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Technological trajectories and multidimensional impacts: further remarks on the nanotechnology industry

Paulo Antônio Zawislak*, Luis Fernando Marques**, Priscila Esteves*** and Fernanda Rublescki****

* Graduate Center on Business Administration, School of Management, Federal University of Rio Grande do Sul, PPGA/EA/UFRGS, Rua Washington Luiz, 855, Porto Alegre, RS, 90.010-000, Brazil, paz@ea.ufrgs.br

** Graduate Center on Business Administration, School of Management, Federal University of Rio Grande do Sul, PPGA/EA/UFRGS, Rua Washington Luiz, 855, Porto Alegre, RS, 90.010-000, Brazil, lmarques@redemeta.com.br

*** Graduate Center on Business Administration, School of Management, Federal University of Rio Grande do Sul, PPGA/EA/UFRGS, Rua Washington Luiz, 855 , Porto Alegre, RS, 90.010-000, Brazil, priesteves@gmail.com

**** Graduate Center on Business Administration, School of Management, Federal University of Rio Grande do Sul, PPGA/EA/UFRGS, Rua Washington Luiz, 855, Porto Alegre, RS, 90.010-000, Brazil, fernandarbraga@hotmail.com

The article discusses various views on the emergence and impacts of nanotechnology. It proposes a multidimensional framework for analyzing the different technological, economical, environmental and social dimensions of nanotechnology. The research method consists of a three step investigation of both the positive and negative impacts of nanoscience and nanotechnology on different Brazilian stakeholders. From the insights provided by a group of experts it was possible to design a survey instrument that was applied to 59 Brazilian nanobiotechnology researchers. The survey results show that, on the one hand, nanotechnology is expected to lead to economic development, product development, business competitiveness, greater job specialization, less pollution, improvements to the health system and extended life expectancy. On the other hand, however, nanotechnology may cause specific forms of contamination due to nanotechnological manipulation, more lay-offs, massive industrial restructuring, and other potential risks. Both perspectives would suggest the need for a regulatory framework to deal with the uncertainty and ensure a regular pathway for the stakeholders to be able to exploit this technology to its full potential.

Introduction

Scientific and technological novelties have always been challenging for mankind. New technology brings with it numerous opportunities and great apprehension. In this context, there is a natural interest in emerging technologies, such as biotech, cognitech and nanotech. If, on the one hand, new technological applications normally offer increased opportunities, higher living standards, and lead to the redefinition of social and cultural paradigms, on the other hand, as they lead to the breakdown of previous social rules, they always create a sensation of discomfort and insecurity.

It is essential to prepare the scientific community so that it can provide up-to-date information and new insights to facilitate the dissemination of any new technology, reducing the risk of misunderstanding either the benefits or the negative impacts. As an example, Shellenberger & Nordhaus (2004) have shown that environmental research failed to forecast negative impacts (such as global warming). Another example was the alarming delay between the onset of the social and economic impacts of GMOs (genetically modified organisms) and the initiation of the scientific debate on the subject.

The last five years have seen a significant growth in nanoscience and nanotechnology developments from academic publications and patents to multiple industrial and economic applications. The benefits are extended through new applications in chemistry, materials, electronics, computing, medicine and pharmaceuticals, among others. Due to its overall and horizontal range of applications, nanotechnology has already become inevitable.

The expected positive impacts of nanotechnology range from a technological revolution in the manufacturing process, new employment skills, and the emergence of new industries, to a variety of economic opportunities. However, many of the expected impacts are not exactly clear to the different stakeholders. Moreover, doubts still remain regarding the safety of the nanotechnology for human health and the ecological system. It is claimed that the nanometric size of new molecular structures in itself represents a threat due to the ease with which their action mechanism can spread within life systems, causing contamination and toxicity.

Given this, there is an urgent need to discuss the ways in which social, environmental and economic certainty can be increased. It is our belief that such changes could be better monitored and harmful effects better predicted and controlled, if an enhanced concept of Freeman & Perez´s (1988) techno-economic paradigm, based on the multidimensional interlinking of agents and different outcomes, is used.

Evolutionary Economics (Dosi, 1991; Pavitt, 1992) suggests that any on-going technology is dependent on a path, in which it is possible to foresee its future development. In the case of a new technology it is harder to predict their development path as their path is unknown. The lack of knowledge and the inherent uncertainty of any new venture certainly enhance doubt and create fear. Any new technology will obviously engender both positive and negative impacts. To better understand this issue, it is necessary to understand the entire phenomenon from a technical/economic perspective, while it is also imperative to incorporate new dimensional sights, such as the social and the environmental perspectives.

This paper proposes to identify, through extensive research carried out within the Brazilian nanobiotechnology research network, the potential benefits and threats to the economy, society and environment offered by the emergence of nanoscience and nanotechnology.

This paper includes five more sections: The next, section two, will address the emergence of new technologies in general. Section three focuses on the path of nanotechnology and its positive and negative impacts. Sections four and five are dedicated, respectively, to the methodology and the results obtained from the research effort made during 2004 and 2008. The final remarks are in section six.

The Emergence of New Technologies and Development

The Schumpeterian tradition suggests that the successful spread of innovation throughout the economy and society will generate a new cycle, value creation and wealth. Freeman and Perez (1988) defined any major new technological breakthrough as a new techno-economic paradigm.

This kind of analysis, in which different revolutionary periods are perceived primarily from a techno-economical perspective, has proven to be of limited use when dealing with the complexity of the real world (Perez, 1993). That is why, for example, it was hard for environmentalists to predict impending events, such as global warming and biotech hazardous products, of recent industrial innovations. Ignoring precise test validation, companies violated ethical principles and only considered economic returns (Shellenberger and Nordhaus, 2004; ETC Group, 2004).

In order to deal with a complex world, significant changes are required to the definition of development when attempting to understand an emerging new technology. The current debate, which is actually contributing towards broadening that definition, is primarily focused on research into sustainable development (Asheim, Buchholz and Tungodden, 2001; Banerjee, 2003; Bansal, 2003; Borron and Murray, 2004; Greaker, 2003; Spangenberg, 2004).

In fact, depending on the intensity of the innovation cycle, both positive and negative impacts are felt over a multitude of dimensions. If it is intense, as in the case of revolutionary technologies, the impacts are not restricted only to the economic dimension, but will certainly extend to other dimensions, such as the social and environmental ones.

