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The Impact of Nanotechnologies on Developing Countries

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Abstract:
This chapter provides a brief analysis of how emerging nanotechnologies could, for the better or worse, have an impact on developing countries. I start with clarifications of what developing countries and nanotechnologies are and provide a framework of possible impacts by considering the full life-cycle and socio-economic contexts of technologies. Then I use the framework for the analysis of a few selected issues: whether nanotechnologies meet specific needs of the poor; how they can impact the economies by changing material demands; and how their impact is affected by changing intellectual property rights.

Keywords:
nanotechnologies; developing countries; needs of the poor; materials economies; intellectual property rights.

1. Introduction

Thanks to two Canadian groups, there has been a lively debate since 2003 on the possible impacts of nanotechnology on the developing world. A group from the Joint Centre for Bioethics at the University of Toronto has, besides addressing various other ethical issues, pointed out the opportunities of nanotechnology for developing countries, both by developing products that meet their specific needs and by providing a chance for their own industrial development.[1] In contrast, the Action Group on Erosion, Technology and Concentration (ETC Group), a nongovernmental organization based in Winnipeg, has argued that nanotechnology will further increase the divide between rich and poor countries through political and socio-economical conditions that favor multinational corporations.[2] Several other authors joined the debate; for example, by assessing the actual R&D activities and potential of developing countries[3] and by clarifying the socio-economical context of specific needs.[4] Moreover, in 2005, the United Nations Industrial Development Organization (UNIDO) convened an international conference, UNESCO established an expert group, and the Washington based nongovernmental Meridian Institute started an initiative to bring international stakeholders together for an ongoing dialogue.[5]

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1 Mnyusiwalla A, Daar AS, Singer PA. Mind the Gap: Science and Ethics in Nanotechnology. Nanotechnology 2003;14:R9-13. Salamanca-Buentello F, Persad DL, Court EB, Martin DK, Daar AS, Singer PA. Nanotechnology and the developing world. PLoS Medicine 2005;2(5):100-103. Available at http://medicine.plosjournals.org/perlserv?request=get-document&doi=10.1371/journal.pmed.0020097. Court E, Daar AS, Martin E, Acharya T, Singer PA. 2004. Will Prince Charles et al diminish the opportunities of developing countries in nanotechnology? Available at http://www.nanotechweb.org/articles/society/3/1/1. All accessed 2006 Sep 9.

2 ETC-Group. 2003. The Big Down: Atomtech – Technologies Converging at the Nanoscale. Available at http://www.etcgroup.org/upload/publication/171/01/thebigdown.pdf. Accessed 2006 Sep 9, as well as many other reports available from http://www.etcgroup.org/en/issues/nanotechnology.html.

3 Maclurcan DC. Nanotechnology and Developing Countries, Part 1: What Possibilities? & Part 2: What Realities? AZoJono – Journal of Nantechnology Online 2005. Available at http://www.azonano.com/details.asp?ArticleID=1428 and http://www.azonano.com/Details.asp?ArticleID=1429. Accessed 2006 Sep 9.

4 Invernizzi N, Foladori G. Nanotechnology and the Developing World: Will Nanotechnology Overcome Poverty or Widen Disparities? Nanotechnology Law & Business 2005;2(3):101-10.

5 North-South dialogue on nanotechnology: challenges and opportunities, Trieste, Italy, 10-12 February 2005. Available at http://www.ics.trieste.it/ActivityDetails.aspx?activity_id=387. UNESCO activities on

Supplementing previous publications,[6] this paper adds to the debate by two main contributions. First, I put some efforts on conceptual clarifications and systematical analyses. In particular, after discussing the meaning of 'developing countries', I will point out the diversities of technologies that are nowadays called nanotechnology as well as the variety of possible impacts that these technologies can have on developing countries. That will span the scope for hundreds of case studies to be made and point to the problems of one-sided approaches. Second, I will use that framework for the analysis of a few selected issues that have previously not or, in my view, not carefully enough been addressed: whether nanotechnologies meet specific needs of the poor; how they can impact the economies by changing material demands; and how their impact is affected by changing intellectual property rights.

2. Clarifications

2.1 What are Developing Countries?

Both the term 'developing countries' and its meaning are contentious. Most countries, including the richest ones, are developing according to some indices, whereas some of the poorest countries are actually stagnating or losing ground. The methods for measuring the state of a country's development range from simple per capita gross domestic product (GDP) to complex indices which try to capture sustainable conditions of living, including political stability and equality among the population. For pragmatic reasons, I will use the term 'developing countries' for countries with a low or medium state of development according to the most widely accepted human development index (HDI) by the United Nations Development Programme (UNDP).[7] The HDI is a composite index that combines per capita GDP with life expectancy and educational standards. According to that index, the least developed countries are all in sub-Saharan Africa to be followed by South Asia, Arab States, East Asia, and Latin America.

