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Nanotechnology and Developing Countries - Part 1: What Possibilities

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Topics Covered

Abstract

In recent times, nanotechnology has been included in a number of the debates considering emerging technology and developing countries. However, the literature considering nanotechnology's application to the developing world has often varied in its interpretation of what nanotechnology really is. Furthermore, despite a wide range of perspectives as to the relevance, appropriateness and potential impact of nanotechnology for developing countries, the key debates have often remained disengaged. This paper attempts to clarify understandings of nanotechnology and synthesize discussions on issues of relevance, appropriateness and distribution with respect to developing countries. In support, recent developments in nanotechnology and healthcare are provided.

Background

In recent times, a number of research groups have stimulated debate on nanotechnology's possible applications and implications for developing countries [see, for example, 1, 2, 3]. However, many of the subsequent papers have failed to distinguish theoretical- from currently feasible-nanotechnology [see, for example, 3, 4, 5]. In international debates, distinction between the near-term, possible reality and theoretical science is crucial to the efficient exchange of information.

Furthermore, amongst those considering developing country engagement with nanotechnology, a range of perspectives are held concerning 'appropriateness' and nanotechnology's likely impact on the developing world. Some individuals challenge a pervasive acceptance of nanotechnology, expressing concern about developing country exploitation [Shiva cited in 6], insubstantial consideration for issues of risk and regulation [7], the loss of traditional markets [8] and an identification of nanotechnology applications that fails to consider historical trends and current barriers to technology distribution [9]. Others adopt a more utilitarian approach, linking nanotechnology applications in water, energy, health, food and agriculture to the fulfilment of the United Nation's (U.N.) Millennium Development Goals[a] [4, 10], despite earlier recognition of its potential to stimulate a greater divide between the 'haves' and 'have-nots' [1].

Despite surprising levels of nanotechnology research and development (R&D) in the developing world [1], arguments concerning nanotechnology's role as a protagonist or antagonist to sustainable development[b] remain disengaged.

In this paper we seek to clarify understandings of nanotechnology and synthesize discussions on issues of relevance, appropriateness and equity with respect to developing countries. With infectious and parasitic disease remaining the greatest cause of death in the developing world [12] and nanotechnology predicted to affect half of the world's drug production by 2011 [13], examples relevant to health are commonly cited.

What is Nanotechnology and How is it New?

For citizens in the developed world already exposed to the term 'nanotechnology', associated impressions may be that it deals with 'very small things', concerns 'submarine robots in the bloodstream' and brings with it the threat of 'grey goo'[c]. The latter, more popular ideations, essentially stem from K. Eric Drexler's proposal that atoms and molecules could act as self-assembling machinery, performing production tasks at the nanoscale[d] [15].

However, what is now universally accepted as 'nanotechnology', yet sometimes less noted, is an area evolving somewhat independently of Drexler's visions. Following challenges from the general scientific community, on the basis of technological feasibility, Drexler renamed his understanding and aspirations for nanotechnology: 'molecular manufacturing'. Thus, in the 21st Century, the term 'nanotechnology', whilst similar to molecular manufacturing in that it involves work on the level of atoms and molecules, refers to an applied science, focussed upon exploiting novelties arising from size-dependent phenomena exhibited in nanoscale matter. When dealing with matter below approximately 50 nanometres, the laws of quantum physics supersede those of traditional physics, resulting in "...changes to a substance's conductivity, elasticity, reactivity, strength, colour, and tolerance to temperature and pressure" [16]. Such changes are useful to all industrial sectors where nanotechnology will enable smaller, faster, 'smarter', cheaper, lighter, safer, cleaner and more precise solutions [17-19]. For example, in the field of drug delivery, Peppas notes that nanoscale pH-sensitive hydrogels for treating patients with multiple sclerosis, "release at varying rates depending on the pH of the surrounding environment", suggesting that "...these nanoparticle carriers may protect drugs from being broken down in the body until they reach the small intestine" [20]. Furthermore, progressing from the micro- to nano-scale involves inherent increases in a material's surface area and surface-to-volume ratio that can be used to manufacturing advantage.

