Converging Institutions: Shaping Relationships Between Nanotechnologies, Economy, and Society

Ingrid Ott
Christian Papilloud
University of Lueneburg, Germany

Nanotechnologies are technologies applied to a molecular level, which can be embedded in materials including human cells and atoms of mineral, chemical, or physical substrates. Nanotechnologies have been used in attempts to foster interactions between a multitude of products, production processes, and social actors. Just like bio, info, and cognitive science, nanotechnologies belong to the so-called converging technologies, which are expected to change main societal paths toward a more functional and coarser mesh. However, research, development, and diffusion of converging technologies depends on the adaptability of existing economic structures and on the social acceptance of products and services augmented by nanotechnologies. Because of these characteristics, externalities and the risk of systemic divergences caused by potentially noncontrollable or unwanted interactions between sectors, actors, and environments may arise and disturb the efficiency of the innovation process. Converging institutions, however, aim to manage these market imperfections and social risks in the long run.

Keywords: *converging institutions; nanotechnologies; systemic risks; economics; society*

In the opinion of various experts, nanotechnologies will be the dominant general purpose technologies of the next decades.[1] In contrast to "simple" product or process innovations, a general purpose technology is characterized by (a) pervasiveness, meaning that it may be adopted to a multitude of uses; (b) innovative complementarities, that is, it affects the innovation process in upward and downward industries, while at the same time, it is itself affected by these innovations; and (c) a reorganization of working processes within society or, in other words, having a stake in the development of societal structures. The notion *nanotechnologies* unifies technologies that apply to a molecular scale. The generic function they provide includes the possibility of manipulating atoms and molecular structures, building completely new and unexpected ones. A lot of application possibilities exist, for example, implantation in the human body, in microelectronic components, or in chemical gas. Therefore, nanotechnologies are frequently called *enabling technologies*.

Additionally, nanotechnologies form part of the so-called converging technologies, which unify a web of technological developments coming together from several fields in order to envision a new technology with its own characteristics, efficiency, and fields of applications (e.g., as germanium chips or bacteriological hard disks in the field of microelectronics). As converging technologies and because of their characteristics, nanotechnologies influence the organization of economic sectors, as well as civil society, in which nanotechnologies will be embedded. Nanotechnologies require not only that borders between the established techno-industrial developments fade, but also a full-fledged interdisciplinary approach. They also lead to newly emerging linkages between various economic sectors as well as social structures not only synonym for societal benefits, but also potential systemic risks.

Scrutinizing current literature on converging technologies and risk analyses in order to investigate the relationships between technology, economy, and society, we observed a paradox: Although almost all contributions mention, more or less explicitly, possible growth barriers

Bulletin of Science, Technology & Society Vol. 27, No. 6, December 2007, 455-466
DOI: 10.1177/0270467607309764

on the one hand, and risks related to the development and embedding of nanotechnologies on the other hand, the arguments are nearly never integrated. Even though it is well recognized, the converging character of nanotechnologies in its full potential seems hardly to be taken into account. Convergence, however, does not only cover the network of technologies embedded in nanotechnologies. It also includes the network of actors involved in their diffusion and embedding. Or in other words, aside from possible technological frictions, converging technologies also have to overcome structural divergences in the network of actors involved in their diffusion and applications.

In order to tap the full potential of nanotechnologies, one must investigate the growth barriers and risks of structural inconsistencies they may contain, depending on the level of acceptance and adaptation of nanotechnologies to economic and social contexts diffusing and using them. Managing these situations requires a broad range of competencies related to collective collaboration and communication about these externalities and risks in order to identify and to describe them adequately, bringing together specialists and nonspecialists on nanotechnologies. This is precisely the field of activity taken on by converging institutions. The aim of this article is to explore how they have to be positioned in order to accommodate the challenges of the application of nanotechnologies. The starting point of this article will be the description of some important building blocks at the crossroads between institutions and technologies.

Institutions and Technologies: Important Building Blocks

According to North (1990), institutions are "the rules within the game of society or, more formally, they are the humanly devised constraints that shape human interaction. . . . In consequence they structure incentives in human exchange, whether political, social, or economic" (p. 3). Institutions provide structures and restrictions on human actions. For example, economic institutions frequently focus on the structure of property rights, as well as on the presence and the perfection of markets. Accordingly, they affect the structure of economic incentives in society, and influence investments in physical and human capital, technology, and the organization of production. Recent discussions highlight the necessity of "appropriate institutions," covering the idea that different institutional arrangements are appropriate at different stages of economic development and societal change (Eicher & García-Peñalosa, 2006).[2] According to Acemoglu, Johnson, and Robinson (2005), institutions are at least partly determined by society or by a segment of it. From a more sociological point of view, they can be described as (symbolic, human, material-related) mediations controlling and supporting relationships between actors, their activities and their representations in different fields of society, during different phases of the societal transformations.[3] Institutions secure functions in society, and in addition, they adapt their functions and decisions with respect to changing environments, diversifying themselves as a "complex of status-role relationships" (Kaplan, 1960, p. 179). This does not only specify their profile. It also makes their interventions more appropriate for the public and stresses the necessity for institutions to evolve over time. Finally, both sociological and economic interpretations of institutions emphasize the fact that institutions almost always embed a general societal aim or universal ideal, which is communicated in each of their acts. These aims and ideals often have philanthropic characteristics (e.g., contributing to the improvement of human knowledge) and thereby provide a basis for the embodiment of institutions as converging institutions. On the one and maybe traditional hand, institutions can be described as guardians; they establish borders in terms of frameworks differentiating and grouping societal actors. On the other hand, they also act as bridges, meaning they are stimulators of new linkages and networks. This active/bridging rather than reactive feature of institutions is a key function, when it comes to the field of nanotechnologies and their relational structures.[4]

