Nanotechnology and the need for a new regulatory agenda: towards a broader approach for the technological paradigm leading concepts

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Abstract

Nanotechnology is a promise of revolution over industry and society. We have learned that this type of revolution also brings with it a sort of "technofear". Breakthrough technologies very often inspire the popular imagination, causing distortions and rejections, like it happened with Genetically Modified Organisms. Nanotechnology has also received negative labels and associations.

As a matter of fact, new high technology needs different analytical approaches. It is our belief that the analysis of technological development within the traditional approach, which focus mainly on technological and economic impacts, will fail to shed light on important considerations regarding environmental and social impacts. While technology normally brings benefits to society and its industries, it also causes sufficient damage to suggest that care should be taken.

This paper proposes that this new approach for the technological paradigm concept should encompass dimensions of analysis as much as necessary to understand the complexity of the technology development and to guide actors towards a regulatory set. The first essay on using this new and broader approach have been made in the Brazilian scene based in a set of interviews made with nanotechnology companies' members, as well as government, political and scientific experts. Preliminary results confirm that nanotechnology impacts, both positive and negative, are a true paradox. Its effects have either clear potential to create better life and environment conditions or to generate risks from new products, increasing nature and human health damages. All these suggest that any regulatory effort must search for a fine balance between the different outcomes.

1. Introduction

Almost all the industries in the world are about to be revolutionized by a new technology: nanotechnology.

On the one hand, scientists and practitioners outline how nanotechnology can be of use in a wide range of industrial applications, such as the reduction of energy consumption, the advancement of medicine's ability to cure and prevent diseases and the enhanced precision and effectiveness of military devices and weapons (Glenn & Gordon, 2004).

On the other, however, we have learned that this type of revolution also brings with it a sort of "technofear". Breakthrough technologies like nanotechnology very often inspire the popular imagination, causing distortions and rejections. Like Genetically Modified Organisms, nanotechnology is also receiving negative labels and associations, such as the so-called "gray goo" – a sort of living substance that will invade human bodies (ETC Group, 2003).

Until now, every new technology that has changed industrial standards, organizational patterns, companies' arrangements and size, market demand, consumer behavior, profit margin, environmental impact, social relations in society, and so on, has been perceived through the lens of the so-called traditional techno-economic paradigm approach (Wonglimpiyarat, 2005). This demarche, however, seems to generate some misunderstanding and further misconceptions about both positive and negative impacts.

This misconception (of both the potential positive and negative impacts!) occurs because the approach to dealing with new problems, based on the traditional technological paradigm (see Dosi, 1982), often leads to incomplete conclusions, focused mainly on economic and technological concepts. As a matter of fact, new high technology will need different analytical prisms. It is our belief that the analysis of technological development within this traditional approach will fail to shed light on important considerations regarding the environmental and social impacts. While technology normally brings benefits to society, its industries and communities, it also causes sufficient damage to suggest that care should be taken. In other words, it is our belief that to use the traditional approach as an adequate tool to understand such pervasive technology is to fail to apply the analytical robustness necessary to cope with its complexity.

This paradoxical situation highlights a theoretical question: should the definition of any emerging and enabling technology as a true candidate for radical innovation be sanctioned exclusively by technical and economic conceptual dimensions, or should other ones, such as social relations and the environment be taken into consideration? Or, in a more complex way, should a new and broader approach of technological paradigm be evolved to a further stage where technological, economic, social and environmental concepts are intertwined in a new analytical dimension?

A broader approach for the techno-economic paradigm concept should be based on the assumption that other analytical dimensions, not usually considered by the traditional approach, such as the social and environmental aspects, would be taken in account. By doing so, it will be possible to infer various relationships among actors and probable outcomes. By changing the perspective, it is possible to build a new regulatory agenda, in which a fine balance between outcomes could be reached.