Ancient Origins of Nanotechnology

Yet, utilising science at the nanoscale is not new. For example, in the 4th Century A.D., the Romans applied gold and silver nanoparticles to colour glass cups [21]. The resulting artefacts were red in transmitted light and green in reflected light - a sophistication not reproduced again until medieval times. There are many scientists today who would argue they have been conducting research in the realms of the nanoscale since well before 1990.

Reasons Why Nanotechnology has only Come to the Fore in Recent Times

So how come more and more people are talking about nanotechnology as the 'next big thing' if it has 'existed' for such a long time? There are three main reasons. Firstly, only in the past few decades have we really had the experimental means to conduct work focussed on activity at the nanoscale. Emerging tools, including scanning probe microscopy, quantum mechanical computer simulation and soft X-ray lithography, have combined with new synthesis methods, such as chemical vapour deposition, leading to a significantly greater, ever accelerating understanding of scientific endeavour at the nanoscale. These progressions have been paralleled by the discovery of materials such as fullerenes and nanotubes and, in more recent years, stimulated by a flood of government nanotechnology funding in countries such as the U.S., China and Japan.

Secondly, nanotechnology has, as its underlying aim, the desire to manufacture with ultimate precision on the atomic scale in a 'bottom-up' manner. This means that, rather than the traditional approach to manufacturing whereby bulk materials are whittled down, nanotechnology aims to produce devices commencing with the self-assembly of individual atoms into precise configurations, as has been the case with combinational chemistry for many years. Whilst a great deal of nanotechnology continues to utilise 'top-down' processes such as lithography, the gradual trend is towards 'bottom-up' approaches that hold numerous, long-term manufacturing, financial and environmental advantages.

Thirdly, and arguably most importantly, the recognition of nanotechnology as an emerging field demands and creates new levels of multi-disciplinary collaboration and cross-fertilisation amongst the sciences. Practically, this happens because of the integrated exploitation of biological principles, physical laws and chemical properties at the nanoscale [22]. The increasing desire and need to classify technology resulting from nanoscale manipulation and the progressive integration of scientific disciplines at a unifying length-scale, has led to the accepted term 'nanotechnology', under which new research is growing and existing research is often re-classified. Whilst nanotechnology is projected by the U.S. National Science Foundation (NSF) to have a global market value of $1 trillion[e] by 2011 [23], early signs in the information and communications technology (ICT) and textile industries are that nanotechnology is more complementary, than displacing.

According to a UNESCO-sponsored study in 1996, "nanotechnology will provide the foundation of all technologies in the new century" [24]. However, basket-casing nanotechnology as 'another biotechnology' runs the risk of disregarding novel implications (both advantageous and detrimental). For those involved in the development of nanotechnology policy, one of the greatest challenges will be the efficient use of time; distinguishing and dealing with novel ethical, legal and social implications whilst ensuring appropriate contextualisation.

Relevant, Appropriate Applications for Developing Country Healthcare?

Given the 'capital intensive, high-tech, science fiction' branding it has received from much of the developed world media, nanotechnology would appear highly incongruous with sustainable development practices. In response to a recent study that ranked nanotechnology applications, from social development cluster areas[f], according to their potential benefit for developing countries [10], Invernizzi and Foladori, cite the ability of China and Vietnam to significantly reduce malaria in the last century without the use of emerging technologies [9].

Furthermore, Brown notes that, "within development circles there is a suspicion of technology boosters as too often people promoting expensive, inappropriate fixes that take no account of development realities" [26]. Others believe the promotion and debate about nanotechnology in countries such as India, China and Brazil, threatens to divert and detract resources, political will and attention from the needs of the poor [27] and could inhibit research necessary to "address society's problems in a systemic manner" [Mulvaney cited in 6]. In addition to nanotechnology possibly promoting a 'technical fix' approach [28], there is a concern that high entry prices for new procedures and skills are "very likely to exacerbate existing divisions between rich and poor" [Healy, cited in, 28].