Nanotechnologies, Converging Technologies, and Technological Platforms

Frequently, nanotechnologies are reduced to the aspect of providing generic functions that may be adapted to a multitude of usages—this merely reflects the feature of pervasiveness (as, for example, the rotary motion of steam engines or binary logic in information and communication technologies);[5] however, nanotechnologies more fundamentally are enablers for new technologies and scientific knowledge systems that add to each other for the achievement of a shared aim.[6] In isolation or combined, nanotechnologies, biotechnologies, infotechnologies, and cognotechnologies (NBIC technologies), for example, are likely to contribute to such convergences by, for example, improving human performance.[7] Hence, because of their very structure, nanotechnologies are converging technologies. According to Lipsey, Bekar, and Carlaw (1998), they have huge potentials for improvement at the beginning of their development, are open to a multitude of possible uses, have an

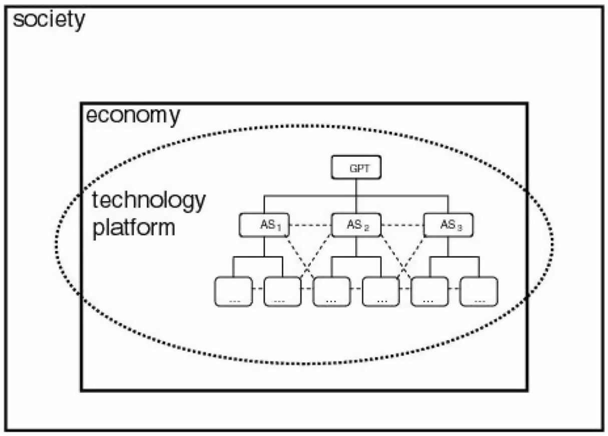

Figure 1. Technology Tree: Horizontal and Vertical Linkages
Note: GPT = general purpose technology; AS = applying sectors.

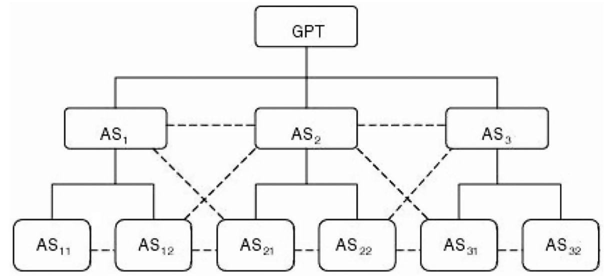

Figure 2. Technological, Economic, and Social Levels: Starting Points For Converging Institutions
Note: GPT = general purpose technology; AS = applying sectors.

impact on nearly every part of economy and society, and can be embedded in already existing technologies (causing major changes affecting production structures, network relationships, and the social differentiation). As such, nanotechnologies form part of technological platforms that organize future actions, and enable and constrain them (see research and development; also Robinson, Rip, & Mangematin, 2006, p. 4f.).

Figure 1 demonstrates the interdependencies between several sectors, firms, and/or actors that include nanotechnologies within the production process. Looking at the simplest case, the hierarchical interdependencies as well as the network character are most suitably illustrated by a technology tree. Nanotechnologies represent the sector of general purpose technology (GPT), whereas applying sectors (AS) reflect the downstream industries that actually or potentially make use of the general purpose technology or augmented products as intermediates. Aside from vertical relationships, horizontal linkages exist between actors at the same level of the value chain. The dashed lines indicate potentially emerging horizontal as well as vertical linkages. Note that such a conjunction of horizontally and/or vertically linked actors could also be interpreted as building a joint technological platform (see Figure 2).

In order to depict the development and implantation logics of nanotechnologies, let us give an example of a possible technology tree application. Nanotechnologies have a lot of applying sectors, such as, for example, the chemical industry (AS 1), microelectronics (AS 2), or pharmacy (AS 3). New materials could be demanded by further downstream sectors such as aviation industries (AS 11; which use fire-resistant materials for inboard equipment), or automobile industries (AS 12; which use scratch-resistant lacquers). Additionally, ICT industries make use of nanocomponents to augment the calculating capacity of computers. Again, these are used by downstream sectors as, for example, automobile industries (AS 21; on-board computers) or medicine techniques (AS 22; magnetic resonance tomograph). Both fire-resistant materials and scratch-resistant lacquers could not only be used within aviation but also in automobile industries. Similar relationships may be identified for other downstream sectors, taking into account that sometimes these relationships do not exist until the downstream sectors make use of nanotechnologies.

Another feature of GPT are induced technological dynamics. Because of continuing innovation and learning effects, generic functions of GPT could be provided at fewer costs and/or in a better quality. The use of GPT in downstream sectors then would become more attractive and increase profits. As a consequence, the application of the (augmented) GPT would also become interesting for other sectors, and the fields of applications would increase. As a consequence, nanoparticles are now used in a wide range of products—for example, in suntan lotion or lacquers.

The third constituent attribute of GPT is the existence of innovative complementarities between the sectors of the GPT and the application sectors. This reflects the phenomenon that technological progress in one sector also spurs progress in the other sector and vice versa. Both sectors are linked by their innovating activities, wherefore the profit in one sector also depends on the technological conditions in the other sector. Applied to nanotechnologies, these interdependencies could be illustrated with microelectronics or information technologies as applying sectors. It is undoubted that because of their calculation capacities, information technologies have contributed significantly to the emergence of nanotechnologies. All illustrations of nanoscale effects and structures are based on digitally constructed pictures. For more than 30 years, the capacity of computers has doubled every 12 to 18 months (Moore's law). However, within the next several years, physical boundaries will put an end this development because, at nanoscales, the technological characteristics of solid state physics cease to hold (what? the capacity? the improvement?) and the usual transistor will be unusable. At this point, quantum physics will become relevant and molecules—manipulated by nanotechnologies—could replace the transistors known today. Consequently, technological progress in nanotechnologies becomes a precondition for future innovations in microtechnology, which anew spurs technological progress in the nanotechnologies sector.

Fourth, general purpose technologies induce major changes in production processes and work-life organization.[8] Applied to nanotechnologies, this argument is undifferentiated because today these technologies are still at the very beginning of their development. But just to get a vague idea, one could imagine how, for example, functional materials that measure functions of the human body and transmit the results directly to the medicine could enable people suffering from chronic illnesses to live their daily lives much more independently and less dependent on regular health checks or hospital visits.