A new analytical approach, though, in which the techno-economic paradigm is expanded to include new dimensions, could help on better explaining nanotechnology's different role and its real different change in the patterns of development (Greenpeace Environmental Trust, 2003).

The first section of the paper presents the origins of the approach based on the traditional technological paradigm concept, presents some of the potential beneficial and harmful effects of nanotechnology, as well as the limitations involved in the use of the traditional approach when analyzing such matters. Following on, section 3 deals with some key concepts derived from the debate on sustainable development and to be used to frame the broader approach to the analysis of new breakthrough technologies like nanotechnology. Section 4 details the design used and section 5, some preliminary results from a study carried out in Brazil. In the last section, the paper presents further stages to validate this new approach and raises important questions regarding the construction of an analytical framework to be used to shed some light on such complex matter.

2. Nanotechnology under the traditional technological paradigm approach

The origins of the concept of paradigm applied to human development issues began with the thinking of T. Kuhn. The general idea was that revolutionary scientific discoveries would dominate the scene during a certain period until the moment when they would be replaced by a new wave of discoveries, and so on (Kuhn, 1962). Later, Dosi (1982) borrowed the Kuhnian conceptual basis to coin the concept of technological paradigm in which the general idea was that revolutionary technological innovation would undermine forthcoming techno-economic trajectories.

Freeman and Perez (1988) enlarged the definition, calling it a techno-economic paradigm and including some social and economic effects of innovation. From this point of view, different periods of evolutionary behavior were possible to be identified and, even more, foreseen (Clark, 1987; Perez, 2004).

That kind of analysis, in which different revolutionary periods – technological phases or business cycles – are viewed only from a techno-economical perspective, has shown, however, some limited ability to deal with real world complexity (Perez, 1983). This is why, for example, it was hard to environmentalists to predict the upcoming impacts of recent industrial innovations, such as global warming and biotech hazardous products. Ignoring precise test validation, companies violated ethical principles and only considered economic returns (Shellenberger and Nordhaus, 2004; ETC Group, 2004). In other words, the traditional approach was incapable of dealing with the unforeseen issues that arose.

Changes in any on-going techno-economic paradigm normally come from the disruptive potential of new technology (Wood et al., 2003). In such matter, we will not disagree with the so-called traditional approach. In the case of nanotechnology, the technical capability of manipulating elements and fabricating products with sizes of less than 100 nanometers let us foresee a wide range of promising technological and economic possibilities (see, for example, European Commission, 2004, Rashba and Gamota, 2003; Greenpeace Environmental Trust, 2003; Wood et al., 2003; Meridian Institute, 2005; Royal Society/Royal Academy of Engineering, 2004; Rossi, 2004; Appenzeler, 2002; Greenpeace Environmental Trust, 2003).

Our very point is, adversely, the fact that a paradigm shift induced by nanotechnology may also produce some harmful effects.

The ETC Group (2003) refers to the possibility of unimpeded self-assembly devices using nanotechnology that could invade the human body (popularly called and above mentioned "gray-goo"). A more realistic scenario would be cell contamination by and the accumulation of nanoparticles causing cell contamination risk and accumulation of toxicity in the life chain (Hett, 2004; Nanoforum, 2004). Hett (2004) warns of the risks of toxicity and pollution involving products containing nanotechnology, without leaving any visible trace.

Nanotechnology can also be responsible for damaging economic and social effects, the magnitude of which would be worldwide due to globalization. The widespread application of nanotechnology will probably have a disruptive effect, definitively replacing old technologies and so causing job losses, economic recession, power imbalance between companies and countries, and social class segregation (Anton et al., 2001; Greenpeace Environmental Trust, 2003).

The list above not only shows us that nanotechnology is a pervasive and multidisciplinary technology, but also that it should have important possible beneficial and harmful effects. Nanotechnology has the power to significantly modify so many different industries and economic sectors that is impossible not to consider environmental and social conditions, and forthcoming impacts. In realty, as one can see, those benefits and risks seem to be like different sides of the same medal, though creating a sort of double effect on almost every scientific, economic, social, and environment drivers.