Beyond these statistical and geographical features, most of the less developed countries share some characteristics. For instance, historically, they were former colonies and frequently still have some special ties (economical, political, or military) to their former colonial powers. Many happen to be rich of material resources for the long-term benefit of the colonial powers. Large parts of their populations suffer from very basic needs, like malnutrition and the lack of safe drinking water, sanitation, education, and health care, despite devastating epidemics like AIDS and malaria. Rural exodus has even increased these needs through exploding slums around big cities. They have only poor infrastructures of public and private research and development, including small public research budgets and virtually no venture capital. Even if they are currently developing such infrastructures--as in China--they have little experience in technology governance, including the launch and conduct of research programs, safety and environmental regulations, marketing and patenting strategies, and so on.

Nanotechnology and Ethics. Available at http://portal.unesco.org/shs/admin/ev.php?URL_ID=6314&URL_DO=DO_TOPIC&URL_SECTION=201. Meridian Institute. 2005. Nanotechnology and the Poor: Opportunities and Risks. Available at http://www.meridian-nano.org/gdnp/. All accessed 2006 Sep 9.

[6] Schummer J. Cultural Diversity in Nanotechnology Ethics. Interdisciplinary Science Reviews 2006a;31(3): forthcoming. Schummer J. Identifying Ethical Issues of Nanotechnologies Amidst the Nano Hype. In: ten Have H, editor. Nanotechnology: Science, Ethics and Policy Issues, Paris: UNESCO; 2006b, in print. Schummer J. Forschung für die Armen versus Forschung für die Reichen: Verteilungsgerechtigkeit als moralisches Kriterium zur Bewertung der angewandten Chemie. In: Sedmak C., editor. Option für die Armen: Die Entmarginalisierung des Armutsbegriffs in den Wissenschaften, Freiburg: Herder; 2005, p. 605-626.

[7] http://hdr.undp.org. Accessed 2006 Sep 9.

2.2 What are Nanotechnologies?

Among definitions of 'nanotechnology', three different approaches are currently in use and all are conspicuously vague.

The first approach, which philosophers call *nominal definition*, provides necessary and sufficient conditions that a technology must meet to be called a nanotechnology. Typical definitions require that the technology must investigate and manipulate material objects in the 1-100 nanometer range in order to explore novel properties and to develop new devices and functionalities that essentially depend on the 1-100 nanometer range. Unfortunately, such a definition covers all the classical natural science and engineering disciplines that investigate and manipulate material objects, such as chemistry, materials science, solid state physics, pharmacy, molecular biology, and chemical, mechanical, and electrical engineering. This is because almost any material is structured in the 1-100 nanometer range in such a way that its structure in this range determines their properties and (technologically speaking) their functionalities.[8]

The second approach, called *teleological definition*, defines nanotechnology by its future goals. In order to be specific, one needs to provide more than just generic values, like health, wealth, security, and so on, and more than just relative attributes, like smaller, faster, harder, cheaper. Since its first introduction by Eric Drexler (1986) teleological definitions of nanotechnology have come in the particular form of visions about a futuristic technology to be developed that will radically change everything, from industrial production to the somatic, mental, and social conditions of human life. According to this approach, current research belongs to nanotechnology if it is guided by the vision of the future nanotechnology which in turn will achieve the prospective goals. Apart from the questionable feasibility of the futuristic visions, it is impracticable to identify current research as belonging to nanotechnology by the visions that researchers publicly propagate.

The third definitional approach, called *real definition*, refers to a list of specific research topics. Such lists, which vary from country to country and over time, typically include scanning probe microscopy, nanoparticle research, nanostructured materials, polymers and composites, ultra-thin coating, heterogeneous catalysis, supramolecular chemistry, molecular electronics, molecular modeling, lithography for chip production, semiconductor research and quantum dots, quantum computing, MEMS, liquid crystals, LEDs, solar cells, fuel cells, biochemical sensors, targeted drug delivery, molecular biotechnology, genetic engineering, neurophysiology, tissue engineering, and so on. Unrelated as these topics are to each other apart from their common topicality, it is appropriate to speak of nanotechnologies (plural) rather than of one nanotechnology (singular), particularly because there is, in contrast to many claims and hopes, no particular interdisciplinary collaboration.[9]

In the following, I will refer to the real definition, despite its substantial shortcoming of liberally attaching the nano-label, because that is how scientists, science managers, business, and the media mostly use 'nanotechnology`' nowadays. From an ethical perspective, it is hard to identify any one possible issue that would equally apply to all these research fields. For discussing the impact on developing countries, I will therefore select only some specific fields as well as the general context in which they emerge. Before, however, I will provide a systematic survey of what the possible impacts can be, which might be used as a checklist for future scrutiny.

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8 Schummer J. Interdisciplinary Issues of Nanoscale Research. In: Baird D, Nordmann A, Schummer J, editors. Discovering the Nanoscale. Amsterdam: IOS Press; 2004, p. 9-20.

9 Schummer J. Multidisciplinarity, Interdisciplinarity, and Patterns of Research Collaboration in Nanoscience and Nanotechnology. Scientometrics 2004; 59:425-65.

2.3 What are Possible Impacts of Technologies on Developing Countries?

In order to analyze the impacts of nanotechnologies on developing countries, we need to consider the full life-cycle of technologies in their socio-economic contexts, from early R&D decisions and activities, to the manufacturing and use of products, to the dumping of waste, and the various roles that developing countries could play in each of these phases.