These examples show quite plainly what one can easily observe within the field of nanotechnologies; the concrete and possible interactions within the technology tree require a lot of coordination, and consequently failures may arise. This is why some authors notice that the converging characteristic of GPT and particularly of nanotechnologies may also be its most controversial characteristic (see Dupuy, 2005, p. 75f; also Berne & Schummer, 2005). In other words, as any other technology, nanotechnologies are ambivalent.

Ambivalence of Nanotechnologies

As shown above, nanotechnologies incorporate lots of benefits for economy and society. Technological progress reduces production costs, provides new and/or improved products and is accepted to be the main source of ongoing economic growth.[9] But just like any other technological innovation, nanotechnologies drive a process of creative destruction.[10] On the one hand, they create unusual development possibilities;[11] on the other hand, however, they enforce strong modifications or even disruptions of older processes and habits.[12] Because the emergence of nanotechnologies enables unlimited linkages between all economic and societal elements, it could also reinforce the sources of loose and lost interconnections within the networks built. It can be stated that nanotechnologies increase the complexity of the world we live in by increasing growth opportunities and decreasing structural consistencies in society. So, their full potential can only be realized if all adjustment processes going along with creative destruction are completed. Therefore, the further development and diffusion of nanotechnologies may favor the emergence of systemic risks by destructuring all dimensions of already existing networks, thus revolutionizing entire spheres of society.

Altogether, does this mean that we have to fear nanotechnologies, or do the chances prevail? Actually, the circumstances are more complex. First of all, it has to be noted that nanotechnologies are not an innovation in themselves. They obtain their fully innovative character by being embedded at nanoscale in all kinds of media (i.e., biological, mineral, chemical, mechanical), thus realizing sometimes unexpected convergences between people, social systems, and environments.

Second, these convergences do not always gain acceptance. Having to rely on lots of actors involved in the development, diffusion, and use of nanotechnologies, the convergences also multiply the risks of network inconsistencies and network failures. This can hinder or even interrupt the innovation process of nanotechnologies, thus reinforcing possible breaks and ruptures between the involved actors. Indeed, the convergences deriving from the diffusion and embedding of nanotechnologies in society are based on existing functional and structural dependencies as well as creating new ones. This leads to so-called path dependencies, meaning that earlier investments and competencies shape the range of possibilities in a later stage of the process. Once established, they can hardly be revised. In an extreme scenario, assuming a critical point within the innovation process, path dependencies can be the driving factor, which makes a further development of nanotechnologies impossible in a given field. This could have disastrous consequences for existing economic sectors (e.g., a collapse of the market for nanoproducts and nanoservices) or individuals engaged in the innovation process or in the use of nanotechnologies (e.g., medication which can not be provided any more).

Third, another cardinal characteristic of nanotechnologies is their size, which makes it impossible to deliver them directly to the public. They require to be implemented in media (human body, objects, liquid, gas, the natural environment), which is a typical attribute of an on-board technology. This explains why the economic sectors are often considered the prime actors to be taken into account when referring to the development and diffusion process of nanotechnologies. Actually, economic sectors do not only support the development but also the diffusion of nanotechnologies by interacting with each other (developers, scientists, technicians, engineers). The public is more likely considered as the "public of end users," whose concerns are the applications and related uses of nanotechnologies. This distinction between the development, diffusion, and application areas is more than just a pedagogical one, even if in practice, there are no impermeable borders between sides. The distinction allows us to identify coordination failures and, thus, economic growth barriers related to shaping actors of the technology platform on the one hand, and risks emerging from the diffusion and implantation of nanotechnologies in the public sphere on the other hand. As a consequence of the innovation process, nanotechnologies themselves are deeply ambivalent.[13] Therefore, the question asked by Kearnes, Macnaghten, and Wynne (2006), in their report on nanotechnologies in the United Kingdom, remains of urgent actuality: "How are individuals and institutions, confronted with rapid technological change, to imagine new social possibilities, and choose among them wisely? And how may all of this pan out . . . for the development process generally?" (p. 14).

Stumbling Blocks in the Innovation Process

According to the specific conceptualization of both economics and social sciences, we use the term *externalities* to describe prior economic risks related to coordination or market failures. We refer to the term *systemic risk* to take into account the more general societal risks related to the use of nanotechnologies in public, which have the potential to destruct individual lives and social habits, thus also reshaping societal relationships.

Economic Level

As illustrated in Figure 1, lots of interactions between upstream and downstream sectors exist. These interdependencies do not only arise in a production context but also during the innovation processes within companies. They incorporate two fundamental externalities:

- Vertical externalities: Because of innovative complementarities, the innovation activities in upstream and downstream industries are related, and both sectors have linked payoffs. A familiar problem of imperfect access to the social returns arises, except that here it runs both ways. This bilateral moral hazard problem implies that neither side will have sufficient incentives to innovate. Altogether, both sectors innovate too little and too late.
- Horizontal externalities: Applying sectors include actual and possible users of the general purpose technology. Their demand depends positively on the quality and negatively on the price of the general purpose technology. At the same time, quality within the general purpose technology sector depends on marginal production costs and on the (aggregate) technological level of all applying sectors. Hence, if one single applying sector innovates to increase its own technological level (with the goal to reduce its own production costs), the aggregate level of the applying sectors will increase. This leads to improvements within the general purpose technology and hence to reduced costs not only in the originally innovating sector but also in the other (noninnovating) downstream sectors. Consequently, all applying sectors benefit from innovations of a single applying sector. Again, this characteristic induces a moral hazard problem: Why should one applying sector innovate if it could benefit at zero cost from the innovation in another sector?[14]