Dispelling Misconceptions about Nanotechnology

Yet much of the early commentary from research groups and developing countries engaging in nanotechnology discussions has been united in the identification of relevant applications in areas such as solar cell technology, water purification; and health-related diagnostics and therapeutics [1, 4, 29-32]. At an international policy level there has been a push from individuals, such as the U.N. Under-Secretary for Economic Affairs, to include nanotechnology in discussions concerning emerging technology and sustainable development [33]. Representatives from the U.N. Conference on Trade and Development and Commission on Science and Technology for Development have suggested that nanotechnology can help "reduce the cost and increase the likelihood of attaining the Millennium Development Goals" [34]. Individuals with the National Science Foundation of Sri Lanka believe that, whilst nanotechnology research and development is 'high-tech', the products it enables, can be appropriate for use throughout the world [30]. Harper suggests it is this misconception, that nanotechnology is "all about high technology, semiconductors and science fiction", that is creating a major barrier to nanotechnology being viewed as appropriate to the development setting [35].

Potential Benefits of Nanotechnology to Developing Countries

In a recent study that ranked nanotechnology applications according to their potential benefit for developing countries, water treatment, disease diagnosis/screening and drug delivery systems respectively rated 3rd, 4th and 5th, behind energy storage, production, and conversion (1st) and agricultural productivity enhancement (2nd) [10]. Salvarezza believes nanotechnology offers an area such as developing country healthcare, "safer drug delivery, new methods for prevention, diagnosis and treatment of diseases" [36]. In rural areas, Harper argues that pulmonary or epidermal drug delivery applications utilising nanotechnology, "have the potential to free up the large numbers of trained medical personnel who are currently engaged in administering drugs via hypodermic needles" [35]. Furthermore, Barker comments that slow-release drugs, important for those in remote areas, could be assisted by nano-porous membranes [4]. In a joint project between groups in the U.S., India and Mexico, inexpensive, maintenance free solar panels, aimed at powering rural clinics and refrigerating medicines, are currently being developed [37]. Could nanotechnology empower local healthcare auxiliaries, in rural settings worldwide, to address diagnostic and therapeutic concerns by reducing reliance on trained specialists or technical assistance? Or does such as suggestion sound similar to the many promises of past technological revolutions that were challenged by the realities of global development and domestic technology distribution?

Diagnosis and Treatment of Tuberculosis using Nanotechnology

Many believe nanotechnology offers new ways to address residual scientific concerns for Mycobacterium tuberculosis (TB). Declared a global emergency by the World Health Organisation (WHO) in 1993, the re-emerging threat of TB continues to be technically compounded by significant increases in the prevalence of multi-drug resistance (MDR), in a number of settings [38]. Treatments with improved sustained release profiles and bioavailability can increase compliance through reduced drug requirements and therein minimise MDR-TB [39]. Additionally, improved diagnostic tools are required to meet the needs of the WHO's expansion of the Directly Observed Treatment Short-course, MDR and co-infection with HIV [40].

In India, the country with the highest estimated number of TB cases [41], research is underway into the role nanotechnology can play in addressing such concerns. A nanotechnology-based TB diagnostic kit, designed by the Central Scientific Instruments Organisation of India and currently in the clinical trials phase, does not require skilled technicians for use [42] and offers efficiency, portability, user-friendliness and availability for as little as 30 rupees [43] (less than US$1). In the Medical Sciences division of the U.S. Department of Energy, researchers are investigating an optical biosensor for rapid TB detection [44]. Furthermore, a group at RMIT University, in Australia, is conducting research into the application of novel tethered nanoparticles as low-cost, colour based assays for TB diagnosis [45].