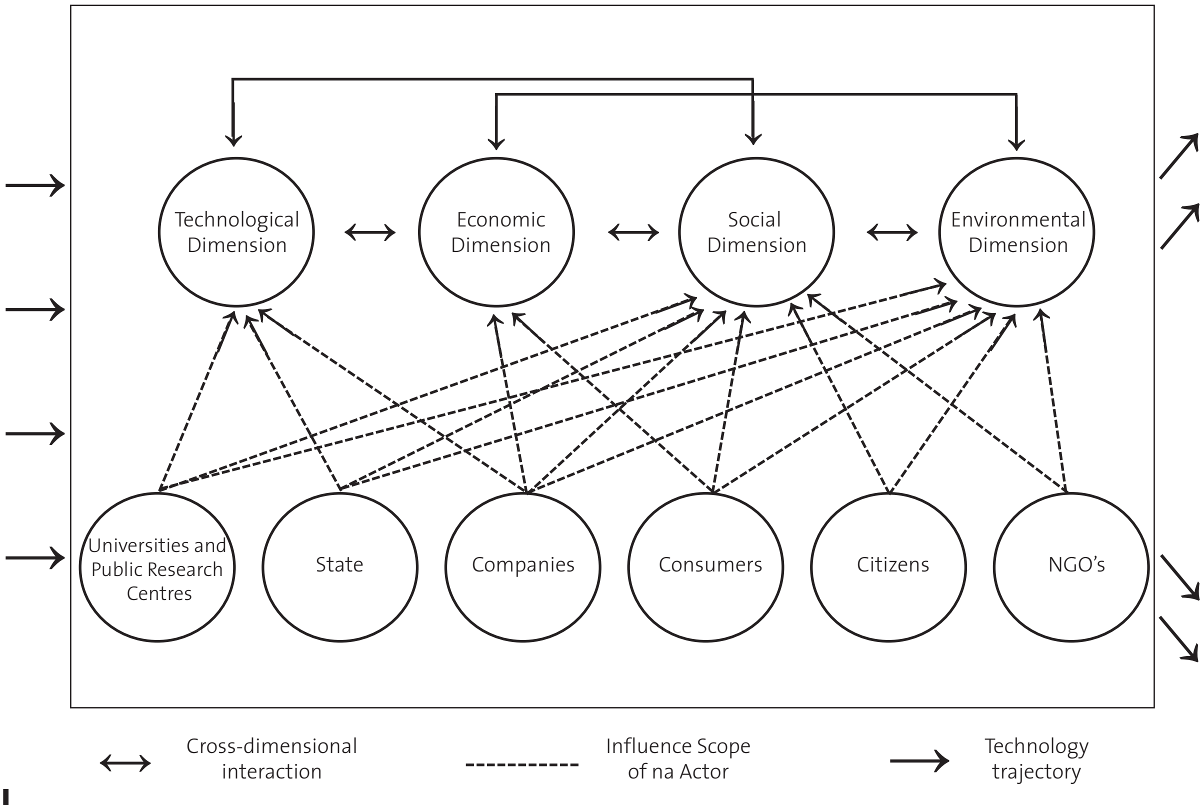
In order to cope with these nonlinear impact flows, it is important to provide a general concept to incorporate them. Since the classical definition of the techno-economic paradigm only partially fulfils the task, Zawislak et al (2006, p.4) have enlarged the concept of development as to be:

"a set of actions that can ensure the best conditions for mankind's survival, which can be deployed into different dimensions, such as better tools and techniques to solve problems (technological dimension), an increase in wealth generation (economic dimension), wide comprehensive welfare for the society (social dimension), and natural resource conservation (environmental dimension)."

This multidimensional approach (i.e. technological and economic dimensions plus social and environmental ones) better reflects the complexity of the contemporary technology scenario.

This approach emphasizes the role of different relevant agents, such as the individual, organizations, or groups of organizations, as engines for and/or the consequence of change. This situation suggests that the scope of analysis that explains the existence and the systemic role of any individual or organization should be enlarged to consider their different interlinkages (Nielsen, 2001). If, on the one hand, these actors may fulfil a more significant role in a certain dimension, on the other hand, they can also play simultaneous roles in different dimensions. The major stakeholders are universities and public research centres, companies, the State, consumers, citizens and non-governmental organizations (NGOs) (Marques, 2008).

Figure 1 Multidimensional model for the analysis of the impacts of new technology



This complex system is better understood by considering the cross impacts of the different dimensions and their respective interlinked stakeholders, who undergo possible general effects (both positive and negative) of a new technological trajectory. Figure 1 shows how the multidimensional model for the analysis of new technology impacts works.

Since we are dealing with technological impacts, technology itself is the primary driver in the achievement of economic development. From this multidimensional perspective and considering that new technology is increasingly general purpose in nature, its diffusion throughout society normally leads to (Bresnaham & Trajtemberg, 1995; Carlaw & Lipsey, 2002; Carlaw et. al, 2005):

1) more complex forms, with undeniable increases in productivity;
2) a new range of applications;
3) a wide range variety of economic results;
4) and the emergence of a diversity of new products and technological processes.

However, many different paths can be followed. First, the use of new technology implies positive effects in the economic dimension, by establishing productivity growth and wealth creation (Schumpeter, 1934; Solow, 1957; Nelson & Winter, 1982). Second, it also implies negative effects like, the disappearance of economic sectors, increases in new investments, the exclusion of existing businesses in the market, as well as more difficulty on distributing wealth, generating employment and standards of competence (Tobin, 1989; Furtado, 2001).

In order to fully comprehend the phenomenon, besides understanding the impacts of new technology on the economic dimension, it is also necessary to understand how it affects the social and the environmental dimensions.

Normally, the mainstream society continues to follow as old concept of development that adheres to a different pattern of generating social benefits and exploiting natural resources. But as new industries and products emerge, a new social structure is needed. New cultural behaviour and attitudes change expectations and profiles. It is as if a new kind of society emerges within the old as a result of new techno-economic trends. New behaviour also leads to new environmental impacts.

Martinet and Reynaud (2004) have shown, for example, that deforestation for commercial use has impacted on water resources, soil and world climate; in some regions, the looming desertification has caused soil erosion and infertility, the extinction of species, and shrinkage of the agricultural area. In fact, the impacts are all interlinked, and generate significant direct and indirect technological costs, and the emergence of new sub-patterns and the search for new technical solutions.