In the earliest state, when decisions about governmental R&D funding are made, negative impacts particularly result from wrong decisions that are misled, for instance, by unfounded hopes, hype, unclear concepts, or wrong information. While richer countries can afford the waste of research money to a certain degree, the effect of big and misguided projects on poorer countries with small research budgets can be disastrous, because their relative investments, for instance for new instrumentation, is much higher. It is particularly important, therefore, that they do not simply copy industrialized countries but instead focus their research efforts on well-defined projects tailored to specific needs rather than on such vague projects as nanotechnology overall. Informed science policy decisions would also be cautious about hype-words such as 'novel' and, instead, rely on careful patent researches that proof whether a research field is already claimed by patents or not. If such a new and promising field is identified and focused on, developing countries could benefit not only from meeting their specific needs but also from becoming leaders in a new technology.

In the actual R&D state, uncertainties remain, some of which require sensible decisions as to what directions of research and product development should be followed. Yet, since scientific research always explores the unknown, there are also uncertainties regarding the safety of researchers and their direct environment that can only be handled with caution. The lack of long-standing research experience in related fields and of strict safety regulations in many developing countries increase the risks of hazards there, for instance by unknown nanoparticle toxicities. Furthermore, if the product development includes test phases, people in developing countries could easily become the guinea pigs for risky technologies by other countries because of lower wages, poorer regulations of human experiments, and less public attention to hazards.

In the state of manufacturing and marketing technological products, countries can play different roles as producers, consumers, and as providers or buyers of materials, know-how, and waste processing. Each role can be beneficial or harmful for a country. For instance, if a country hosts the manufacturing of products, it may economically benefit from revenues and employment but also carry the risks of environmental pollution, uncertain worker safety, and hazards. The consumption of a product may meet the specific need of the population, but the necessary imports could lead to trade deficit and the dependence on manufacturing countries. The materials demands by a new technology can be economically beneficial to a country that mines these materials, but also harmful, if the new technology replaces former technologies for which the country had previously provided the materials. A country can benefit from selling certain know-how, unless it is the primary importer of the products manufactured somewhere else. Waste-processing has become an attractive global market, but if short-sightedly performed at low regulation standards and poor recycling rates, it goes at the expense of environmental resources and public health.

Whether a product is actually useful and its use beneficial to a country is difficult to assess in advance. Scientists frequently jump from mere inventions to overly optimistic conclusions, ignoring the prevailing socio-economic and cultural factors, such as: social acceptance, customs, and specific needs; moral, legal, economic, and political barriers; and social and environmental costs; as well as unexpected negative side-effects. Ultimately, the product's impact on the human development index (HDI) seems to be a useful measure. However, the HDI is difficult to estimate in advance and ignores important value aspects. A technological product can increase the inequality within a country and thus induce the perception of injustice by its mere use. For instance, an expensive health product benefits only the economical elite and increases the health divide between poor and rich. Or, if the beneficial use of a product requires advanced education, the product benefits only the educational elite. Furthermore, any technological product made for the improvement of life is based on and confers an idea of what a good life is. Since countries differ to some degree in their ideas of a good life, the wide use of imported technological products can impact the cultural value system.[10]

Finally, technologies can impact countries also from a global economical perspective. The US National Nanotechnology Initiatives and others have propagated that nanotechnologies will bring about the "next industrial revolution". If that is more than a thoughtless marketing slogan, then it should alert welfare economists to the opportunities and risks of industrial revolutions. For developing countries, it might be a signal to embark on nanotechnologies as soon as possible, as a unique opportunity to quickly catch-up with their economic development, achieving in a few years for what industrialized countries have needed centuries. However, such hopes rest on a simplistic understanding of the historical industrial revolution, according to which some technological innovations alone would have moved the economies of European countries in the 19th century. Many of today's historians of economy rather hold to the "dependency theory" according to which "one country's industrial revolution is another country's underdevelopment and these are two sides of the same coin of world capitalist development".[11] The dependency theory emphasizes other factors, such as international trade, property rights, economic infrastructure, human resources, and political power, that determine the relative developmental state of a country, which technological innovations can only reinforce. If nanotechnologies have a potential for an legitimate industrial revolution--which is doubtful because of their unclear identity--the dependency theory would predict that, all else equal, they would reinforce the divide between the rich and the poor.

Given the diversity of nanotechnologies and the many different factors through which they can impact developing countries, it is obvious that no simple answer can be provided. Indeed we need hundreds of case studies that integrate all the available scientific, engineering, economical, political, legal, sociological, cultural, and ethical knowledge, which requires true interdisciplinary cooperation. In the following, therefore, I will discuss only a few selected issues that assess some of the previous suggestions and point to problems that have thus far been neglected.

3. Addressing Specific Needs of Developing Countries

3.1 Water Purification

Safe drinking water is arguably one of the most important needs in many developing countries; at least 1.1 billion people lack access to safe water, and this results in several million deaths per year, mostly children in poor Asian and African countries.[12] Many authors have suggested that nanotechnology will provide the crucial remedy. To assess that promise, we need to have a closer look at the pollutants that are particularly important for unsafe water in non-industrialized areas, which are microbes that are usually from human sources due to insufficient sanitation and heavy metals dissolved from minerals.