Polylactide co-glycolide nanoparticles are being investigated by groups at Harvard University (U.S.), the Postgraduate Institute of Medical Education and Research (India) and the Council for Scientific and Industrial Research (South Africa), as drug carriers for treating TB [46-48]. So far, all groups have registered high levels of drug encapsulation efficiency, whilst both the Indian and South African groups have demonstrated sustained release profiles. Furthermore, the Indian group have reported increased bioavailability and "undetectable bacterial counts in the lungs and spleens of Mycobacterium tuberculosis-infected mice" 21 days post-inoculation [49]. The South

African group claim that a prototype of their work should be ready for commercialisation by 2007/8 [39]. Furthermore, a nanotechnology-based vaccine adjuvant for TB was developed by the U.S firm, Biosante, in 2002 [50].

Nanotechnology Research into Prevention of Other Infectious Diseases such as HIV/AIDS

TB is just one example of current nanotechnology research relevant to infectious diseases most prevalent in the developing world. Inter alia, science ministers from South Africa, Brazil and India have been working together on identifying ways in which nanotechnology can assist HIV/AIDS [3]. An Australian company, Starpharma™, is developing a preventative, clear, HIV microbicide gel, based on dendrimer nanotechnology, that would remain effective when applied by women up to four hours in advance of sexual intercourse [51]. Also in Australia, the Austin Research Institute has conducted successful trials into nano-vaccines for malaria [52]. Researchers at the State University of Campinas, Brazil, are investigating drug and vaccine delivery for leishmaniasis [53]. At the Chidicon Medical Center in Nigeria, researchers are studying nanoscale copolymer assemblies for diagnostic imaging and therapeutic management of infectious diseases [54]. Furthermore, in a joint project between the Rensselaer Polytechnic Institute (U.S.) and Banaras Hindu University (India), scientists are investigating easy-to-manufacture, carbon nanotube filters that remove nano-scale germs, such as the polio viruses, E. coli and Staphylococcus aureus bacteria, from water [55].

Long Term Effects of Nanoparticles

Whilst Barker comments that "any helpful technologies should be brought into service..." for developing countries [4], others caution about the unknown risks associated with nanoparticle accumulation, toxicology and permeation [2]. As a report to the European parliament noted, "the state of research concerning [sic]... The behaviour of nano-particles is actually rather limited, preliminary as well as contradictory" [56]. Whilst the comprehensive 2004 report by the Royal Society and Royal Academy of Engineering (U.K.) recommends that "factories and research laboratories treat manufactured nanoparticles and nanotubes as if they were hazardous waste streams" [28], many traditional Chinese medicines are now known to have contained metal nanoparticles [57]. Hoet et al. argue that "...producers of nanomaterials have a duty to provide relevant toxicity test results for any new material, according to prevailing international guidelines on risk assessment" [58], leaving others disturbed that the cosmetic industry has refused to release test data into the public domain[g], despite claiming that products such as sunscreen lotions are safe [59].

Furthermore, early suggestions from the U.S. and U.K., that nanotechnology is inherently regulated [56], have encountered stiff opposition from the action group on erosion, technology and concentration (ETC group), and others, who believe nanotechnology enters a 'regulatory vacuum' and that some new properties of nanoparticles are not covered by existing chemical regulations [2, 60].

Risk versus Benefits of Nanotechnology and its Effect on Applications

However, in light of the debate surrounding Genetically Modified foods, Court et al. argue that an exclusive focus from the developed world upon issues of risk threatens to divert attention from identifying and applying nanotechnology to the developing world [1]. An engagement with 'risk' and the consideration of nanotechnology's application to the developing world need not be mutually exclusive. In fact, although technological 'risk' affects countries in different ways depending on the nature of their engagement with change, it remains a universal consideration and a crucial factor in ensuring the appropriateness of new technology, to any setting.

Although in-depth discussions about health risks and the contribution of developing country perspectives are beyond the scope of this paper, it is clear that a number of issues remain unresolved and require greater consideration that incorporates truly global perspectives.

