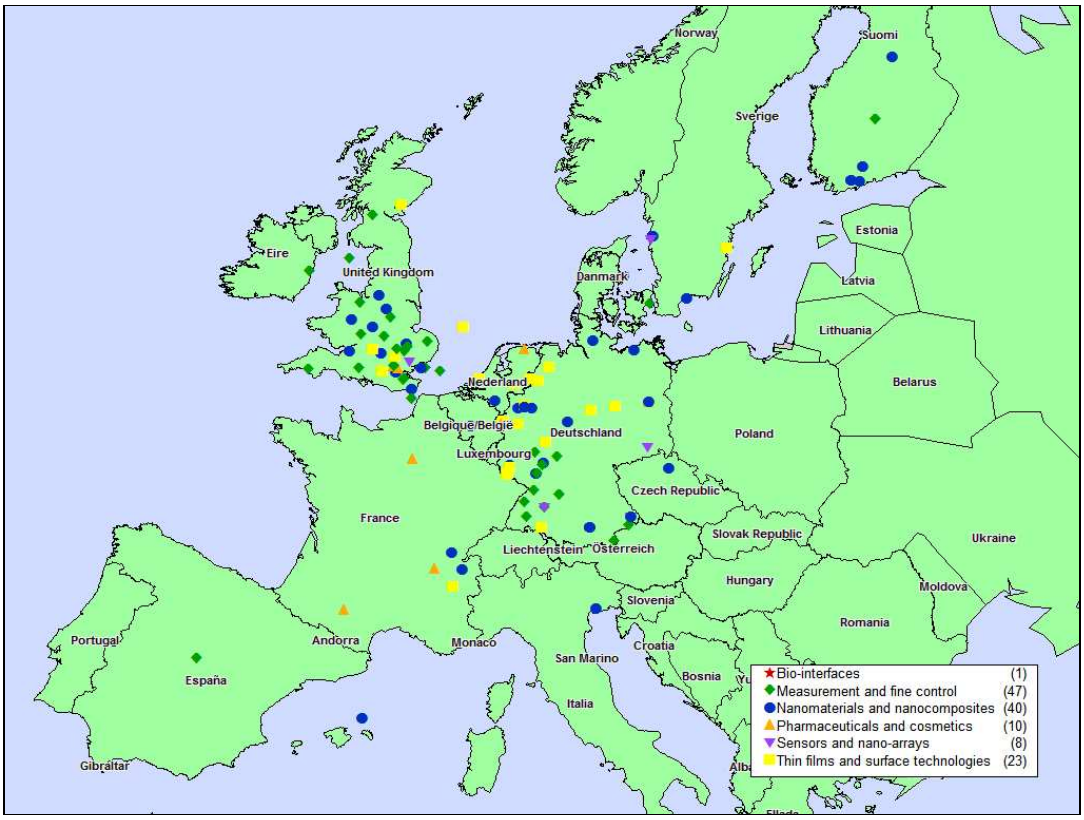

FIGURE 4. Distribution of nanotechnology-related firms in Europe, according to the type of activities in which they are involved