Apart from some specific microbial diseases, like schistosomiasis, trachoma, and intestinal helminths, "approximately 4 billion cases of diarrhea each year cause 2.2 million

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[10] See Schummer 2006a (note 6) for some examples from nanotechnology.

[11] Hudson P. The Industrial Revolution. London: Arnold; 1992, p. 20. For a review of various theories, see Shrum W, Shenhav Y. Science and Technology in Less Developed Countries. In: Jasanoff S et al., editors. Handbook of Science and Technology Studies. Thousand Oaks: Sage; 1995, p. 627-51.

[12] WHO. 2005. Water, sanitation and hygiene links to health: Facts and figures. Available at http://www.who.int/entity/water_sanitation_health/factsfigures2005.pdf. UN Millennium Project. 2004. Interim Full Report of Task Force 7 on Water and Sanitation. p. 23. Available at http://www.unmillenniumproject.org/documents/tf7interim.pdf. All accessed 2006 Sep 9.

deaths",[13] which is by far the biggest problem owing to unsafe water. According to the WHO (2005), the death toll of diarrhoeal diseases could be prevented by better sanitation (32%) and hygiene education (up to 45%), and by improved water supply (6-25%) or water treatment (35-39%). It is difficult to see where nanotechnologies could help here other than by competing with established and simple but efficient water treatments, like chlorination,[14] that are still lacking in many areas. The main problems are not of technological nature, but a lack of basic infrastructure, facilities, and education.

It happened that many developing countries, by the help of development projects from rich countries since the 1970s, rather than providing better sanitation and hygiene education, focused on improved water supply by replacing surface water with underground water from wells. Unfortunately, in many regions (particularly in Bangladesh, Nepal, India, Taiwan, Thailand, Argentina, Chile, China, and Mexico), the switch to the allegedly safer underground water supplies has led to high concentrations of arsenic (and other heavy metals), which has become the number one poison in drinking water in rural areas.[15] Since arsenic, like other heavy metals, readily binds with iron hydroxide, a number of simple by highly efficient filters, tailored to the needs and possibilities of poor rural areas have been developed, ranging from Susan Murcott's sand plus iron nails to Arup SenGupta's granular alumina or polymeric beads covered with iron hydroxide.[16]

Against the background of the real problems and their existent efficient solutions, one needs to be careful with media reports announcing nanotechnology's solution to the drinking water problems of the developing world. There is no doubt that micro- and nanoporous filter development can lead to improved removal of microbes and other pollutants from water, and that desalination plants can open up new water sources. However, these filters and plants will hardly be affordable and manageable by the neediest in the foreseeable future. One should also note that filters based on zeolites and ceramics, which are nowadays subsumed under nanotechnology, have been produced since many decades,[17] without meeting the needs of developing countries. And the latest approach, the use of the extremely expensive carbon nanotubes in water filters, is a project by the US military that, rather than helping developing countries, should provide "water pure enough to use for medical purposes right on the battlefield".[18]

In sum, rather than having a significant positive or negative impact specifically on developing countries, nanotechnologies-based water purification has largely failed to address the specific needs and problems.

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13 UN Millennium Project 2004 (note 11), p. 23.

14 Another simple method is solar water disinfection, which exposes water filled in UV-transparent bottles for some hours to sunlight (see SODIS, www.sodis.ch. Accessed 2006 Sep 9).

15 The other important non-biological pollutant in drinking water is fluoride, leading to serious damages of teeth and bones (fluorosis) in many Asian and African countries (see http://www.who.int/water_sanitation_health/diseases/fluorosis/en/. Accessed 2006 Sep 9). If no other water source is available, flouride ions need to adsorbed by alumina or charcoal.

16 These filters are running already in several hundred villages. For the project websites, see http://web.mit.edu/watsan/worldbank_summary.htm and http://www.lehigh.edu/~aks0/arsenic.html; see also the Grainger Prize by the US National Academy of Engineering http://www.graingerchallenge.org. All accessed 2006 Sep 9.

17 Sherman JD. Synthetic zeolites and other microporous oxide molecular sieves. Proceedings of the National Academy of Science, USA 1999;96:3471-8.

18 Kelly M. Vermont's Seldon Labs wants to keep soldier's water pure. Small Times. 24 Apr 2004. Available at http://www.smalltimes.com/document_display.cfm?section_id=97&document_id=7764. Accessed 2006 Sep 9.

3.2 Solar Energy

About 2 billion people worldwide have no access to electricity, and most of them live in rural areas of developing countries.[19] Although access to electricity is not essential for living, it is a major development step that replaces inefficient energy forms, as for instance in lighting, and enables and facilitates important processes and infrastructures like refrigeration, communication, education, and health clinics.