The Potential Nature of Developing Country Engagement with Nanotechnology

The nature of nanotechnology's global impact will largely depend on the answers to five, key questions surrounding nanotechnology innovation: who? what? when? where? and why? Developing countries will experience differing forms of engagement with nanotechnology but can we comment on any overall impacts? Will nanotechnology, as Daar suggests, be "a profitable industry for countries in the South[h]" [61]? Or will it "exploit the South" [Shiva cited in 6] and threaten developing country markets in primary production areas such as cotton, rubber and minerals [8]?

Will developing countries play the role of the 'manufacturing-base' for nanotechnology innovation, as suggested by Whittingham and Bateman's 2003 'cost-benefit analysis of moving nanotechnology R&D and manufacturing to Eastern European and developing countries' [62]? Already, Malaysia and South Africa have been highlighted as countries with comparative advantage in manufacturing for nanotechnology [32, 63].

Which Countries will Manufacture and which Will become Nanotechnology Importers

Perhaps the nature of developing country engagement with nanotechnology is believed as largely given? Salvarezza argues that an identification of Northern-based nanotechnology applications for the developing world predisposes participants to a scenario where "developing countries appear as passive actors... turning them into NT [nanotechnology] importers", widening economic and technological dependence [36].

Yet others point to the effective development of biotechnology R&D in China, India, Brazil and Cuba, suggesting an early developing country engagement with nanotechnology innovation could reduce the possibility of these countries being net importers of the technology [25, 64]. Given that domestic innovation and technological advance have been identified as the most important mechanism for the ability of countries to improve economically and ultimately close the rich-poor divide [65], nanotechnology has been promoted by a recent UNESCO report as important to developing country innovation [3].

Developing Countries Active in Nanotechnology Development

With this in mind, a 2003 report by the University of Toronto Joint Centre for Bioethics claimed a number of developing countries are exhibiting a "surprising amount of nanotechnology activity" [1]. The study noted that China, India and South Korea had established national activities in nanotechnology; Thailand, The Philippines, South Africa, Brazil and Chile had some form of government support and national funding programs were being developed; whilst Mexico and Argentina had some form of organised nanotechnology activity but no specific government funding [1]. Some see nanotechnology enabling developing countries "to 'leap frog' their way to leadership" [66], with the Indian government looking to use nanotechnology to 'catch up' in global economic terms [67, 68].

Patent Applications as an Indicator of Nanotechnology Activity

However, with patents known to be a useful indicator of "technology development" [69], an assessment of 2003 figures from the U.S. Patent and Trademark Office (USPTO) highlighted the commanding lead held by the U.S. in nanoscale science and engineering patenting, with 42% of the overall share. Germany followed with 15.3%, and Japan was placed 3rd, with 12.6% [69]. Fast growth was said to be occurring in South Korea, the Netherlands, Ireland and China. A report later that year claimed China was ranked 3rd in general nanotechnology patents behind the U.S. and Japan [70].

Furthermore, of all the U.S. patent applications in nanotechnology, 90% are held by the private sector, with the remainder split amongst the public sector (roughly 7% from universities and 3% from government agencies and collaborative research centres) [71]. In recent times, companies such as '3M', 'IBM' and 'Hewlett Packard' are allocating approximately one-third of their respective R&D budgets to nanotechnology [72]. Canadian-based nanotechnology start-up, 'C Sixty Inc', has, as its core assets, numerous patents concerning fullerenes and drug delivery. As their CEO stated, "if people want to get in this game they have to deal with us" [Sagman, cited in 73]. These figures and comments raise the concern that innovation will be tied up by the private sector of the North, with broad-sweeping patents limiting the development of new technologies and increasing global science's ties to market demands [24].