Societal Level

Up until now, societal risks generated through the uses of converging technologies have hardly been discussed in literature, and if so, discussions are mainly concerned with application in areas dealing with life sciences or biotechnologies. It is often unnoticed that there is a deep lack of independent safety assessments and regulations concerning implantation of nanotechnologies in consumption goods.[15] Little attention is paid to risks that directly threaten the social acceptance of nanotechnologies in all areas in which they are or shall be implemented.[16] Thus, it is of major importance to understand and to assess these risks, and on this basis, to analyze possible communication strategies for these risks and their transfer between technoscience, economy, and society (see e.g., O'Riordan, Jungermann, Kasperson, & Windemann, 1989). It would then be possible (a) to transmit information about risks, which requires (b) mediations that (c) shape public trust in transmitted information, and can afterwards (d) prepare individuals to get involved in controlling the embedding and the use of new technologies. Risks will be managed at two levels:

- Stereotypes associated with nanotechnologies: They arise currently and intensely when it comes to nanotechnologies because of their invisibility and their characteristics as an all-purpose technology. This may fuel the feeling within society that everybody will be under surveillance always and everywhere. Communicating nanotechnologies pursue the goal of managing the stereotypes associated with these technologies in order to facilitate their acceptance and thus leading to a successful implantation in the public sphere.
- Control of the implantation and use of nanotechnologies: The feeling of losing control could lead to individuals developing a technocratic vision of experts that manipulate nanotechnologies to their convenience (and in secrecy) in order to robotize the population.[17] This may create severe gaps between the developers of nanotechnologies, the economic sectors diffusing nanoproducts, and the public. Another discrepancy may arise within the public itself between those people who want to benefit and make use of nanotechnologies, and those who are not in contact with nanotechnologies. Thus, the management of control is an important social challenge in order to shape public trust.

In other words, nanotechnologies themselves are not new but become so because they enable unexpected interactions between expertise on developing nanotechnologies, economic sectors diffusing them, and the civil society in which nanotechnologies are embedded and used. These interactions are not automatically spontaneous results of the development, diffusion, and implantation of nanotechnologies, and they bring about possible risks of systemic divergences that are caused by noncontrollable or unwanted interactions between involved actors, technological objects, and embedded environments. Supporting these interactions means, first of all, not to perceive the convergences that nanotechnologies may favor in society as a given, but instead, to understand how to regulate their ambivalence and oscillation between expected growth and risks of systemic inadequacy. Following analogous intuitions, some authors already suggested that "governments and civil society organizations . . . should establish an International Convention for the Evaluation of New Technologies . . . including mechanisms to monitor technology development" (ETC-Group, 2003, p. 6). Others argue that organizations experiencing uncertainty and insecurity, as well as organizations dealing with innovations in general and with nanotechnologies in particular, "will be more likely to adopt new institutions that will help them deal with the uncertainty they are experiencing" (Guthrie, 1998, p. 477).[18] Bresnahan and Trajtenberg (1995) argue, "However, where there is potential for coordination failures there is also room for coordination, and which ultimately prevails depends upon the institutional arrangements that are developed, alongside or in lieu of market arrangements" (p. 3). We focus on this last more explorative recommendation without totally declining the first one, considering the regulation of nanotechnologies development and applications from the point of view concentrating on converging institutions. How could they support and possibly harmonize the convergences that nanotechnologies undertake in the environments in which they may be implemented?

From Nanotechnologies to Converging Institutions

As argued above, nanotechnologies incorporate huge potentials for improving welfare. But because of the interdependencies of the various actors, technological complementarities, and the dynamics within the innovation process, frictions at the economic and the societal level are very probable. So there still is room for improvement. Figure 2 illustrates interdependencies between all stakeholders involved in the innovation process of nanotechnologies. The interdependencies between upstream and downstream companies are taken on from Figure 1, and have been assembled to an exemplary technology platform, embedded in the rest of economy, and interacting with society. Converging institutions may be assigned to the two lines of argument stated above.

Figure 2 reveals some insights on the main functions of converging institutions within an embedded technology tree and considering economic and a societal context:

- Economic level: Because of the innovative complementarities, the innovation activities of one single actor affects the outcomes of all other agents. Consequently, existing suboptimality affects all involved agents. Converging institutions are thus interpreted as institutions that reduce or remove coordination failures that arise because of the interrelatedness between companies. Starting points for concrete intervention at a vertical level could be, for example, technology-push strategies. At a horizontal level, coordination of individual demand for general purpose technology could increase aggregate demand, thus reflecting a demand-pull strategy.

- Societal level: A converging institution mediates the processes by which (a) nanotechnologies are integrated into society in terms of nanotechnological innovations, and by which (b) society integrates nanotechnologies in diffusing them, for example, in selling, using, considering or not considering, or debating them.[19] As with many other institutions, a converging institution may be basically interpreted as involving actors jointly dealing with various organizational structures and processes. Their main task is to decompose systemic risks and preferably to harmonize the communication focusing on them.

However, as stressed in some working papers on "converging technologies and institutions,"[20] the converging character of nanotechnologies supposes that an institution dealing with them and their universe is not only a reactive structure administrating the synergies between actors involved in the development and in the application of nanotechnologies. Their place is not outside the convergences nanotechnologies enable, but inside. This kind of institution has to assimilate the convergences between technology, science, economy, and society that nanotechnologies enable. Converging institutions are thus responsible for the developments and applications of nanotechnologies just as any other actor involved in the innovation process of nanotechnologies. Correspondingly, they have to be proactive in the planning of communicating possible inconsistencies in the development and the application of nanotechnologies, as well as in the dealing with related public fears, economic externalities, and systemic risks, which nanotechnologies could drive. Furthermore, they have to maintain an open structure and adapt to changes appearing within the network of actors involved in the development of nanotechnologies. Thus, converging institutions are partly shaped by their surroundings, for example, by techno-scientific, economic, and societal actors. It is then evident that converging institutions do not only have to fulfill responsive functions in supporting and regulating nanotechnologies. They also have to proactively interact as one actor within the convergences that nanotechnologies favor in order to support and develop them. To put it metaphorically, a converging institution is not only a transmission instance enabling the unproblematic development and delivering of nanotechnologies from science and industry to economy and society; rather, it is a translation instance, which enables possibilities of exchange between all actors involved. As an interactive agent within the nanotechnologies' networks, converging institutions are therefore:[21]