Unlike the latest water purification nanotechnologies, solar energy technologies seem to be much more promising for developing countries, particularly for those in geographical areas with high solar radiation. Of the three main technologies, photovoltaic, solar collectors, and solar thermal power plants, only the first one has thus far been related to nanotechnologies, if one ignores the coatings of mirrors and other specialized materials. What makes photovoltaic (and solar collectors) particularly interesting for developing countries is their decentralized use in rural areas, i.e. they do not depend on central power plants and grids, and their sustainability. Therefore many international organizations have promoted solar rural electrification since the 1980s, such as UNESCO's annual summer schools on Solar Electricity for Rural Areas and the Solar Village Programme.

However, the use of photovoltaic in rural areas of poor countries means that the technology must meet requirements that essentially differ from, say, their use in Southern California. When solar cells are the first ever electricity supply in a village, people at first need to accustom themselves to electricity. Apart from considerable cultural barriers, people need to build up and learn how to use basic electric facilities, including cables, switches, fuses, transformers, and rechargeable batteries, in addition to the electric devices for which the whole setting is built up. Nanotechnologies cannot contribute to that. They can perhaps improve the efficiency and price of solar cells by a few percentage points, or make solar cells smaller, more flexible, and transportable, which are humble contributions to the real problems. As with water purification, the real challenges are very basic and largely of educational and cultural nature. However, technology can help develop integrated photovoltaic devices that are easy to handle, durable, and cheap. It is up to nanotechnologists to find out if they can assist here.

3.3 AIDS Prevention

AIDS/HIV is arguably the most devastating epidemic in the recorded history of humanity. In 2005, about 4.1 million people became newly infected with HIV and 2.8 million died from AIDS related diseases, with an estimated 40 million people living with HIV infection. It happened that the least developed countries, particularly in sub-Saharan Africa, are mostly affected by the epidemic; for instance, Swaziland has an adult HIV prevalence of as high as 33.4%.[20]

Against that background, a small Australian company has recently caught the attention of the nano-media, because one of its products, a dendrimer called SPL7013, might be used for a vaginal microbicide gel to prevent HIV-infection of women during sexual intercourse. Dendrimers are tree-like polymers that have been researched since the late 1970s. Because the nano-label was attached to dendrimers in the early 2000s, the nano-media could praise nanotechnology as a cure against AIDS.

The UNAIDS 2006 report claims that "[t]he steady growth of the AIDS epidemic stems not from the deficiencies of available prevention strategies but rather from the world's failure to use the highly effective tools at its disposal to slow the spread of HIV" (p. 124).

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[19] World Energy Council. The Challenge of Rural Energy Poverty in Developing Countries. London; 1999. Available at http://www.worldenergy.org/wec-geis/publications/reports/rural/download/download.asp. Accessed 2006 Sep 9.

[20] UNAIDS. 2006. Report on the global AIDS epidemic. p. 6ff. Available at http://www.unaids.org/en/HIV_data/2006GlobalReport/default.asp. Accessed 2006 Sep 9.

Since vaccines will likely be unavailable for many years, the primary prevention tools against sexual transmission are condoms and safer sex education. Yet, from Catholic Church policy to male preference of condom-free intercourse, many social factors have prevented effective implementation. Therefore, many experts indeed advocate the development of vaginal microbicides, because it gives women control over their own protection.

Vaginal microbicides (i.e., anti-viral agents against HIV to be inserted in the vagina shortly before sexual intercourse) have been developed since the early 1990s.[21] At least 33 agents with 10 different inhibitor mechanisms are currently under development, of which 5 have reached clinical phase III trials.[22] SPL7013 has recently entered only phase I, and because of the typically high production costs of dendrimers, it is unlikely that it could ever be affordable in poor countries. Indeed, it would have to compete with cheap microbicidial substances like soap (sodium lauryl sulphate, also called the 'invisible condom'), cellulose sulphate, and lemon juice (all currently in phases I to III), as well as with a bunch of other preventions methods specifically tailored to the needs and customs in poor countries.[23]

I do not want to diminish any R&D efforts on microbicide, because any possibility of AIDS prevention should be researched. However, the nano-label, which could equally be attached to soap or cellulose, seems to be reserved for high-tech research that is, for economical reasons, very unlikely to benefit the neediest.

4. Changing Materials Demands

The impact of nanotechnologies on materials demands seem to be less obvious because we tend to associate nanotechnology with small things. On an industrial world market scale, however, small things easily sum up to hundreds or thousands of metric tons of materials per year that cost millions to billions of dollars. Since raw material resources that need to be mined, particularly metals, happened to be mostly in developing countries, any change of materials demand on the world market mostly affects the economies of these countries. Western countries have a long history in researching substitutes for expensive, natural, or foreign materials resources. For instance, synthetic dyes substituted for natural dyes from Asia in the late 19th century, synthetic ammonia substituted for natural niter from Chile in the early 20th century, and plastics have substituted for wood, natural rubber, and metals since the mid-20th century. All these substitution processes had drastic effects on local and national economies. Many of the research topics provided in the real definition of nanotechnology follow this long-term trend.[24]

4.1 Catalysis

Most of the catalysts used in oil refinement, chemical industry processes, and automobile air pollution abatement are based on precious metals that are largely mined in developing countries. For instance, rhenium, which is used in petroleum reforming, has a world market of about $47 million and comes mainly from Chile[25] (44%), Kazakhstan (19%) and Peru (12%). The most widely used catalysts for pollution abatement and chemical processes are based on

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21 Weber J, Desai K, Darbyshire J. The development of vaginal microbicides for the prevention of HIV transmission. PloS Medicine 2005;2(5):e142. Available at http://medicine.plosjournals.org/perlserv?request=get-document&doi=10.1371/journal.pmed.0020142. Accessed 2006 Sep 9.