In the opinion of experts, nanotechnology is an emerging general purpose technology. The forthcoming nanorevolution needs to be better understood (Carlaw et al. 2005; Elsi, 2005; Roco & Bainbridge, 2006).

Nanotechnology: Trajectories and Impacts

Nanotechnology is the group of technologies resulting from scientific discoveries made in different fields of knowledge, such as chemistry, physics, biology, material and computational engineering, where the dimension of manipulation is nanometric (Nanologue, 2006). In essence, nanotechnology consists in the ability to manipulate matter at an atomic scale, in order to create structures with a differentiated molecular organization and different properties (Crandall, 1997).

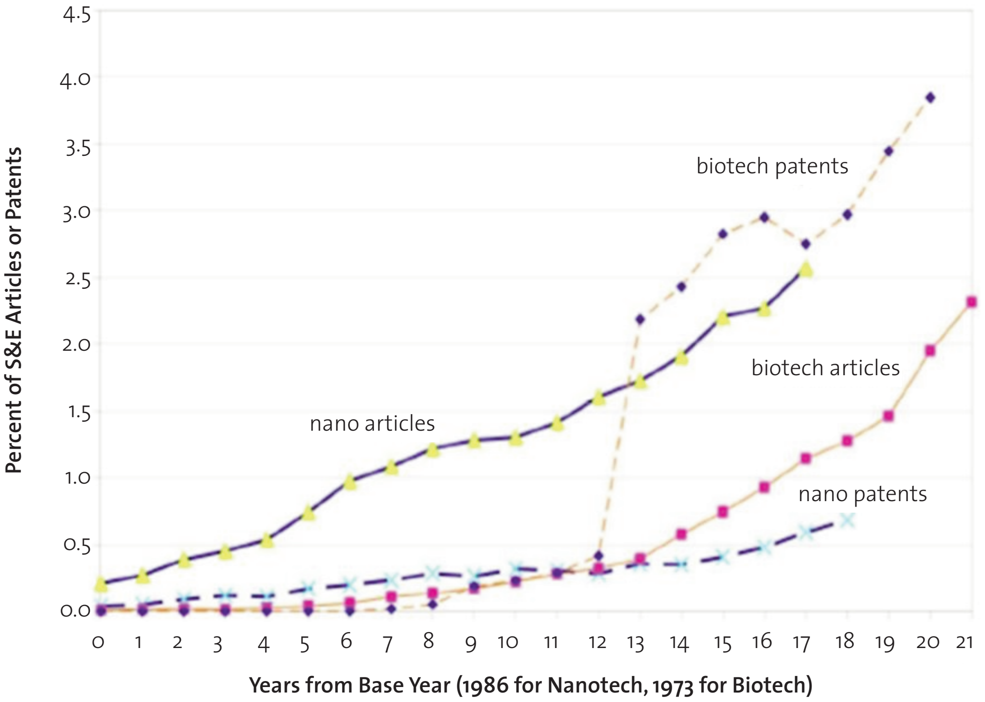
Regarding that material property, nanotechnology has the potential of creating several technical applications with impacts in many different economic sectors. One example is the carbon nanotube that promise to enable lighter, stronger materials that can be used in civil construction, heavy machinery, car manufacturing, electronics industry and so many others (Nanologue, 2006). This variety of applications makes it difficult to evaluate and measure the impacts of nanotechnology using the traditional linear view (NIST, 1999; Royal Society/Royal Academy of Engineering, 2004).

Nanotechnology as an Emerging Technological Trajectory

When analyzing the development of nanotechnology and its various spill-overs, publishing (articles) and patenting (number of patents) are interesting ways of measuring the timelag that occurs between the publication of scientific findings to the patenting of technological applications (Zucker & Darby, 2005).

This timelag can be clearly seen by comparing the number of articles and patents involving nanotechnology vis a vis biotechnology

Figure 2 Comparison of indicators (biotechnology versus nanotechnology) Source: Zucker and Darby (2005)



(of which Genetically Modified Organisms is a significant example), as shown in Figure 2 below.

Between 1983 and 1990, the number of articles dealing with nanoscience and nanotechnology grew exponentially, doubling roughly every 7.3 years. Between 1991 and 2005, however, the rate of new publications increased considerably, doubling every 3.3 years (Zucker and Darby, 2005; Kaiser, 2006). With biotechnology research and applications, the results are almost the same: exponential growth. Observing the biotech time lag pattern, it is interesting to note that there was an increase in number of related patents several years after the expansion in the number of new papers.

By following the trends shown in Figure 2, the same pattern can be expected to take place with nanotechnology.

This idea is reinforced by Zanetti-Ramos and Creczynski-Pasa (2007) for whom the growing number of articles published suggests significant investments in research. Consequently, Fishbine (2002) claims that research stimulates investments in nanotechnologies reaching figures that surpass billions of dollars.

Research leads to new investment and stimulates new entrants in the business of nanoscience and nanotechnology. According to Kingon et al. (2004), in 1999 the number of new entrants whose main products or services were based on nanotechnology was around 100. However, this figure has now surpassed 1,000 in only 3 years. Moreover, according to Alves (2004), 15 years from now, the estimated annual production of products based on nanotechnology will be in the range of 1 trillion dollars, a value that will require the employment of at least 2 million workers in this sector.

These figures are sufficiently important to draw attention to the debate on the predictability of nanotechnology. It is particularly important since the expected negative impacts of nanotechnology include applications that would be potentially harmful to mankind, such as the capacity to build mass destruction weapons (Marques, 2008). These potential negative impacts cast doubt on the safety of nanotechnology in terms of human health and various biological chains (Nanologue, 2006).

Multidimensional Impacts

The problem with nanotechnology is not

just related to size but, instead, whether it is safe and controllable. This has led to a new debate, which addresses the consequences of the nanotechnology. This debate covers the technological, economic, social and environmental dimensions of the impacts of nanotechnology.

Regarding the technological dimension, it is necessary to asses the impact on the pace of progress in nanoscience and the diversity of its technological applications. This evolution will raise the level of professional skills and enhance scientific discoveries and future scenarios for the nanotechnology trajectory.

Regarding the possible variables involved in the economic impact of nanotechnology on the various agents it is necessary to consider the level of economic development, the average level of profitability, the degree of optimization of the use of inputs, the average prices of new products in relation to those of a previous technological generation, the level of manual labour required to establish the new paradigm, as well as the cost of living and income distribution.