- Collaborative: Converging institutions have to animate involved actors to communicate even if they do not use the same language, and even if they do not evolve at the same speed, in the same direction, at the same time, and for the same reasons regarding the development and applications of nanotechnologies. As a consequence, converging institutions neither follow a bottom-up nor a top-down approach but rather fulfill the characteristics of a network on their part;[22]
- Responsive: Converging institutions have to work toward an encounter of technological, scientific, industrial (more concerned with the first point of the definition), economic, social, and political stakes of nanotechnologies (more concerned with the second point of the definition) considering their respective peculiarities;
- Flexible: Converging institutions have to be sensitive for changes in the convergences between actors involved in converging technologies. This enables converging institutions to quickly react to possible inconsistencies in these convergences, and to better identify, manage, and communicate the risks, which an implantation of nanotechnologies in society contains. The general purpose of the converging institution is then to shape relationships between converging technologies and all actors involved in nanotechnologies, particularly those who may benefit from the outcomes of nanotechnologies but who fear the related uncertainty of their implantation in economy and society.

The concept of converging institutions can be described as an empirically oriented example of the so-called "churn theory" of knowledge value and innovation (Bozeman, 2005, p. 5f). The word *churn* implies no particular direction of scientific innovative outcomes. They may be positive, negative, neutral, or, most likely, mixed. This is almost exactly what we are facing today with the emergence of nanotechnologies and this is what converging institutions should aim at as actors involved in the convergences that nanotechnologies favor. As Bozeman (2005) observes, the position of converging institutions can be defined as the following: It considers all parties and itself "as part of the knowledge value collective because each is producing knowledge, using it or enabling its use" (p. 6).[23] Converging institutions, therefore, play a major part in reflecting the fact that the converging capacity of nanotechnologies does not only depend on all fields of science, but also on each field of society offering science the multiple uses that characterize converging technologies. If one says about the development of technologies in the cold war that "Codeword science engendered a codeword community" (Cloud, 2001, p. 244), converging technologies prepare a new era for a collaborative society in which converging institutions are of central stake, shaping the relationships between nanotechnologies, economy, and society. Therefore, it is to be expected that converging institutions will gain increasing attention in the research agenda for nanotechnologies as well as the management of externalities and societal risks related to their implantation in society.

La Maison des Micro- et Nanotechnologies (MMN): An Emerging Converging Institution?

Taking a closer look at the innovation processes of nanotechnologies, it becomes obvious that increasing attention to the management of externalities and societal risks related to their implantation in society will become necessary. And that converging institutions play a major part in this context. One example of a potential converging institution is the Maison des Micro- et Nanotechnologies (MMN) founded at the Pôle d'innovation en Micro et Nanotechnologies (MINATEC) in Grenoble, France.[24]

MINATEC exists as a project since 2000 in the metropolitan area of Grenoble. It has been planned and supported by the French government, the region Rhône-Alpes, the Department Isère, the public institutions Grenoble Alpes Métropole and the Caisse des Dépôts et Consignations, the city of Grenoble, the Centre d'Energie Atomique (CEA), and the Institut National Polythechnique (INP) in Grenoble. The region Rhône-Alpes has been chosen as a location for the construction of this knowledge cluster because of its economic excellence and the prevailing industrial structures. The convention of January 18, 2002, and the first financial support of 150 billion euros led to the realization of the project (Institut National Polytechnique de Toulouse, 2002). MINATEC has been inaugurated on June 1, 2006.

MINATEC has a mixed structure consisting of public and private research and investments. It consists of three platforms, namely (a) a platform for education, (b) a platform for research focusing on microtechnology, biochips, and microsystems for applications in the fields of communicating objects (clothes, robots for the kitchen, etc.), and (c) a platform for economy concentrating on the developments of start-up companies or bigger industrial conglomerates which work together with the education and research platforms. In this context, the MMN has been developed as a center for integrating the platforms, and more generally of bringing together nanotechnologies, economy, and society (Institut National Polytechnique de Toulouse, 2002, p. 11). The aims of the MMN are:

- To accelerate and optimize the process of innovation;
- To build transdisciplinary and international networks;
- To favor the encounter between the old and the new in order to adapt the cultural identity of the region to changes driven by nanotechnologies.

In order to achieve these goals, the MMN cooperates with the Observatoire des Micro- et Nano Technologies (OMNT) founded by the CEA and the Centre National de la Recherche Scientifique, France, and established in February 2005. The OMNT is unique in Europe. It provides information about nanotechnologies and their applications in order to communicate the possible externalities and risks related to nanotechnologies and to prevent stereotypes associated with nanotechnologies.[25] As such, the MMN gives an example of a typical converging institution structure. Its work faces the main challenges of converging institutions, which can be summarized as follows:

- Economic level: Efficiently supporting the diffusion of nanotechnologies so that the economic sectors may benefit from the convergences between developers of nanotechnologies and companies at a common level on the value creation chain, in order to achieve the expected economic growth potential that nanotechnologies are intended to bring about.
- Societal level: Proactively counteract stereotypes associated with nanotechnologies in order to build public trust regarding the implantation and the use of nanotechnologies in civil society.

Converging institutions are innovative institutional structures in the making, as the example of the MMN shows. Also, these structures have not been studied up until now. Thus, it is an exciting challenge to closely observe their emergence linked to the centers of developing nanotechnologies. It will provide a better knowledge about how they will act as a mediation instance in the network of actors involved within the entire innovation process, from the development over diffusion up to the implantation in civil society. Converging institutions have to prove their capability to manage the structural externalities and systemic risks related to possible inconsistent convergences in this network and the resulting consequences for economy and society. Furthermore, they have to open up possibilities for economy and society to adapt the rules of technological innovation to society in order to initiate a discussion regarding hoped-for usages and applications.