22 Lederman MM, Offord RE, Hartley O. Microbicides and other topical strategies to prevent vaginal transmission of HIV. Nature Reviews Immunology 2006;6(May):371-82.

23 Short RV. New ways of preventing HIV infection: thinking simply, simply thinking. Philosophical Transaction of the Royal Society B 2006;361(1469):811-20.

24 The following data are from U.S. Department of the Interior & U.S. Geological Survey. Mineral Commodity Summaries 2006. Washington (DC); 2006.

25 According to the HDI, Chile is ranked among the countries with high human development, which has largely been owing to its rich material resources.

platinum and palladium, with world markets of $6.2 billion and $1.3 billion, respectively.[26] Both metals are mainly mined in South Africa (78% / 38%) and Russia (12% / 44%). The platinum production alone corresponds to about 2.5% of South Africa's GDP. One of the declared short-term goals of nanotechnology by science policy-makers is the production of "improved catalysts with one or more orders of magnitude less precious metals",[27] which would dramatically affect the economy of the supplying countries. On the other hand, platinum and palladium are also the most promising catalysts for hydrogen fuel cells, such that the negative effects of one nanotechnology could be compensated by another.

4.2 Electronics

The impact of the materials demand by the electronics industry is more complex. There are ambitious goals, following-up the long term substitution policy by industrialized countries, to replace semiconducting and metallic elements with carbon based materials. For instance, organic semiconductors, including carbon nanotubes, are researched as possible substitutes for semiconductor elements, like gallium, germanium, indium, cadmium, selenium, arsenic, and antimony, for many of which China is the main supplier. In addition, carbon nanotubes, because of their extraordinary electric and thermic properties, are expected to substitute for high-conductive metals in electronics, like copper, silver, and gold. Although the amount of these three metals used in electronics is relatively low compared to other uses (with a combined market of more than $100 billion), technological breakthroughs could affect their market prices and thus the economies, for instance, of Chile (36% of copper world production), Peru (15% of silver), and South Africa (12% of gold). A similar effect is expected from the ongoing shift in electronic signal transmission from cables to glass fibers and wireless connections.

Research and development of optoelectronic devices (e.g. LEDs, laser diodes, LCDs, photodetectors) and solar cells employ various semiconducting elements other than silicon, but it is difficult to see a general trend that would impact specifically developing countries. However, if quantum-dots (i.e. materials with semiconducting properties varying by particle size rather than by elemental composition) become more advanced, they would make the industry more independent from specific semiconducting elements. The "hottest" element in optoelectronics is indium, the price of which has risen by a factor of ten since 2002. The extraordinary combination of light transparency and electric conductivity makes nano-layers of indium-tin-oxide (ITO) an ideal choice for most optoelectronic devices, which sum up to several hundred metric tons of indium per year and a world market of $370 million. China has quickly responded to the new demand and almost tripled its indium mining production since 2002, with a global share in 2005 of 55%. But again, the magic carbon nanotubes have been promised to be future substitutes for ITO.

Countries that have benefited from recent materials demands in electronics, but are challenged by new nanotechnological developments, include:

- Chile, which produces 39% of the global lithium for recharchable batteries, is challenged by the transportable fuel cells; and
- Many African countries, including Mozambique, Congo, Rwanda, Ethiopia, Nigeria, Namibia, Burundi, Uganda, Uganda, and Zimbabwe, which together produce about a third of the global tantalum for capacitors, are challenged by ceramics capacitors.

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[26] See also ETC-Group. 2005a. The Potential Impacts of Nano-scale Technologies on Commodity Markets: The Implications for Commodity Dependent Developing Countries. Available at http://www.etcgroup.org/upload/publication/45/01/southcentre.commodities.pdf. Accessed 2006 Sep 9.

[27] President's Council of Advisors on Science and Technology. The National Nanotechnology Initiative at Five Years: Assessment and Recommendations of the National Nanotechnology Advisory Panel. Washington (DC), May 2005. p. 22.

4.3 Materials

With more than a billion metric tons per year, steel is the most important industrial material and will certainly remain so for several decades. Yet, there are many different types of steel for specific purposes, depending on the alloying elements other than iron which are frequently mined in developing countries. Typical alloying elements, including their 2005 world markets and mining productions by developing countries, are:[28]

- nickel ($22 billion; Indonesia, 9%; Cuba, 5%; Columbia, 5%; China, 5%; Dominican Republic, 3%; Botswana, 2.5%);
- molybdenum ($11.7 billion; Chile, 28%; China, 17%, Peru, 6%);
- manganese (ca $5 billion; South Africa, 22%; Gabon, 13%; Brazil, 13%);
- vanadium ($2.4 billion; South Africa, 42%; China, 34%);
- chromium ($2.0 billion; South Africa, 44%; Kazakhstan, 18%; India, 17%);
- cobalt ($1.8 billion; Congo, 31%; Zambia, 17%; Cuba, 7%); and
- niobium ($490 million; Brazil, 88%).