Macnaghten et al. (2005), as we do, sustain that there is a need for a different and broader technological paradigm approach to deal with the impact of nanotechnology. They consider technology not as given within a strict frame of analysis, but, on the contrary, fully modifiable in its purposes in line with the wishes of society. In proving the limitations of the traditional approach, what paradigm approach could be proposed to replace the techno-economic one, and what are the concepts that are behind the proposed broader approach?

In the next section, the key concepts that shape this broad based approach within the technological paradigm are presented. Also the elements are shown that encompass the multiple dimensions required to deal with the complexity of nanotechnology.

3. Concepts involved in establishing a broader approach of technological paradigm

The concept of development that naturally follows on from technological innovation, i.e. economic wealth creation, must change in order deal with the growing complexity of the real world and, also, in order to allow a better analytical tool-box. On that field, the most important on-going debate is, probably, centered on sustainable development (Asheim et al., 2001; Banerjee, 2003; Bansal, 2003; Greaker, 2003; Spangenberg, 2004; Boron and Murray, 2004).

In this sense, development can be defined as a set of actions that may guarantee better conditions for the mankind's survival which can be deployed at different levels, such as more and better tools and techniques to solve problems (technological dimension); increased wealth generation (economic dimension); many benefits for society (social dimension); and natural resource conservation (environmental dimension).

However, mainstream society continues to follow the old concept of development that adheres to the unlimited exploitation of natural resources, the consequences of which are harmful to mankind and Earth. Martinet and Reynaud (2004) show that deforestation, for example, will impact on water resources, soil and world climate, and desertification will cause soil erosion and sterilization, the extinction of species, and shrinkage of the agricultural area. As a matter of fact, the impacts are all interlinked, and generate significant direct and indirect technological costs.

All the above mentioned effects have led to three different approaches to address the problem. Gladwin, Kennelly and Krause (1995) and Egri and Pinfield (1999) present a typology with three different views of sustainable development:

- the conventional technocentrism or dominant socialist view;
- the anti-ethical ecocentrism or the radical environmentalism view; and

- the sustaincentrism or renewed view.

The authors state that the two former views have been shown to be inadequate to analyze benefits or risks, because they were, after all, as biased as the traditional technological paradigm approach. They claim, on the other hand, that sustaincentrism represents an evolution.

The origins of sustaincentrism or the renewed views began in the nineteenth century when philosophers first began to criticize the industrial revolution. Following this view, technological paradigm leads to scientific and economic progress and provides instruments to detect and manage environmental risks, which menace human survival and welfare. In this sense a mechanical metaphor is quite evident as there is a rational use of the natural resources that minimizes economic effects from pollution (Gladwin et al., 1995). However, this paradigm brings out a complementary approach toward environmental sustainability that carries out a system entropy concept and recognizes a physical and economic limit in the systems, from which drives to renewable power resources development and to non-renewable resources conservation.

Related to sustainable development from the renewed paradigm, Egri and Pinfield (1999) outline some criticisms (usually coming from radical environmentalism paradigm) which are mainly focused on the attempts to include many other approaches and points of view at the same concept that could make it incoherent and weak. Moreover, the sustainable development concept allows governments and industries to engage in environmentalism without having a strong commitment. Macnaghten et al. (2005) also claim that a more active role for the paradigm model is necessary to modify negative impacts and minimize risks before the harmful effects of technology take effect. While the criticism is recognized, the sustaincentrism paradigm is adopted to build a wider model of paradigm analysis.

Martinet and Reynaud (2004) have argued that organization should evolve from the dominant economic logic to a multidimensional (e.g. economic, technological, social, environmental, among others) logic with multiple stakeholders (e.g. society, government, employees, costumers, suppliers, shareholders, and so on) involvement. Sachs (2004) also supports the same point of view and includes involvement across nations.