Concluding Remarks

For the most part, converging institutions are not a reactive instance beside the network of actors involved in nanotechnologies, but an interactive, responsible, and flexible meditative structure within this network, leading us to three final observations in order to bring our theory closer to practice. First, as the MMN illustrates, more than one prototype of converging institution structure can be expected, particularly when regarding the specific conditions of the region in which nanotechnologies have to be developed. Therefore, one major stake of investigating converging institutions is to identify types of structure they should apply regarding the area where nanotechnologies are developed. In this respect, an investigation of converging institutions should provide a differentiated analysis of specific functions and structures emerging from converging institutions that are of special interest in a given region and by which these converging institutions can manage systemic risks and market failures related to nanotechnologies. Thereby, it becomes possible to empirically inform and differentiate the concept of nanotechnological convergence in order to investigate the specifics of a network of actors involved in nanotechnologies in which converging institutions have been embedded. This kind of investigation is then able to provide an evaluation of the changes that a converging institution could enable in the economic and sociocultural sectors, given the region in which converging technologies have to be developed and diffused. Taking these steps, it will then be possible to investigate instruments that stimulate the public discussion about nanotechnologies, thus leading to a global and an unequivocal exploitation of their entire innovative potentialities.

Summary

This article derives the concept of converging institutions as a consequence of economic and social considerations of nanotechnologies and as part of the so-called converging technologies. This concept is based on the entire innovation process beginning with research and development, diffusion (here mostly interpreted as the diffusion between upstream and downstream industries) up to the implantation of nanotechnologies in society. The article merges both economic and social perspective and thus results in an interdisciplinary concept of converging institutions. Three constituent characteristics that define the type of a converging institution are derived: They are responsive, collaborative and flexible; that is, converging institutions evolve along the development process of nanotechnologies. Next, the concept is applied to a showcase converging institution, namely the MMN in Grenoble, France. However, there are several caveats that have to be analyzed during future work, among them answers to the following questions: How may converging institutions be differed from traditional institutions that also arise in the context of newly emerging technologies? How can converging institutions be implemented on regional, national, and supranational levels? From where do converging institutions get their knowledge to act in a welfare-enhancing manner? Thus there is much work left to be done.

Notes

1. See, for example, BMBF (2004). In our article, we use the label *nanotechnologies* instead of *nanotechnology*. Nanotechnology denotes a conceptual frame used to define the process of developing technologies at nanoscale. Thus, nanotechnologies refers to various technologies developed at nanoscale.

2. Note that these analyses compare alternative institutional arrangements between economies near the technology frontiers to less developed economies, whereas institutions in the context of our article explicitly focus on institutional settings that evolve along the technology frontier.

3. Based on first reflections by ethnologists and anthropologists on institutions as "a group of people united for the pursuit of a simple or complex activity" (Malinowski, 1945, p. 40), analysts of institutions concentrate on the relationships between actors in order to define institutions as meditative regulators between activities, practices, and representations (MacIver & Page, 1949, p. 16).

4. As an example, one can consider the concept of "institutional entrepreneurs" developed by Maguire, Hardy, and Lawrence (2004), accentuating this active component of institutions, and applied to nanotechnologies by Mangematin, Rip, Delemarle, and Robinson (2005).

5. Roco (2001) underlines this, seeing in the converging attribute characterizing nanotechnologies a possible "synergism among the converging fields play[ing] a determining role in the birth and growth of new technologies" (p. 355). There are lots of examples of such applied synergisms as the implantation of nanotechnologies in the human body or the embedding in microelectronic devices in chemical gaz, cars' brine, and liquid cleaning agent (see also BMBF, 2004).

6. According to the European Union, technological platforms are being set up that bring together companies, research institutions, the financial world, and the regulatory authorities at the European level to define a common research agenda which should mobilize a critical mass of (national and European) public and private resources (Robinson et al., 2006, p. 8, fn. 8).

7. See Nordmann (2004, p. 19), and also Roco and Bainbridge (2002, p. 282). *NBIC-Convergence for Improving Human Performance* is the name of a prominent agenda for converging technology research in the United States. In Canada, *Bio-Systemics Synthesis* suggests another agenda for converging technology research, whereas

Converging Technologies for the European Knowledge Society (CTEKS) designates the European approach. It prioritizes the setting of a particular goal for converging technology research. This presents challenges and opportunities for research and governance alike, allowing for an integration of technological potential, recognition of limits, European needs, economic opportunities, and scientific interests. Defending a strict technological classification of the expression *converging technology*, Roco and Bainbridge (2002, p. 282) refer it to the combination of four major NBIC provinces of science and technology, namely, (a) nanoscience and nanotechnology; (b) biotechnology and biomedicine, including genetic engineering; (c) information technology, including advanced computing and communications; and (d) cognitive science, including cognitive neuroscience. For a broader application of this expression, compare the description given by Wood, Jones, and Geldart (2003): "Many of the applications arising from nanotechnology may be the result of the convergence of several technologies" (p. 23).

8. An example for the implications for work-life organization can be illustrated in the context of the general purpose technology electricity. Its development and diffusion made people independent from daylight and, with this, had a very strong impact on the organization of daily life.

9. See Barro and Sala-I-Martin (2004) for this argument and an overview of the most essential growth determinants.

10. This expression draws back on Schumpeter (1950) who describes the destruction of the old as being an inherent part of the innovation process.

11. Examples are genetically modified organisms for the production of food, improvement of health care for people suffering of cancer or diabetes, improvement of the efficiency and the safety of vehicles by the use of "on-board" supercomputers (Silverstein et al., 1995; see also SwissRe, 1998, p. 6).

12. For example, the secondary effects of new molecules improved with nanotechnologies in order to make people awake during a week or the use of nanotechnologies in medicine which could push medicine to abandon open-minded, holistic caring for patients (see e.g., Timmermans & Angell, 2001). Indeed, as Branscomb observes "in various segments of the public there is confusion and ambivalence about the mission of research in science and technology" (Branscomb, Holton, & Sonnert, 2001, p. 26). See also Douglas and Isherwood (1979) or Rosenberg (1982). On the opposite side, Roco and Bainbridge (2002) defend the view of a radical functionalization of society understood as the progress due to the application of nanotechnologies: "This progress is expected to change the main societal paths, towards a more functional and coarser mesh instead of the less organized and finer one we have now" (p. 294). The duty to involve the public in the largely unknown consequences of the applications of nanotechnologies in economy and society is that of public media: "The public media should increase high-quality coverage of science and technology, on the basis of the new convergent paradigm, to inform citizens so they can participate wisely in debates about ethical issues such as unexpected effects on inequality, policies concerning diversity, and the implications of transforming human nature" (Roco & Bainbridge, 2002, p. 294).