The social dimension involves the impact of nanotechnology on the level of employment in various economic sectors, the level of welfare created, and the progress made with its application in human health.

Finally, the environmental dimension concerns the degree of environmental pollution, the degree of contamination, the destruction of different existing biomes and the conservation of natural resources.

This complex scenario demands a new regulatory framework to control the pace of nanotechnological development in a fair manner. If such a regulatory framework is delayed, nanotechnology could come to be seen in a negative light. It is necessary to stress that a regulatory framework may lose its capacity to guide the development of the technology, thus becoming incapable of controlling its spread and that of its associated dangers.

To prevent such an "unstoppable" trend, it is worth carrying out a cross study of the major events that have characterized the emergence of previous revolutionary technologies. The opinions of experts and the perceptions of the actors involved are useful in identifying the most relevant impacts of nanotechnology and represent an important guideline for a future regulatory framework.

Important questions are raised within this debate such as: what are the major impacts emerging from nanotechnology? When will they occur? What is the right timing for regulation?

Methodology

In an effort to analyze the technological trajectory of nanotechnology and its possible impacts a two-fold, in-depth study and a survey were carried out. The research was conducted in three different stages between October 2004 and May 2008. In the first stage, experts in nanotechnology, from various analytical perspectives, were asked to identify the potential impacts of nanotechnology. In the second stage, a survey was conducted among the researchers belonging to the Brazilian Nanobiotechnology Network. The third stage consisted in an effort at reconfirming the data by interviewing businessmen involved in and affected by the application of nanotechnology.

Stage 1: Interviews with Experts in Nanotechnology

Sixteen experts from diverse fields of knowledge and experience were interviewed. They were selected in a non-probabilistic way from the areas of basic sciences, engineering, social sciences, ethics, politics, and representatives of non-governmental and commercial organizations. The experts were: 6 researchers (Biotechnology, Physics, Chemistry, Materials, Pharmacology, Sociology); 1 catholic priest who is a federal congressman; 1 federal judge; 1 international NGO representative; 6 Brazilian government representatives (from CNPq, FINEP, 2 MCT, MMA and Embrapa); and 1 businessman.

They were interviewed using a semi-structured questionnaire dealing with the potential impacts of nanotechnology that, in their opinion, may actually occur.

From the collected data, a set of impacts was listed showing the potential general effects from nanotechnology on the technological, economic, social and environmental dimensions. This list gave rise to 35 statements that were used in the survey instrument.

Stage 2: Survey

The focus of this survey was the Nanobiotechnology Network, which operated between 2003 and 2005, with members from 18 national and state institutions from eight Brazilian states

In an effort to facilitate the understanding the interlinked effects, the statements relating to the application of nanoscience and nanotechnology were limited to the field of nanobiotechnology, and two specific economic sectors: cosmetics and pharmaceuticals. Both sectors have a high level of R&D investment (around 10% of sales) and also, due to the already mastered scientific capability of designing new molecular structures, are accelerating the launch of new products.

The sample consisted of members of the Brazilian Nanobiotechnological Network (an institutional research and development network formed by the Brazilian National Council for Scientific and Technological Development – CNPq – of the Ministry of Science and Technology – MCT). The Network consists of 92 PhD researchers; 59 of whom returned the questionnaire (64% return rate). They were contacted by telephone and e-mail in order to reduce time and costs involved.

The sample profile shows that 93.2% of surveyed researchers are primarily related to public institutions, and the remaining 6.8% related to private institutions.

Regarding the type of institution, 86.4% are from universities, 11.9% from technology centres and 1.7% from foundations. By using the Lattes-CNPq database it was possible to identify each professor's areas of knowledge in relation to nanotechnology (Lattes, 2006). Thus, researchers with recognised expertise in physics constitute 25.4% of respondents, chemistry 22%, biology 33.9% and pharmacology 18.6%.

Using the data collected in stage I, a survey instrument (questionnaire) was elaborated which included a four-step Likert scale, where the level of agreement of the respondent varied from a lower limit, represented by the number one (1) –meaning "I totally disagree" – to an upper limit, represented by the number four (4) – meaning "I totally agree". The use of this scale required the researcher to position himself in relation to a determined aspect of the subject. Appendix shows the general results (percantage) for all statements. Furthermore, the results will be presented as means (m) and standards-deviation (s) of the total of responses to the four-step Likert scale.

The statements followed the order of the multidimensional model, where the first part dealt with the technological dimension, followed, in sequence, by the economic, social and environmental dimensions.

Stage 3: Interviews with Businessmen

The second exploratory in-depth study was conducted with five representatives from companies within the cosmetic and pharmaceutical industries. It was decided to restrict the research to companies geographically established in Brazil.

This phase consisted on comparing the outcomes from the survey (scientific and technological-based study) with the points of view offered by the companies (profit-oriented impression) in order to deal with real possible effects and impacts of nanotechnology on the dimensions under consideration.

In order to identify companies with in-house R&D into nanotechnology that could provide representatives for interviews the Brazilian Innovation Agency (FINEP) was consulted. As a result, five companies were selected and their respective representatives were interviewed using a semi-structured questionnaire.

Analysis of the Results

The analysis of the results is divided into three sections. First, the impacts, as perceived by the experts in the interviews are presented and then divided into seven domains. In the second section, the survey statistics are described following the order of the four nanotechnology impact dimensions, the impacts on stakeholders, and the need for a regulatory framework for nanotechnology. The final section shows the perceptions of entrepreneurs in relation to potential impacts of nanotechnology.

Impacts Determined from Interviews with Experts

The research findings shows that nanotechnology affects the stakeholders involved both positively and negatively. However, although it is impossible to identify the full consequences, it is possible to outline a set of double impacts that may be used to establish a future regulatory framework.

The following section contains a summary of the foreseen impacts. As can be seen, new businesses, new products and new materials will certainly lead to new productions systems and yet unknown social impacts.

Integration and substitution of technology

Nanotechnology will provide a wide range of new applications, based on either in-use technology or completely new applications. As a general purpose technology, nanotechnology is fully able to create or to enhance novelty within almost every scientific domain.

New scientific research areas, new kinds of raw materials, new products and new industries, will lead to a new individual, organizational and collective behaviour.