The new analytical framework is built based on the idea of incorporating multiple dimensions and of dealing with the intertwined effects from the stages of technological development until market acceptance. It is our belief that, within this new and broader approach, a better grasp of all the complex relationships involving benefits and harmful effects of such a new technology as nanotechnology could be gained, which would permit the construction of the pillars of a new regulatory set.

Figure 1, below, illustrates the proposed new approach.

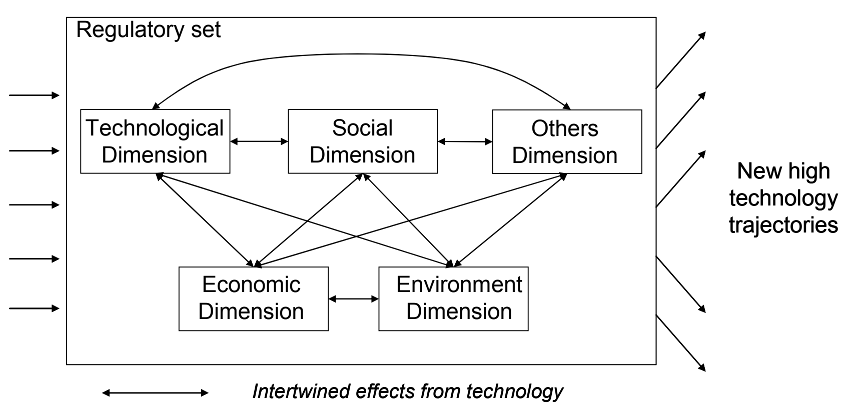

Figure 1 – A broader approach to the technological paradigm concept

This schematic depicts a more approximate condition faced by nanotechnology, in which multiple dimensions can cause effects within one another and affect the behavior of the whole. Environmental dimensions can affect social dimensions that can affect economic dimensions, and so on, in a continuum, mirroring a transversal and systemic flow of effects.

It is possible for all these effects to be limited by a regulatory set which may balance the development of nanotechnology by respecting each requirement from each considered dimension of analysis and, consequently, be accepted by the market. In consequence every nanotechnology trajectory can be diverted towards a more appropriate path by the dimension responses.

4. The research: method and design

The method used in this research was designed to make it possible to deal with the complexity of the impacts and the overlapping relations among different actors (figure 2 depicts the entire method).

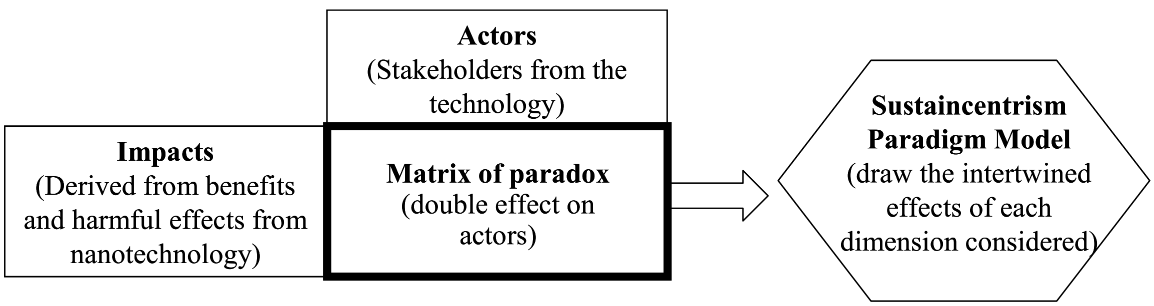

Figure 2 – Research method design

The process began with the identification of the general potential benefits and harmful effects for nanotechnology. At the same time, we have performed the identification of the most important actors involved with these technology outcomes. International literature and institutional reports were researched, and several interviews were carried out with experts in different nanotechnology fields, such as hard science, engineering, social sciences, ethics and politics, as well as representatives from NGOs, and commercial organizations in Brazil. Nine interviews were made during 2005: five Brazilian professors that work with nanobiotechnology; one member of a NGO (ETC Group); one member of the legislative power; one researcher from EMBRAPA (at São Paulo) national institute of agriculture research; one researcher from IPT (at São Paulo); one member of the private sector. The interviews were made with a semi-structured questionnaire that offered to the experts the opportunity to present their professional opinion regarding the impacts of nanotechnology and to infer the possible effects of such impacts on different actors within the nanotechnology scenario.