13. This particular signification of the ambivalence of technologies has been observed by Silverstein et al. (1995):

> The complexity of the relationship [that technologies embody] comes out as a kind of ambivalence of the public toward the whole science-technology complex. The public may be positive on things like improvements in their quality of life and at the same time fearful of the changes in values, with a sense perhaps of social disintegration that may be vaguely tied to what's going on here. (p. 12)

Bennett and Sarewitz (2005, p. 1) observe that "people have converged around the notion that, whatever nanotechnology is, and whatever it will become, its implications for society are going to be transformational, perhaps radically so, in social realms as diverse as privacy, workforce, security, health, and human cognition." For Roco and Bainbridge (2005), "converging technologies integrated from the nanoscale could determine a tremendous improvement in human abilities and societal outcomes" (p. 282). Compare also, in the same vein, the report of the European Commission (2005), as well as Whitman (Whitman, 2006). Dupuy (2005) points it out dexterously when he shows the ambivalence of the slogan "Bringing Nanotechnology to Life" used by a research center in the field of nanobiotechnology (p. 60). It expresses the will to use nanotechnologies in order to make progress in human biology, but, according to Dupuy, it is impossible not to imagine that it remains related to the old utopia to fabricate life using these technologies.

14. This phenomenon is summarized by the term *dual-inducement hypothesis*, thus describing the interrelationships between the innovation activities in the sector of the general purpose technology and the applying sectors (see Bresnahan & Trajtenberg, 1995).

15. An exception is given by genetically modified food. (See European Commission, 2005; also Mehta, 2002.)

16. Note that there already exist several antinanotechnologies movements; see, for example, http://pmo.erreur404.0rg/Necrotechnologies.htm or http://pmo.erreur404.0rg/.

17. This is one of the most current objections raised by interest groups that decline against nanotechnologies. One example is the group Opposition Grenobloise aux Nécrotechnologies in Grenoble, France.

18. Heinze observes in analogous terms: "For describing and analysing the formation of new science-based fields of technologies, it is essential to understand the interface between different institutional settings, such as companies and public research institutions" (Heinze, 2006, p. 22).

19. The need for that kind of institution is not new, although nobody seems to refer to it when it comes to the specifics of nanotechnologies, which is their converging property (see Sarewitz, 2004, p. 29).

20. See, for example, the project description concerning the Center for Nanotechnology and Society at Arizona State University (http://cns.asu.edu/network/asu.htm).

21. Our focus differs from the institutional approaches of Maguire et al. (2004), who define institutional entrepreneurship as the activities of the actors who have an interest in particular institutional arrangements, and who leverage resources to create new institutions or to transform existing ones. See also Mangematin et al. (2005), who discuss cluster-institutionalizing entrepreneurs as those who promote the creation and the institutionalization of clusters in the context of nanotechnologies.

22. Bottom-up and top-down concepts in the context of nanotechnologies are analyzed by VDI (2005) with a more technological focus, and by Robinson et al. (2006) with a more sociological focus.

23. In this sense, converging technologies and converging institutions lead to more complex (loosely coupled) networks of diffusion and application of innovations as, for example, those envisaged by Etzkowitz within the triple helix model declining the various possible relationships between university-science-government in the promotion of technological innovations (Etzkowitz, 2003).

24. Note that there exist various regions that also develop nanotechnologies strategically. An overview can be found at the home page of the nanodistrict project, www.nanodistrict.org.

25. This is one of the motivations often associated with the arguments underlining the necessity of the build of the MMN at MINATEC (cf. also Gutierrez, 2004).

References

Acemoglu, D., Johnson, S. & Robinson, J. A. (2005). Institutions as the fundamental cause of long-run economic growth. In P. Aghion and S. Durlauf (Eds.), *Handbook of economic growth* (pp. 385-472). New York: Elsevier.

Barro, R. J., & Sala-I-Martin, X. (2004). *Economic Growth*. Cambridge, MA: MIT-Press.

Bennett, I., & Sarewitz, D. (2005). *Too little, too late? Research policies on the societal implications of nanotechnology in the United States*. Phoenix, AZ: Arizona State University, Consortium for Science, Policy, and Outcomes.

Berne, R. W., & Schummer, J. (2005). Teaching societal and ethical implications of nanotechnology to engineering students through science fiction. *Bulletin of Science, Technology & Society*, *25*(6), 459-468.

BMBF. (2004). *Nanotechnologie erobert Märkte, Bundesministerium für Bildung und Forschung*. Berlin, Germany: Bundesministerium für Bildung und Forschung.

Bozeman, B. (2005). *Public value mapping of science outcomes: Theory and method* (pp. 3-48). Washington DC: University of Columbia, Center for Science, Policy and Outcomes.

Branscomb, L., Holton, G. & Sonnert, G. (2001). *Science for society: Report on the November 2000 Conference on Basic Research in the Service of Public Objectives*. Washington DC: Center for Science, Policy and Outcomes.

Bresnahan, T. F., & Trajtenberg, M. (1995). General purpose technologies: engines of growth. *Journal of Econometrics*, *65*, 83-108.

Cloud, J. (2001). Imaging the world in a barrel: CORONA and the clandestine convergence of the earth sciences. *Social Studies of Science*, *31*(2), 231-251.

Douglas, M., & Isherwood, B. (1979). *The world of goods*. New York: Basic Books.

Dupuy, J.-P. (2005). Complexity and uncertainty. A prudential approach to nanotechnology. In *Nanotechnologies: A preliminary risk analysis on the basis of a workshop organized in Brussels on 1-2 March 2004 by the health and consumer protection directorate general of the European Commission* (pp. 53-70). Brussels, Belgium: European Commission.

Eicher, T., & García-Peñalosa, C. (Eds.). (2006). *Institutions, development, and economic growth*. Cambridge MA: MIT Press.