The replacement of existing principles and techniques is, perhaps, the most important impact. Obsolescence will affect business competiveness, employment perspectives and social wealth. Since it is almost impossible to mechanically replace obsolete technological and competence structures for new ones, outdated knowledge and practices will be erased from different communities. It is unlikely, for example, that the workers from the traditional metal-casting industry will simply be employed by new steel injection companies.

The cost of the shift to a new educational and professional paradigm will change State and university institutional structures. Once-valued skills may not necessarily be applicable to new technology.

New products and business

The new technological standards will certainly change the way in which matter is manipulated. Since nanotechnology deals with physical structures at the molecular level, a whole range of new products can be imagined and developed. As a consequence of this technological innovation, a variety of new businesses will emerge.

Not only new companies with, as yet unknown, new product alternatives, but also existing businesses will profit from the opportunities provided. R&D capabilities will reach new levels, both in terms of the specific skills of personnel and in terms of laboratory structures, thus requiring greater expenditure on R&D. Sectors and companies with less investment capability will tend to fall behind in this new technological trajectory.

Since nanoscience and nanotechnology are new fields, companies will certainly need to establish new patterns of open innovation with universities and technocentres. Equally, to avoid the misuse of principles and techniques, research and laboratory procedures will need to be redesigned.

New products will lead to new patterns of consumer behaviour. It is expected that new products will appear with significant advantages in terms of quality, reliability and price. However, major doubts have emerged in relation to the issue of consumption. Since particle manipulation is the very essence of nanotechnology, consumers may be exposed to different and unknown forms of contamination and environmental change. The risk to health is greater the more invasive is the product, such as food, drugs or cosmetics.

State agencies, NGOs and citizen's organizations will face new challenges to understand, prevent and avoid any possible negative impacts.

Extraction of raw material

One of the most important positive impacts is the complete change in the supply of raw materials. Nanotechnology has the potential to replace traditional extraction by synthetic production and, thus, to effectively reduce environmental impacts. This touches on one of the basic pillars of capitalism, i.e. the exacerbated use of natural sources of inputs.

According to the experts, this major shift will completely change the structure of value chains. Reductions in raw material and logistics costs, as well as in other transaction costs will to lead to a reorientation of business strategies. There will be a shift from supply to demand oriented strategies, where new products, with new price relations, will become easier to obtain, not only because they may become cheaper, but also due to the reduction in procurement and sales.

New materials, new logistic and operational structures, new products and new consumer behaviour will give rise to new industrial production chains, where productivity, efficiency, quality and cost will reach new standards.

However, as with any new production process, the extraction of the raw material demanded by nanotechnology will require new safety and hazard-free structures. As yet there are no standardized technical procedures to ensure safety with nanomanipulation; therefore nanoproduction is certainly one of the major challenges to be overcome. Universities, research centres, industrial organizations and NGOs have a key role to play in this quest.

Changes in the mode of production of common products

Nanoproduction, as stated above, is one of – if not - the major challenge for business ventures seeking to take advantage of nanotechnology. While new materials, new applications and new products are perfectly imaginable, the problem remains as to how to use, apply and produce them.

It is not merely a question of quality or productivity. It is more a question of how to concretely produce stable nanometric structures. Size has not yet been fully mastered and many nanoproducts are still micrometric products. Moreover, there is still a knowledge gap in relation to inert and active matter. While new nanoelectronic devices have already been successfully produced in the semiconductor industry, there remains a problem in bionanotechnology sectors, such as chemicals.

University-based scientific research, especially in engineering, will face great challenges in the next ten years. Society, as a whole, is still waiting for new nanoproduction technologies. Until then, traditional production process will be adapted to new nanotechnology products. And here lies a high risk of creating a negative impact, as traditional production processes may not be fully adequate to deal with nanometric structures. In the cosmetic industry, the unstable scale of the nanometric liposome in dermocosmetics can be expensive for costumers or harmful for human health, since if they are too big they may be useless, while, if too small, they may reach the bloodstream and produce undesirable side effects.

It will be difficult for State regulatory agencies to deal with such uncertainties.

Impact of automation on employment

As a result of the challenges that come with nanoproduction, automation seems to be absolutely necessary to achieve competitive productivity and high quality standards in nanometric products. Since it is almost impossible to use traditional manufacturing procedures, labour tasks will certainly change.

Even highly trained personnel will probably find themselves out of the work. On the one hand, the above-mentioned gap between scientific knowledge and technical practice is hard to be filled using their existing skills. On the other hand, there is still a lack of people with sufficient experience in the new technology to efficiently work in nanoproduction.

Because of the rapid pace at which nanotechnology is being adopted in many sectors, new investment will probably be much more equipment oriented then competence oriented. Therefore, nanotechnology is likely to reduce job generation and so affect welfare and undermine social relations.

Here, government and NGOs seem to have an important role; in developed countries, to avoid high rates of unemployment and, in emerging economies, to guarantee balanced investments in new technology and new industrial sectors.

Generation of hazardous particles

This is, perhaps, the classic negative impact. The “nanofear” effect is based much more on ignorance than on reality. The popular idea that nanostructures will invade human bodies and then dominate the world is science fiction, but there are hazards involved.

Since people lack of information, consumer behaviour will remain sceptical. This certainly affects the demand for new products and, thus, the success of the new companies based on nanoproduction. In fact, the ease with which nanoparticles could penetrate living systems, both human and natural resources, could effectively cause damage to health, contamination, pollution and degradation. However, the extent to which this can happen is not fully measurable. For example, as has happened with agro-toxins, cumulative and chronic effects may only come to light many years later.

Once again, in this area regulatory agencies and NGOs have a major role to play. The State should increase expenditure on research, prevention and control, while NGOs should dedicate themselves to gathering relevant information and increasing public awareness. This is why a new regulatory framework is urgent.

Until further information is available, the care taken by civil society will prevail over blind confidence in this new technology.

Impact on health systems

Here, once again, there is an evident double effect. The discovery of new medical procedures and drugs are the most valuable developments of nanoscience, though, at the same time, the risk of contamination remains high.

On the one hand, medical research is pointing to a whole new world of possibilities. New treatments, new cures, new devices, new techniques can and will make use of new nanoscience and nanotechnology-based developments and devices. Moreover, further extending the human life span is a long-held dream of mankind. Improved human health and life quality are without doubt the most hoped outcomes of nanotechnology.