The market prices of these metals strongly fluctuate, depending on national stockpile policies, world politics, and economy. However, apart from short-term trends, materials research could have a long term impact on the demand for metals that are used for specialized high-end steels and other alloys. Particularly the blossoming fields of (nanostructured) ceramics, composites, and aluminum alloys aim to develop substitutes, the prices of which depend less on raw materials, and thus less on imports from developing countries, but on the value added by domestic manufacturing.

The chemical element that seems to be mostly challenged by nanotechnological advances is tungsten, 90% of which is mined in China with a global market of $1.35 billion in 2005. Since many decades, its major uses have been the production of ultra-hard materials (tungsten carbide and nitride) and filaments and electrodes in lighting applications, for both of which nanostructured ceramics have emerged as competing materials. In addition, LEDs (and perhaps filaments out of carbon nanotubes) are likely to conquer the lighting industry, leading to further reduced demands of tungsten.

Apart from becoming less dependent on raw materials, industrialized countries have pushed materials research towards more sophisticated manufacturing that produces the desired material properties through nanostructuring, nanocomposites, coating technologies, etc. The value of the resulting materials thus depends less on the value of the raw materials and more on the added value by the manufacturing. In a global economy, that devalues the raw materials mined in and exported by developing countries, who, in order to be competitive in other areas, need to import the manufactured materials at much higher prices. In the 20th-century, many developing countries exported cheap ores, unrefined metals, crude oil, etc. and imported expensive refined metals, alloys, petroleum, plastics, and so on, leading to increasing trade-deficits and astronomic debts. Now that many developing countries can manage these older refinement industries that are no longer protected by patents, the recent boost in materials engineering is likely to renew the post-colonial pattern on another industrial level of more sophisticated materials engineering.

5. Changing Intellectual Property Rights

Although that issue is not specific to nanotechnologies, these technologies are emerging when intellectual property rights (IPRs) and practices have been changed in Western countries and

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[28] Other elements mined in developing countries and used for specialized steels include bismuth, tellurium, tungsten, tantalum, titanium, boron, but their main uses are frequently in other applications and for some the exact data are withhold.

worldwide with negative side effects on developing countries. Three trends are particularly important in that regard.[29]

5.1 Changing IPR Criteria in Developed Countries

The subject matter eligible for IPR protection has incrementally changed since the early 1980s, particularly in the US and, more recently, in Europe.[30] Since 1980, genetically modified organisms and DNA sequences are patent-eligible in the US. Apart from ethical concerns about the patentability of living organisms, the move started an erosion of two previously upheld patent criteria. First, it undermined the distinction between material objects (here, the actual DNA molecules) and mere information (here, the DNA sequence codes) that might be used for further R&D in, say, bioinformatics.[31] Second, with the introduction of automatic DNA-sequencers, the production of patentable knowledge became routine work, which the original "non-obvious" clause had excluded to keep "obvious" know-how in the public domain. In the early 1980s, also software, which was previously treated like mathematical and scientific truths, became patent-eligible, thereby further eroding the two mentioned patent criteria. Moreover, since the late 1990s also databases, including DNA sequence databases, are covered by IPR protection.[32] These legal changes, along with liberalizations in the actual patent granting practice, have moved types of knowledge that were formerly public domain into the realm of proprietary knowledge and commodities. Is far from clear whether that move has been beneficial, or even an incentive, for industrial research overall; and it is rather questionable if it has a net positive impact on national or global welfare.

5.2 Changing IPR Practice at Universities

The changes in patent legislation had an indirect impact also on publicly funded research. Starting with the Bayh-Dole Act of 1980 in the US and more recently in some European countries, new regulations require that university employees must report their inventions of possible commercial value to their university administration in so-called "disclosure reports" prior to possible publication. The administration then decides on whether patents are filed in order to earn revenues from licenses. Based on these "disclosure reports", the number of patent filings in the US raised from 600 in 1991 to 17,000 in 2004, which increased the annual license revenues of universities from $200 million to $1.4 billion in that period.[33] While the policy has improved the income of universities and, evidently, the exclusive knowledge transfer to small local companies and start-ups, it is likely that it has directed publicly funded research to the needs of local business rather than to the specific needs of developing countries. Even if such needs are addressed, researchers can no longer decide themselves on the use of their results, and publications are much delayed through the patent filings. Most importantly, however, the policy has once more moved types of knowledge that were formerly public domain into the realm of proprietary knowledge and commodities.

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29 See also ETC-Group. 2005b. Nanotech's 'Second Nature' Patents: Implications for the Global South. Available at http://www.etcgroup.org/documents/Com8788SpecialPNanoMar-Jun05ENG.pdf. Accessed 2006 Sep 9.