ETC-Group. (2003). *From genomes to atoms. The big down. Atomtech: technologies converging at the nano-scale*. Winnipeg, Canada: ETC-Group.

Etzkowitz, H. (2003). Innovation in innovation: the triple helix of university-industry-government relations. *Social Science Information*, *42*(3), 293-337.

European Commission. (2005). *Nanotechnologies: A preliminary risk analysis on the basis of a workshop organized in Brussels on 1-2 March 2004 by the health and consumer protection directorate general of the European Commission*. Brussels, Belgium: European Commission.

Guthrie, D. (1998). Organizational uncertainty and labor contracts in China's economic transition. *Sociological Forum*, *13*(3) 457-494.

Gutierrez, E. (2004). *Privacy implications of nanotechnology*. Available from http://www.epic.org/privacy/nano/default.html

Heinze, T. (2006). Emergence of nano S&T in Germany: Network formation and company performance. *Fraunhofer ISI Discussion Papers Innovation System and Policy Analysis*, *7*, 1-26.

Institut National Polytechnique de Toulouse. (2002). *INP-Communiqué de Presse 2002*. Toulouse, France: Author.

Kaplan, H. B. (1960). The concept of institution: A review, evaluation, and suggested research procedure. *Social Forces*, *39*(2), 176-180.

Kearnes, M., Macnaghten, P., & Wynne, B. (2006). *Nanotechnology, governance and public deliberation: What role for the social sciences?* (pp. 1-39). Lancaster, UK: Lancaster University.

Lipsey, R. G., Bekar, C., & Carlaw, K. (1998). What requires explanation. In G. Helpman (Ed.), *General purpose technologies and economic growt*h (pp. 15-54). Cambridge, MA: MIT Press.

Maguire, S., Hardy, C., & Lawrence, T. B. (2004). Institutional entrepreneurship in emerging Fields: HIV/AIDS treatment advocacy in Canada. *Academy of Management Journal*, *47*(5), 657-679.

Malinowski, B. (1945). *The dynamics of cultural change*. New Haven, CT: Yale University Press.

Mangematin, V., Rip, A., Delemarle, A., & Robinson, D. (2005). *The role of regional institutional entrepreneurs in the emergence of clusters in nanotechnology* (Working paper GAEL 2005-15). Grenoble, France: Laboratoire d'Economie Appliquée de Grenoble.

Mehta, M. D. (2002, April). *Regulating biotechnology and nanotechnology in Canada: A post-normal science approach for inclusion of the fourth helix*. Paper presented at the International Workshop on Science, Technology and Society, Lessons and Challenges, Singapore.

Nordmann, A. (2004). *Converging technologies: Shaping the future of the European societies*. Brussels, Belgium: European Commission.

North, D. (1990). *Institutions, institutional change and economic performance*. Cambridge, UK: Cambridge University Press.

O'Riordan, T., Jungermann, H., Kasperson, R., & Windemann, P. (1989). Themes and tasks of risk communication. *Risk Analysis*, *9*(4), 513-518.

Robinson, D. K. R., Rip, A., & Mangematin, V. (2006). *Technological agglomeration and the emergence of clusters and networks in nanotechnology* (Working paper GAEL 2006-5). Grenoble, France: Université Pierre Mendès France,.

Roco, M. C. (2001). International strategy for nanotechnology research and development. *Journal of Nanoparticle Research, 3*, 353-360.

Roco, M. C., & Bainbridge, W. (2002). Converging technologies for improving human performance: Integrating from the nanoscale. *Journal of Nanoparticle Research*, *4*, 281-295.

Roco, M. C., & Bainbridge, W. (2005). Societal implications of nanoscience and nanotechnology: Maximizing human benefit. *Journal of Nanoparticle Research*, *7*, 1-13.

Rosenberg, N. (1982). *Inside the black box*. Cambridge, UK: Cambridge University Press.

Sarewitz, D. (2004). *Perfect bedfellows: Why science makes environmental controversies worse*. Manuscript submitted for publication. Retrieved from http://www.cspo.org/products/articles/valueinsciencecirculate.pdf

Schumpeter, J. A. (1950). *Kapitalismus, sozialismus und demokratie*. Tübingen, Germany: A. Franke Verlag.

Silverstein, S., Nelson, R., Yudken, J., Brooks, H., Gilbert, L., & Cozzens, S. (1995). *Science the endless frontier 1945-1995:*

Learning from the past, designing for the future; Discussion roundup summaries—Part 2. Phoenix, AZ: Arizona State University.

SwissRe. (1998). *Genetic engineering and liability insurance: The power of public perception*. Zürich, Switzerland: Corporate Communications, Reinsurance & Risk Division.

Timmermans, S., & Angell, A. (2001). Evidence-based medicine, clinical uncertainty, and learning to doctor. *Journal of Health and Social Behavior*, *42*(4), 342-359.

VDI. (2005). *Nanotechnologie als wirtschaftlicher Wachstumsmarkt - Innovations- und Technikanalyse, Bericht im Auftrag des BMBF*. Düsseldorf, Germany: VDI Technologiezentrum.

Whitman, J. (2006). Governance challenges of technological systems convergence. *Bulletin of Science, Technology & Society*, *26*(5), 398-409.

Wood, S., Jones, R., & Geldart, A. (2003). *The social and economic challenges of nanotechnology*. Swindon, UK: Economic & Social Research Council.

Ingrid Ott is an assistant professor of economics and head of the Chair of Innovation and Growth, University of Lüneburg, Germany, and a research associate at the Hamburg Institute of International Economics, Hamburg, Germany. Her main research interests are growth theory with special attention to governmental activity and institutions, innovation theory and policy, and economic geography. At the moment, she conducts a research project on the economic and social consequences of the implantation of nanotechnologies in European countries with Christian Papilloud.

Christian Papilloud is an assistant professor at the Chair of Sociology of Culture, University of Lüneburg. His main interests are the theories of social change, particularly the theories of the new social control, and the related research area on the transition from an institutional control to its replacement by technological devices.