On the other hand, if this is achieved, society as a whole and the State will benefit. Public health services will enhance quality and reduce expenditure, since new upcoming nano-based treatments are expected to be more accurate than existing procedures. That is why most R&D expenditure made by private companies is still being cantered on the medical, pharmaceutical and cosmetic industries.

The Survey

In this stage of the study, 35 statements – that were based on the experts opinions, referring to both the positive and negative impacts of nanotechnology, and that were formulated into a survey instrument which was sent to the Brazilian nanobiotechnology network researchers – are presented one by one according to their specific dimensions.[1]

Technological Dimension

From the data collected, for example, the mean of the responses to the first statement shows that the researchers tend to believe (m = 2.6) that nanotechnology can provide unlimited solutions to many of the problems faced by society, and almost all (m = 3.9) believe that research in nanotechnology will open new frontiers for knowledge and new scientific discoveries (see Table 1).

Regarding the impact of nanotechnology on the process of product development, most of the researchers (m = 2.93) believe that the time between a product's development and its launch will be reduced.

Yet, the analysis of the standard deviation shows that there is wide variance in the responses to the majority of the statements concerning the technological dimension, which may suggest a certain level of doubt in relation to the real potential of nanotechnology, notably in terms of what products will look like.

Economic Dimension

Most of the researchers strongly believe that nanotechnology will stimulate the growth of new industries and the disappearance of old ones, it will also require investment in professional training for future employees, and will increase R&D expenditure (see the results in Table 2)

Moreover, they believe that nanotechnology could increase the level of employment in the economy, since most of the researchers disagree that nanotechnology will be a factor leading to the exclusion of the low-income-population (m = 1.85).

Another aspect pointed out by the researchers was that the expense involved in treating waste from nanotechnology will be lower when compared to other technologies (m = 1.94). It may also lead to a rise in spending on health care, as nanotechnological products will be more expensive than conventional products.

In contrast, the researchers strongly believe in the need for investments in nanotech-

Table 1 Technological Dimension

Impacts	Mean (m) from 1 to 4	Standard Deviation (s)
Offers unlimited solutions to many of the society's problems.	2.60	0.89
Nurtures technological integration at levels previously unimaginable.	3.50	0.68
Opens new research and knowledge frontiers.	3.90	0.31
Requires the creation of new laboratory procedures.	3.36	0.70
Creates a path for the raw material synthesis.	3.19	0.61
May reduce the development time of a new product.	2.93	0.70

1) Statistical tests were applied to cross-reference data. The first set of statistical tests used was intended to verify whether the sample was subject to a normal distribution. Thus, the homogeneity test and the Kolgomorov-Smirnov test showed that in all the research questions the answers did not show normal distribution. Hence, the nonparametric Kruskal-Wallis test was applied, because statistical techniques are best suited for use with small samples in the absence of normal distribution (MENDENHALL, 1990). The Kruskal-Wallis test revealed the existence of statistically significant differences in the responses from the surveyed researchers due to their different fields of knowledge. The test showed that all the questions received answers of little statistical significance (p> 0.01), concluding that there are differences in responses between the knowledge areas surveyed in all dimensions.

Table 2 Economic Dimension

Impacts	Mean (m) from 1 to 4	Standard Deviation (s)
Will facilitate the emergence of new industries.	3.64	0.51
May increase employment levels in the economy.	3.00	0.63
Will require investment in professional training for future employees.	3.67	0.47
May cause the disappearance of industries that do not apply nanotechnology.	1.91	0.80
May increase the spending level on measures to prevent the problems caused by nano-technology waste.	1.94	0.74
May provide lower cost raw materials for industry.	2.78	0.78
Offers the possibility of unlimited scale of production of consumer goods.	2.27	0.85
Requires increased investment in research and development by enterprises.	3.65	0.51
May lead to more expensive health insurance plans.	1.98	0.83
The treatment of waste from nanotechnology will cost more than any other.	1.94	0.74
The nanotechnology-based products will be more expensive than other products.	2.20	0.73
Will be a factor leading to the exclusion of the low-income population.	1.85	0.79

Table 3 Environmental Dimension

Impacts	Mean (m) from 1 to 4	Standard Deviation (s)
Will assist in reducing pollution in general.	2.88	0.74
It is pollutant to humans and to the environment.	1.79	0.73
Will increase environmental awareness and researcher ethics.	2.25	0.88

nology-qualified-labour (m = 3.65). In the in-depth interviews (stage 1), labour representatives mentioned that such investment will not be only operational but also technological, that is, the workers performing routine activities in the production process will be affected as well as higher ranking staff, and the technical positions will have to hold the necessary knowledge in nanotechnology.

The economic dimension also revealed a wide range of responses to most of the statements. This demonstrates the difficulty involved in forming a position about the potential of a new technology. This happens because of the certainty that nanotechnology demands higher investments in professional qualification (m = 3.67), due to the variation in the physical properties of matter, which leads to a need for greater knowledge specialization.

Environmental Dimension

There is considerable doubt regarding the possible environmental impacts (see Table 3). The interviewed researchers believe in reduction of pollution in general (m = 2.88). Moreover, they disagree that nanotechnology is harmful to the human race and to the environment (m = 1.79), and with a high level of uncertainty (s = 0.88) they tend to disagree that nanotechnology will induce higher environmental consciousness and researcher ethics (m = 2.25).

The standard deviation among the environmental issues is high, which demonstrates a certain degree of uncertainty about the potential benefits of the new technology for the environment.

Social Dimension

The social impact is influenced by other impacts, in both positive and negative ways. However, most of the researchers believe that nanotechnology will be able to improve the quality of life among the population and that it might lead to further extension of the human life span (respectively, m = 3.58 and m = 3.13). But they disagree that, currently, nanotechnology has a negative image among the population (m = 1.69) and that it may cause harm to human health (m = 2.02).

The expectation that nanotechnology will bring benefits to the population is, thus, generally confirmed. The interviewed researchers seem to expect a great deal from the nanotechnological revolution, reflecting the transforming role of the scientific discoveries in the society (see Table 4).