The beneficial and harmful technical, economical, social and environmental effects were constituted by different specific impacts that could be classified as follows: automation impact on jobs, hazardous nanoparticle generation, technology replacement and integration, change in mode of production of ordinary products, impacts on health care systems, raw material extraction and new business and products. We defined these impacts after a content analysis (BARDIN, 2000) that allowed to selected the most relevant ones to be juxtaposed against actors.

The most relevant identified actors were the governments (federal, state and municipal levels), universities and public laboratories, companies, individuals (as citizens), consumers and non-governmental organizations (NGOs).

To generate the matrix proposed in this article, we considered the nanotechnology as a subject of an intensive interdisciplinary debate concerning the limits of the possible benefits and harmful effects that it could bring to society. In this sense, we tried to define how such impacts affect each of the actors involved in the development of the technology. Each impact may either cause a positive effect on the actors, contributing to the enhancement of change in the nanotechnology paradigm, or a harmful effect that could hamper consolidation of the paradigm. As a result of these analyses, a matrix of paradox was built showing the double effect on each actor involved in the nanotechnology trajectories.

5. Preliminary Results

The preliminary results, shown below in table 1, suggest that nanotechnology affects, in a paradoxical manner, the following relations between impacts and actors:

a) Automation impact on jobs: in governmental and company actors, nanotechnology causes a sort of double effect. The experts believe that nanotechnology may cause unemployment because of the regular evolution of the production processes but, at the same time, may lead to significant economic growth and development in countries and companies. The other actors have just one inferred effect.
b) Hazardous nanoparticle generation: beside the positive effect on consumers and individuals that may not be measurable, nanoparticles cause double effect on actors. Although the benefits are widely recognized, the harmful effects lie in life risk category mainly from metallic nanoparticles.
c) Technology replacement and integration: nanotechnology has double effect on all actors, but apparently no negative one on universities and public laboratories. This relation deals with unemployment, value chain development, investment, product efficiency, the quality of life within society and health care improvements.
d) Change in mode of production of ordinary products: as with the prior relation, nanotechnology has a double effect on all actors, though no apparently negative one on universities and public laboratories. This relation specifically encompasses power concentration and segregation between companies and, in a wider perspective, between countries. It is a considerable factor that could consolidate nanotechnology as disruptive technology that will shift the present paradigm.
e) Impacts on health care systems: this relation causes a double effect on each actor, demonstrating the value of nanotechnology to the human health and quality of life improvement as well as contributing to the creation of new operational problems and higher cost of life maintenance.
f) Raw material extraction: to be a candidate to shift paradigm the technology has to replace inputs in the production mode. In this sense nanotechnology has this potential to provide new forms of raw material in order to radically improve production efficiency. Except to universities and public laboratories and consumers that could be affected in a negative fashion, all the actors suffer a double effect. This relation is responsible for environmental damage and economic development.
g) New business and products: the fundamental reason for the companies to develop technologies is to increase capacity to launch new products and business. With no

Table 1 – Paradox Matrix (impacts against actors involved in nanotechnology)