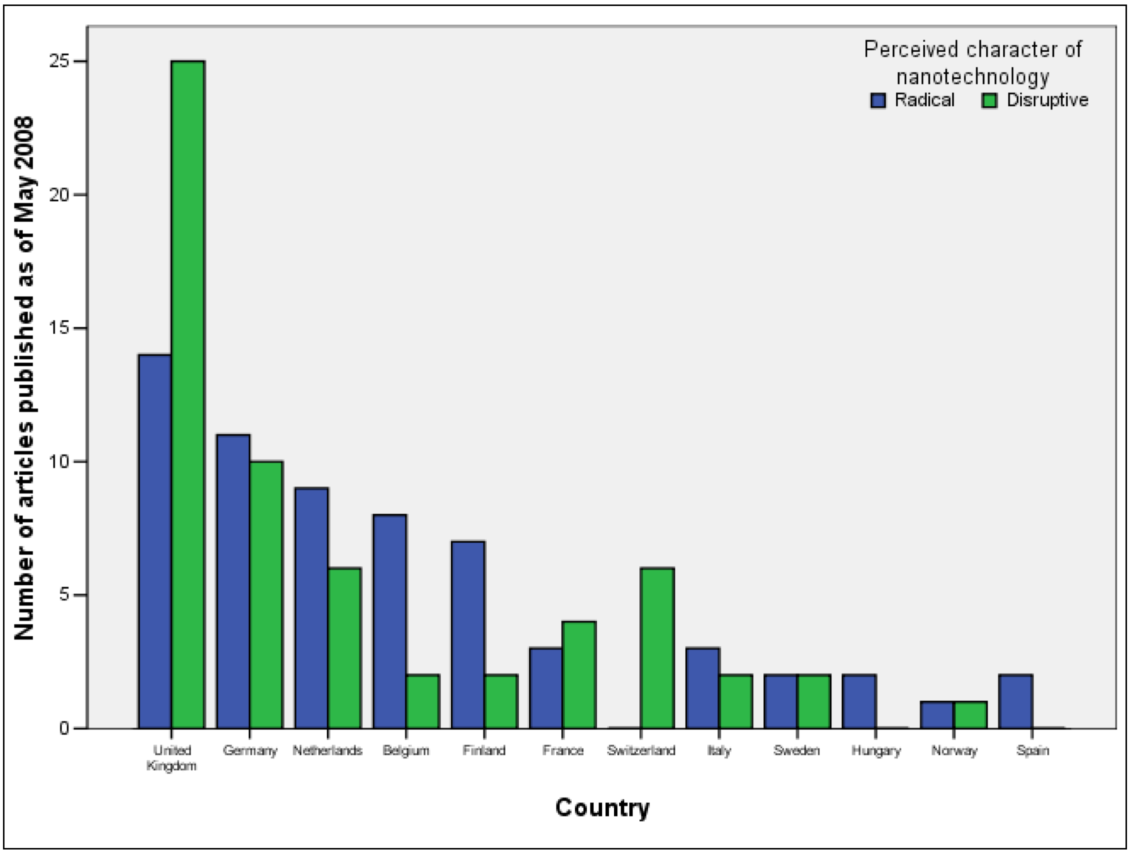

FIGURE 5. The distribution of European academic articles on the social, legal and ethical impacts of nanotechnology listed in ISI Web of Knowledge.