Implications for the Regulatory Framework

The interviewed researchers agree (m = 3.37) that the laws and rules should help prevent any potential negative impact from nanotechnology. However, they are not fully in accordance that the standards of ethical conduct of researchers should be stricter with nanotechnology (m = 2.54 and s = 1.00). This may indicate a certain fear within the academic community regarding the risks of misusing the expected potential of nanotechnology (see Table 5). This is, perhaps, better explained if one considers the fact that they are also doubtful over the standardization of laboratory procedures and health care researchers should be stricter with nanotechnology (m = 2.66 and s = 0.95). However, respondents agree with tightening control of the manipulation of nanotechnology by lab workers in order to prevent health risks. This shows some concern about the possibility of contamination by nanotechnology, with a similar proportion who agree that nanotechnology could pollute the biological chain and cause harm to human health.

Here, once again, the standard deviation is high, reinforcing the perception of uncertainty.

Impact on the Stakeholders

In the course of introducing a new techno-economic paradigm several stakeholders influence and are influenced by the technological innovation process.

Questioned as to whether nanotechnology will negatively impact the stakeholders, the surveyed researchers strongly disagree (m = 1.12 and s = 0.37) that this could happen to the scientific community, industry and companies, consumers, the population, governments, and NGOs (see Table 6).

Moreover, in almost all the statements regarding the impacts on the stakeholders the standard-deviation tends to be low, which suggests the scientific community has a positive concept of nanotechnology.

Table 4 Social Dimension

Impacts	Mean (m) from 1 to 4	Standard Deviation (s)
May improve the population's quality of life.	3.58	0.56
Nowadays, nanotechnology has a negative image among the population.	1.69	0.89
May extend the human life span.	3.13	0.69
May cause damage to human health.	2.02	0.68

Table 5 Implications for the Regulatory Framework

Impacts	Mean (m) from 1 to 4	Standard Deviation (s)
Laws and rules should prevent any potential negative impact from nanotechnology.	3.37	0.85
Regulation may restrain private investment in nanotechnology.	2.43	0.91
The ethical principles governing researchers should be stricter with nanotechnology.	2.54	1.00
The laboratory procedures and health care standards for researchers should be stricter with nanotechnology.	2.66	0.95

Table 6 Impact on the Stakeholders

Impacts	Mean (m) from 1 to 4	Standard Deviation (s)
Will negatively impact on the scientific community.	1.12	0.37
Will negatively impact on industry and companies.	1.26	0.57
Will negatively impact on the population.	1.19	0.40
Will negatively impact on consumers.	1.19	0.40
Will have more negative than positive impacts on governments.	1.20	0.40
Will negatively impact on non-governmental organizations	1.50	0.77

Yet the highest standard deviation (s=0.77) is related to the impacts of nanotechnology on non-governmental organizations (NGOs), which may reflect a certain fear on the part of the scientific communities related to the actions of more critical NGOs that emphasized the negative aspects of Genetically Modified Food technology.

Impacts According Businessmen

While R&D expenditures on nanotechnology is steadily growing in developed countries, in Brazil, the number of companies that have initiated a nanotechnological trajectory is still very low. In our research, only five representatives of such companies were interviewed. Even with the small sample of the representatives from the business world, the impact of nanotechnology outlined in the interviews corresponds with the expectations identified by the experts interviewed in the previous step in this study.

Technological impacts

The technological impacts of nanotechnology are (and will) be significant in several industrial sectors, particularly in the pharmaceutical industry, as shown by the four respondents from this sector.

Nanotechnology is expected to reduce the risks involved in product development to help change the paradigm within the pharmaceutical industry from a process of trial and error to one which is planned, and focused on specific uses of the new active ingredient. In this industry, nanotechnology research is motivated by the special features it appears to offer. On-going research can be divided into two types: the scientific and technological.

The scientific search for new compounds, whether synthetic, vegetable or animal, can generate new drugs. Despite the tremendous advances in biotechnology, the fine chemicals industry still employs the traditional synthesis of substances technique. Nanotechnology offers the opportunity to synthesize the molecules from which substances are made.

The technological research involves the search for new forms of administration and absorption, and longer lasting action of the drug in the body and seeking ways to enhance and restrict the action of the drug at an exact point in the body in order to increase the chances of effective action and reduce side effects. The first discoveries involving the application of nanotechnology are taking place within technological research.

In this section, applications are broken down into the categories of drug action control process, the extent of treatment by synthetic drugs, enhancement of active healing and disinfecting systems, the scope and effectiveness of external (equipment and techniques) and internal (in vivo) diagnosis, new synthesis production processes, new techniques for controlling the dimension of the production process, among others.

The Brazilian cosmetics industry has only two companies capable of designing nanotechnology-based products. A representative of one of these companies asserted that research into nanotechnology offers a number of technological benefits such as increased productivity during the release of the active cosmetics on human skin, increasing the effectiveness of the cosmetic effect on the surface of human epidermis, slowing the aging of human epidermis, increasing the efficiency and effectiveness of the cosmetic action of sunscreen achieved by the combination of functional properties in the cosmetic product (in addition to maintaining the quality of the skin, the cosmetic can change the colour itself in accordance with changes in indicators of the environment such as temperature), among other impacts.

In addition to the impacts on specific technological industries, impacts of greater magnitude were indirectly mentioned, such as unlimited solutions, technology integration, new procedures, creation of new materials and cutting the time required for product development.

Economic Impacts

For both industries, respondents foresee that nanotechnology will save the active ingredient per unit of output, enable faster development of new and efficient products, create jobs for highly qualified professionals (PhDs and researchers), increase competition between companies in different sectors, require higher levels of initial investment for R & D, permit the development of more productive processes, among other impacts.

Social and Environmental Impacts[2]

The reasons given by the interviewees for this were: ignorance of the matter, difficulty anticipating uncertain events (since at the time of the interviews, all the potential products were in the early or intermediate stages of development), and fear that an opinion might impede the path of some innovation strategies.

Unlike the experts, the company representatives do not have clear opinions about impacts on social and environmental dimensions. In general, the consideration of environmental and social concerns in the development of new technologies is relatively new in Brazilian companies, which means that they do not create adequate condition for further nanotechnological innovation.

Regarding this issue, the most plausible conclusion is that the initial investment in nanotechnology, as estimated by these companies, may be significantly increased by the ignoring/exclusion of the social and environmental impacts. Business decisions are increasingly influenced by other types of stakeholders (such as unions, NGOs, etc.) in technologically innovative projects, in addition to traditional stakeholders (employees, customers, suppliers and government). This tends to lead to a lack of a close quality control during the process of developing a new technology or product.