	Agents											
	Governament		Labs and public research centers		Companies		Individuals		Consumers		Non-profit organizations	
Impacts	+	-	+	-	+	-	+	-	+	-	+	-
Automation - job impact	Economic growth and development	Unemployment	Investiment increasing in research and creation of technical functions	*Apparently without any measurable effect*	Economy of scale and cost reduction(raw material and work)	Investment increasing in technology	*Apparently without any measurable effect*	Deterioration of human relations at work and unemployment	Greater mix of products and better quality	*Apparently without any measurable effect*	Survivor assurance	*Apparently without any measurable effect*
Hazardous nanoparticles generation	Generation of new value chains that wil treat it	Raising social and environmental expenses	Unlimited portfolio of scientific solutions to deal with a wide range of problems	Be considered negative for society; health impact on the scientists	Creation of companies with reverse logistic and solution development purposes	Be considered negative for society; high costs to manage wasted particles	*Apparently without any measurable effect*	Health impacts	*Apparently without any measurable effect*	Health damages	Survivor assurance	Investment in work qualification and work methods
Technology replacement or technology integration	Economic growth and development; creation of value chains	Vanishing of old value chains	Opportunities of technology and innovations integration	*Apparently without any measurable effect*	Cost reduction in production; increasing level of efficiency; more profitable rates	High amount of initial investment in adoption of new technologies	Job opportunities for high qualified workers	Job losses at industries affected by new high technology; health damages	More efficient goods	Exposure to health risks nanoproducts	Survivor assurance	Investment in work qualification and work methods
Change to production and assembly mode of ordinary products	Economic growth and development; creation of value chains	Concentration of rents ; unemployment; larger gap between coutries at different stages of development; even more need of regulation and control	Higher demand of research and development of technologies	*Apparently without any measurable effect*	New forms of companies cooperation; market expansion; more profitable rates	Market exclusion for steady companies; higher amount of initial investment	Job opportunities in the new value chains	Unemployment in case of intensive automation	More efficient goods	Shorter product life cycle; diminishing consumer bargain power	Survivor assurance	Investment in work qualification and work methods
Impacts on public helth care systems	Diagnosis improvement; more efficient treatments; less public expenses	Higher amount of structure and education investments	Higher demand of research and development of technologies	Requirement of higher amount of investments in research process monitoring	Workers spend less time staying out of job due to diseases	Negative image due to the reason to be considered a potential source of problems; charged to pay for a large amount of indemnity; higher costs for health care plans	Life span extension	Suffer from new chronic diseases; potential exclusion of health care system	Waiting time in queue will be reduced in case of health diagnosis and treatment	Higher prices for acquiring a health care plan	Survivor assurance	Investment in work qualification and work methods
Raw material extraction	Economic growth and development; creation of value chains; environmental preservation	Non-reversible damages to the environment	Opportunities for development of extraction technology	*Apparently without any measurable effect*	More efficient raw material extraction processes; lower costs in manufacturing; more profitable rates	Negative image due to the reason to be considered a potential source of problems	Environment preservation	Environment damages	Lower prices for goods	*Apparently without any measurable effect*	Survivor assurance	Investment in work qualification and work methods
Criation of new products	Economic growth and development	Non-reversible damages to the environment	Higher demand of research and development of technologies	Requirement of higher amount of investments in research process monitoring	Cost reduction in production; increasing level of efficiency; more profitable rates	High amount of initial investment in adoption of new technologies; products cannibalization	Job opportunities in the new value chains	Health impacts, Environment damages	More efficient goods	Exposure to health risks nanoproducts	Survivor assurance	Investment in work qualification and work methods

exceptions, nanotechnology may cause double effect on each actor studied. This relation can either boost economic development or provoke environmental degradation.

Even though it is an ongoing research, the preliminary results obtained from nanotechnology experts point to the need of more accurate analysis during technology application development and, more importantly, during the market launch of products that use nanotechnology. NANOFORUM (2004) recommends the precautionary principle use to deal with the new discoveries from nanotechnology as a best practice before any concrete set of regulations is promulgated. Furthermore, technology development analysis is recommended in order to include updated information in the wider paradigm model.