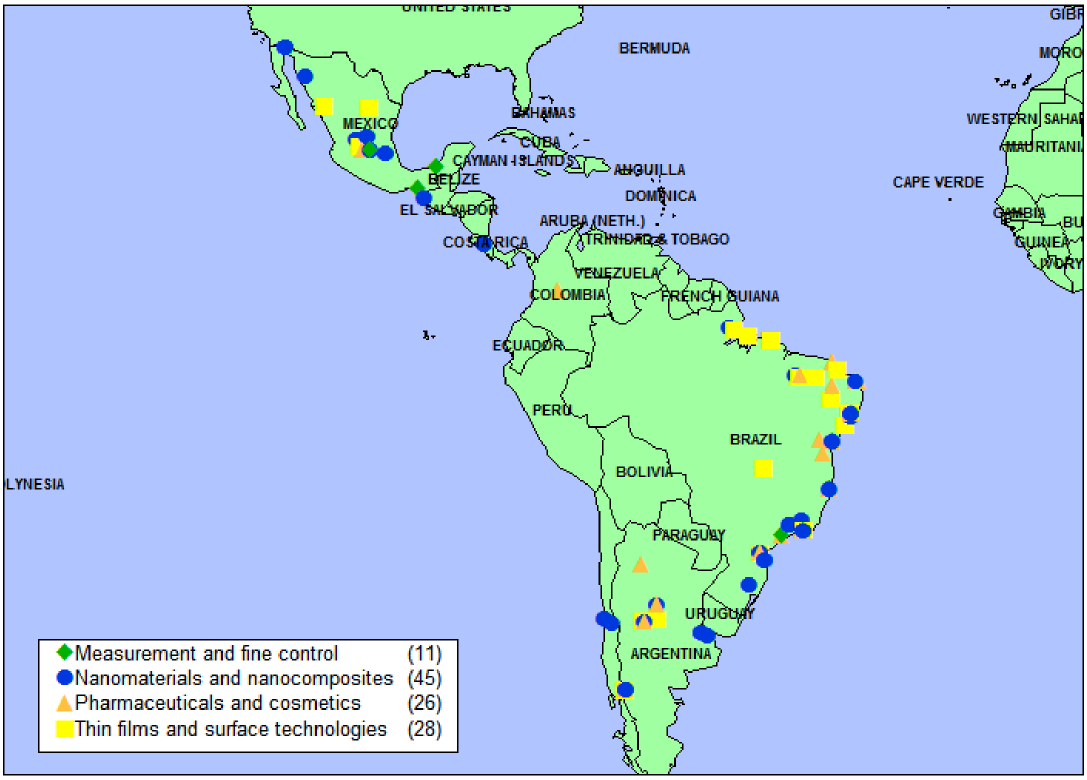

FIGURE 6. The distribution of nanotechnology-related R&D projects in Latin America

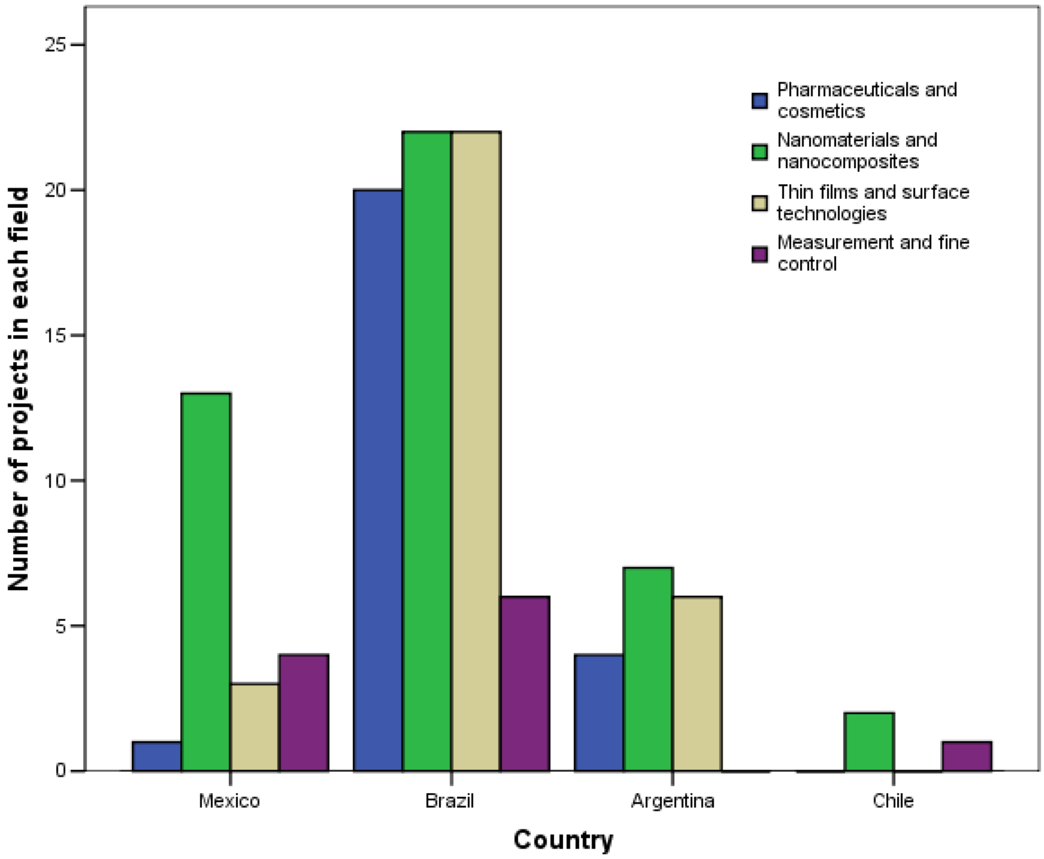

FIGURE 7. Distribution of nanotechnology by type in the Mexico, Brazil, Argentina and Chile