30 Sampat, BN. Recent Changes in Patent Policy and the 'Privatization' of Knowledge: Causes, Consequences, and Implications for Developing Countries. In: Knowledge Flows, Innovation, and Learning in Developing Countries. Washington (DC): Center for Science, Policy, and Outcomes; 2003. p. 39-81.

31 Eisenberg R. How Can You Patent Genes. American Journal of Bioethics 2002;2:3-11.

32 David PA. A Tragedy of the Public Knowledge 'Commons'? Global Science, Intellectual Property and the Digital Technology Boomerang. Oxford Intellectual Property Research Centre. Working paper. 2000. Available at http://www.oiprc.ox.ac.uk/EJWP0400.pdf. Accessed 2006 Sep 9.

33 Association of University Technology Managers. AUTM Licensing Survey: FY 2004. Northbrook (IL); 2006; p. 18, 26

5.3 Extension of IPRs to Developing Countries

Since 2000, the World Trade Organization (WTO) requires that all existing and aspiring member countries sign the Trade Related Intellectual Property Rights agreement (TRIPs), which, in essence, extends the intellectual property rights of developed countries (including much of the recent changes) to developing countries as a measure to prevent "product piracy". Since the early debates about that agreement, which was initiated by the US government, welfare economists have shown that such an extension benefits research-innovative, industrialized countries only, though not always, while having a negative effect on both the welfare of less developed countries and the global welfare.[34] Historically, agreements such as TRIPs were less important as long as the know-how gap between rich and poor countries was big enough so that developing countries could neither imitate the products of developed countries nor compete with own innovations. For quickly developing countries, the impact of TRIPs depends on their imitation/innovation ratio, while for the least developed countries with little innovation but some imitation potential the impact on welfare is clearly negative.[35]

Apart from their specific negative impacts on developing countries discussed above, all three trends move knowledge from the public to the private domain. Therefore, increasing amounts of know-how, which would formerly have been available for free for further innovation and product development, is either unavailable, if exclusive licenses were granted, or must be purchased. While R&D in all countries is affected by these changes, developing countries suffer most, for four reasons. First, located in the periphery of R&D networks, their chance to obtain exclusive licenses first, say from a US university, is very low. Second, global companies have long entered the so-called "knowledge economy", by creating huge patent portfolios for the sale and exchange of licenses and by creating knowledge monopolies and cross-licensing networks in which emerging industries in developing countries can hardly participate. Third, while identifying and purchasing the necessary licenses is difficult and costly for any industry, emerging industries in developing countries are particularly handicapped because they frequently have not the same informational and financial resources. Forth, the increasing costs of patent filings and litigations required for new product developments pose a growing barrier to any R&D effort in poor countries.

In sum, the recent changes in IPRs have brought considerable disadvantages for developing countries, such that the divide between poor and rich countries is likely to increase. Ironically, the more nanotechnologies produce commercial goods of broader interests, the more will they contribute to widening the gap.

6. Conclusion

The selected issues discussed in this paper allow drawing mostly pessimistic conclusions on the impact of nanotechnology on developing countries. However, as outlined in Section 2, the overall situation is much more complex because of the diversities of both nanotechnologies and their possible impacts. Thus, I finally wish to balance the pessimistic conclusions by some more optimistic outlooks.

If developing countries are threatened by declining demands of their natural resources, they could initiate (collaborative) projects that are tailored to increase these demands by new useful products.

If existing nanotechnologies are less able to address the specific needs of developing countries, that is because the specific socio-economical contexts have been ignored in framing

[34] E.g., Deardorff AV. Welfare Effects of Global Patent Protection. Economica 1992;59:35-51. Helpman E. Innovation, Imitation, and Intellectual Property Rights. Econometrica 1993;61:1247-80.

[35] Liebig K. Die internationale Regulierung geistiger Eigentumsrechte und ihr Einfluss auf den Wissenserwerb in Entwicklungsländern. PhD Dissertation, University of Göttingen; 2005.

the problems to which the technologies should be the solution. Smarter engineers would consider these contexts from the very beginning and develop their products accordingly, without caring about the arbitrary nano-label.

If changing IPRs hinder emerging industries in developing countries to imitate products for their local market and to develop new products for the global market, they could focus their innovation potential on products tailored to their local needs. After all, consumer saturation in rich countries has redirected many multinational companies towards the markets of developing countries. However, unlike local industries, they lack exactly the knowledge of the specific socio-economical conditions, which is substantial to product development.

Finally, if nanotechnologies should increase the divide and thus contribute to further inequity, poor countries might more massively insist on their rights guaranteed by numerous international conventions, from the *UN Millennium Goals* to the *UNESCO Universal Declaration on Bioethics and Human Rights* (2005), of which Article 15 states:[36]

> "Benefits resulting from any scientific research and its applications should be shared with society as a whole and within the international community, in particular with developing countries."

[36] Available at http://portal.unesco.org/en/ev.php-URL_ID=31058&URL_DO=DO_TOPIC&URL_SECTION=201.html. Accessed 2006 Sep 9.