So, as seen in table 1, the different dimensions that emerged from the interviews with experts, impact in a paradoxical way on the different actors involved. We consider that these paradoxical relations show all the complexity involved in the nanotechnology scenario. From the moment when we consider the environmental and social dimensions together with the economic and technology dimensions, the development of a regulatory set for nanotechnology becomes more paradoxical and, in consequence, more complex.

The Brazilian case shows that if we want to develop a new and different regulatory set for nanotechnology, within a wider analytical perspective, it is necessary to consider the demands of the different actors involved. Moreover, it is necessary to establish the priorities for the country, and make a balance between the losses and gains that are acceptable for each actor

6. Concluding remarks

This article discussed potential impacts caused by the emergent and disruptive nanotechnology based and presented the limitations of the traditional techno-economic paradigm in dealing with the complex relationship between the benefits and harmful effects of this new technology. Furthermore, a broader approach for the technological paradigm concept was proposed, to include more dimensions within the analysis in order to meet the necessities contained in the concept of sustainable development, which encompasses new demands from society and Earth.

Preliminary results from research carried out in Brazil at a national level showed important relations between impacts from nanotechnology and the actors involved in its development. From those relations, the next stage of the research consists to study a National Nanobiotechnology Network in Brazil, to validate the matrix proposed and to define some elements for a regulatory set in Brazil.

We remark that the preliminary results show that a new regulatory framework for the nanotechnology domain should enable a crossover approach upon the existing different sectoral regulatory sets. For example, the new regulatory framework must deal with specificities such as patent legal system, different regulatory agencies, different government levels, different types of companies, different types of NGOs and so on. In other words, the new regulatory set has to deal with the aforementioned complexity, double impacts, and multidimensional drivers.

In conclusion, the research suggested that nanotechnology causes a double effect on actors, demonstrating the complexity involved in new high technology development, which is not appropriately analyzed within the techno-economic paradigm. The proposed broader approach is better suited to deal with the complex nature of the impacts resulting from the development of nanotechnology. However, the broader based approach paradigm needs to be validated in a complete technology trajectory to reveal weak points and to prove that anticipated analysis of technology is capable of influencing the path of development.

Macnaghten et al. (2005) raise important questions that are very difficult to answer while the debate on nanotechnology remains attached to the traditional paradigm, such as: "At what stages in R&D processes is it realistic to raise issues of public accountability and social concern? Can citizen-consumers exercise constructive influence over the pace and direction of technological (and related social) change? How can these questions be reconciled with the need to maintain the independence of science, and the economic dynamism of its applications? (Macnaghten et al., 2005, page 10)".

As a supplement to these questions, the present authors add: Is it possible to develop a broader analytical approach for the technological paradigm concept in order to better understand and seize the emerging trajectory of nanotechnology? And, if so, how can we go about this?

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Bibliography

Asheim, G. B. ; Buchholz, W. ; Tungodden, B. (2001). Justifying sustainability. *Journal of Environmental Economics and Management*, Elsevier, vol. 41(3), pages 252-268

Anton, Ps., Silberglitt, R.; Schneider, J. (2001): The Global Technology Revolution: Bio/Nano/Materials trends and their synergies with information technology by 2015. *RAND-Report*, Santa Monica, CA.

Appenzeler, J. et al. (2004). Carbon nanotube eletronics. *IEEE Transactions on Nanotech*., 01.

Banerjee, S. B. (2003). Who sustains whose development? sustainable development and the reinvention of nature. *Organization Studies*. v. 24, p. 143-180.

Bansal, P. (2003). From issues to actions: The importance of individual concerns and organizational values in responding to natural environmental issues. *Organization Science*, v.14, n.5, 510-527.

Bardin, L. (2000). *Análise de Conteúdo*. Lisboa/Portugal: Edições 70 lda, 225p.

Boron, S. ; Murray, K., (2004). Bridging unsustainability Gap: A framework for sustainable development. *Sustainable Development*, v. 12, p.65-73.

Clark, N. (1987) Similarities and differences between scientific and technological paradigms. *Futures*. February.