Discussion: Towards a New Regulatory Framework

The present study examined the technological, economic, environmental and social dimensions of nanotechnology. In order to perceive the different interlinked effects and relations, a three-fold study was conduced within different communities. Experts representing different social stakeholders, nanobiotech researchers and some businessmen were consulted in an attempt to shed light on uncertainty surrounding the possible impacts of nanotechnology.

It is our belief that the different insights indicate the possibilities that nanotechnology may provide. The experts seem to be more cautious regarding which impacts are positive and which are negative. Although the researchers are much more optimistic, it seems that their views are based much more on "wishful thinking" than on conviction. The researchers, being directly involved in new scientific and technological discovery, naturally stress the theoretical benefits of any upcoming technology. Finally, the businessmen are much more concerned with the short term rather than the long term results.[3]

However, they all seem to agree with some conclusions. Nanotechnology will certainly lead to the growth of new industrial sectors, requiring increased spending in R&D and new professional skills. Moreover, the new drugs, new treatments and new materials resulting from the nanotechnological revolution will change quality of life for mankind. New products seem to offer a whole new range of value perception and profitability.

Negative impacts were also commonly perceived, especially in terms of the impacts on human health and the growth in unemployment. These two drivers fall within the soci-

2) These impacts were included together in this section because none of the respondents identified any positive or negative social or environmental impacts arising from nanotechnology.

3) It is noteworthy that the type of field research influences the results. It is our belief that, an important limitation of this study was the use of different investigative methods for each community. And, thus, two limitations emerged: the researchers were too optimistic about the application of nanotechnology; and five company representatives is too small a sample to draw generalizations and consistent comparisons. However, even with these limitations, the results show that the impacts identified in the field study are in line with observations made in the literature in relation to nanotechnology.

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al dimension, since they affect public expenditure on maintaining health and social security systems.

Like any other new technology, it is absolutely necessary to have a regulatory framework that ensures the control of any possible harmful impacts. This new framework should consider the commitment of different stakeholders, and the use of and the results from nanotechnology R&D.

Considering the possible impacts listed for Nanotechnology, one can say that universities, in particular, as well as companies and technological centres demonstrate a "commitment" to the new emerging techno-economic paradigm.

There are some significant points that should guide the development of applications and products that relay on nanotechnology, such as: (a) the benefits of nanotechnology must outweigh the highlighted risks in order to reach a wide range of people, both in terms of its use and advantages; and (b) regulation should not overstate the severity of risk, in order not to inhibit investments in the R&D of nanotechnological applications, such as was seen in the case of stem-cell research debate.

A new mode of regulation must, above all, safeguard the rights of consumers and individual citizens. With nanotechnology it should not be different, so that appropriate methods of testing the reliability and safety of products in terms of their effects on human and environmental health need to be developed and introduced. Any product that incorporates nanotechnology should be identified as such and if the advantages, for example, reliability and safety, of such a product are already established they should have preference (e.g. government may subsidize their R&D and production) over products devoid of such technology.

Any regulatory framework should be built within the context of a debate involving all the stakeholders, informed by the technical opinion of scientists, where relations are based on mutual trust and communication is clear and open. All new products should be assessed, considering factors such as the potential risks, interactions with other particles or substances and toxicity, among others. The priority is to evaluate new materials, determine their risk levels and add basic information to establish the regulatory clauses.

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Appendix

Findings

Impacts	Totally disagree	Disagree	Agree	Totally agree
Valid percentage				
Technological Dimension				
Offers unlimited solutions to solve many of the society's problems.	15.5	20.7	51.7	12.1
Nurtures the technological integration in not imagined level before.	0	10.5	28.1	61.4
Allows the research to be opened to new knowledge frontiers.	0	0	10.5	89.5
Requires the creation of new laboratorial procedures for experiment's handling.	1.8	7.1	44.6	46.4
Path for the new raw materials creation for industry.	1.8	5.4	64.3	28.6
May reduce the development time of a new product.	1.8	22.8	56.1	19.3
Economic Dimension				
Will provide the appearance of new industries.	0	1.8	31.6	66.7
May increase the employment level in the economy.	0	20	60	20
Will require investment in professional training for future employees.	0	0	32.8	67.2
May cause the disappearance of industries that do not use the nanotechnology applications.	34.5	41.4	22.4	1.7
May increase the spending level on measures to prevent the problems caused by nanotechnology residue.	7.4	50	29.6	13
May provide lower cost raw material for industry.	3.6	32.7	45.5	18.2
Offers unlimited scale possibility of production of consumer goods.	18.2	43.6	30.9	7.3
Requires increased investment in research and development by enterprises.	0	1.7	31	67.2
May increase the population expenditures with health plans.	29.1	49.1	16.4	5.5
The treatment of nanotechnology waste will cost more than any other.	28.3	50.9	18.9	1.9
The nanotechnological products will be more expensive than other products.	14.8	53.7	27.8	3.7
Will be an exclusion factor for the low-income population.	35.2	48.1	13	3.7

Environmental Dimension				
Will assist in reducing pollution in general.	3.6	23.2	55.4	17.9
It is pollutant to humans and to the environment.	39.3	42.9	17.9	0
Will increase environmental awareness and researchers´ ethics.	21.4	39.3	32.1	7.1
Social Dimension				
May improve the population's life quality.	0	3.5	35.1	61.4
Nowadays, nanotechnology has a negative image to the population.	50.9	32.7	12.7	3.6
May extend human life.	0	18.2	50.9	30.9
May cause damage to human health.	21.8	54.5	23.6	0
Implications in the Regulation				
Laws and rules should prevent potential nanotechnology's negative impacts.	0	3.5	35.1	61.4
The specific regulation may restrain private investments in nano-technology.	50.9	32.7	12.7	3.6
The standardization of researcher's ethical conduct should be stricter with nanotechnology.	0	18.2	50.9	30.9
The standardization of laboratory procedures and researchers health care should be stricter with nanotechnology.	21.8	54.5	23.6	0
Impact on the actors				
Will negatively impact on the scientific community.	89.7	8.6	1.7	0
Will negatively impact on the industry and it's companies.	79.3	17.2	1.7	1.7
Will negatively impact on the population.	81	19	0	0
Will negatively impact on the consumers.	80.7	19.3	0	0
Will have more negative impacts on governments than positives.	80.4	19.6	0	0
Will negatively impact on non-governmental organizations	64.8	22.2	11.1	1.9