Dosi, G. (1982). Technological paradigms and technological trajectories. *Research Policy*, 2,147-162.

Egri, C. ; Pinfield, L. T. (1999). As organizações e a biosfera: ecologia e meio ambiente. In: Clegg, S; Hardy, C.; Nord, W. R. (org.). *Handbook de Estudos Organizacionais: Modelos de Análise e Novas questões em Estudos Organizacionais*. Vol. 1. São Paulo: Atlas, 363-399.

Etc Group (2003). *The big down. From Genomes to Atoms. Atomtech: Technologies Converging at the Nano-scale.* Action Group on Erosion, Technology and Concentration, Winnipeg

Etc Group. (2004). *Down on the farm. the impact of nano-scale technologies on food and agriculture*. Ottawa.

European Commission. (2004). Nanotechnology - Innovation for tomorrow's world. *European Commission Community Research*, Luxembourg

Freeman, C.;Perez, C. (1988). Structural crises of adjustment: business cycles and investment behavior. in: DOSI, G. et al. (eds.). *Technical Change and Economic Theory*. Pinter, London.

Gladwin, T. N.; Kennelly, J. J.; Krause, T. (1995). Shifting Paradigms for sustainable development: implications for management theory and research. *Academy of Management Review*. v. 20, n.4, 874-907.

Greaker, M. (2003). Strategic environmental policy; eco-dumping or a green strategy? *Journal of Environmental Economics and Management*. v.45, p.692-707.

Greenpeace Environmental Trust (2003). *Future technologies, today's choices. nanotechnology, artificial intelligence and robotics: A technical, political and institutional map of emerging technologies* .

Greenpeace Environmental Trust, London
Hett, A. (2004). *Nanotechnology - Small matter, many unknowns.* Risk Perception. Zürich, Swiss Re: 57pp.
Kuhn, T. S. (1962). *A Estrutura das Revoluções Científicas*. Ed. Perspectiva, São Paulo.
Macnaghten, P; Kearnes, M; Wynne, B. (2005). Nanotechnology, governance, and public deliberation: what role for the social sciences? *Science Communication,* 27, 2, 1-25.
Martinet, A.; Reynaud, E. (2004). *Stratégies d'Entreprise et Écologie*. Paris: Econômica, 165p.
Nanoforum. (2004). *4th Nanoforum report: benefits, risks, ethical, legal and social aspects of nanotechnology*. Nanoforum.org, June
Perez, C. (1983). Structural change and assimilation of new technologies in the economic and social systems. *Futures*, 15, 357-375.
Perez, C. (2004). *Finance and technical change: a neo-schumpeterian perspective*. In: Hanusch, H.;Pyka, A. (eds.). The Elgar Companion to Neo-Schumpeterian Economics, Edward Elgar, Cheltenham.
Rashba, E.; Gamota, D. (2003). Anticipatory standards and the commercialization of nanotechnology. J. of *Nanoparticle Research*, 5, 401-407.
Rossi, F. (2004). The excitonic quantum computer. *IEEE Transactions on Nanotech*., 03.
Royal Society/Royal Academy Of Engineering, 2004. *Nanoscience and nanotechnologies: opportunities and uncertainties*. Report of the Royal Society/Royal Academy of Engineering Working Group.
Sachs, I. (2004). Desenvolvimento: includente, sustentável, sustentado. Rio de Janeiro: Garamond.
Shellenberger, M; Nordhaus, T. (2004). *The death of environmentalism: global warming politcs in a post-environmental world*.
Spangenberg, J. H. (2004). Reconciling sustainability and growth: criteria, indicators, policies. *Sustainable Development*. v.12, p.74-86.
Wonglimpiyarat, J. (2005). The nano-revolution of Schumpeter's Kondratieff cycle. *Technovation*, 25, 1349-1354.
Wood, S; Jones, R; Geldart, A. (2003). The social and economic challenges of nanotechnology. *Economic and Social Research Conference*.