A further example of market pressures was witnessed with the 2004 'Nanowater' conference, held in North America. Following the claim by researchers at Oklahoma State University in the U.S. that they could utilise the ability of zinc oxide nanoparticles to remove arsenic from water [74], preliminary conference material presented Bangladesh as an example in which nanotechnology could address the very serious problem of arsenic levels and potable water. Furthermore, the conference aimed "to focus the attention of the nanotechnology community on the potential of technology to change the world for good" [75]. However, the conference did not involve any developing country in its proceedings, and developing country issues were not directly addressed[i].

Already, civil society organisations from South Africa, Ghana, Kenya, Zimbabwe, Mali, Tanzania, Ethiopia and Benin have signed the 'Cape Town Declaration', calling for global participation in decisions about nanotechnology [76], highlighting fear that certain groups will be poorly represented in relevant discussions. The issue of participation is not limited to country participation. For nanotechnology to make a significant contribution to sustainable development within developing countries, a much greater interplay amongst business, academic, donor, non-governmental and governmental sectors is required [4].

Conclusions

Scientific developments and increasing international attention have promoted our ability to work with and understand the nanoscale. Nanotechnology provides a new focus for research through its aim to manufacture from the 'bottom-up' rather than from the 'top down'. It also demands an unprecedented collaborative and integrated approach to science and technology.

In the interest of dialogue, it is important that papers concerning nanotechnology and developing countries distinguish the kind of nanotechnology being discussed.

Like many past technologies, nanotechnology could be both relevant and appropriate to sustainable development practices in developing countries. In an area such as tuberculosis and rural health, nanotechnology has the potential to empower a local response to challenges such as the diagnosis and treatment of infectious disease. However, there is also a danger in viewing nanotechnology as a 'solution' to developing country challenges. In some cases its application may undermine alternative, more appropriate approaches to dealing with the problems at hand. Throughout nanotechnology's ongoing evaluation process, both risk assessment and the global contextualisation of nanotechnology's promises must be recognised as universal requirements in order for debates to progress on mutual ground.

However, with relatively little research commenting on global nanotechnology developments, the true picture, with respect to developing country engagement, remains unclear. A subsequent paper, published in this journal, will seek to clarify: which countries are engaging with nanotechnology R&D; the general focus of such research; who controls research in an area such as healthcare; the orientation of health-related research; and the levels of participation in international nanotechnology policy dialogue.

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[a] 8 goals set by all U.N. Member States pertaining to: eradication of extreme poverty and hunger; achievement of universal primary education; promotion of gender equity and empowerment of women; reduction in child mortality; improvement of maternal health; combating of HIV/AIDS, Malaria and other diseases; ensuring of environmental sustainability; and development of a global partnership for development, by 2015 (see http://www.un.org/millenniumgoals/ for greater detail).
[b] Most commonly defined as being, "development that meets the needs of the present without compromising the ability of future generations to meet their own needs" [11].
[c] The hypothetical, end-of-the-world scenario in which self-replicating, omnivorous nanoscale robots create global ecophagy.
[d] 1-100 nanometres [14], with 1 nanometre equal to 1 billionth of a metre.

[e] All monetary figures in this paper refer to U.S. dollars.

[f] According to the South African Nanotechnology Initiative, nanotechnology sectors can be classified into 'industrial' and 'social development', with the latter incorporating: energy; water; and health. 'The environment' crosses both sectors [25].

[g] Considering their well-known toxicological studies on nanoparticles within fish, Dupont is a notable exception.

[h] In this paper, the term: 'South' or 'Southern' is used to refer to developing countries, whilst the term: 'North' or 'Northern' is used to refer to developed countries.

[i] See www.nanowater.com for a full list of speakers and conference agenda.

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Nanotechnology and Developing Countries - Part 2: What Realities?

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Topics Covered

Abstract

Drawing on search-engine data gained from combining the term 'nano*' with the title of every economy recognised by the World Bank, the research to be described here highlights a widespread developing country engagement with nanotechnology research and development. Subsequent investigation reveals that the orientation of developing country engagement is distant from nanotechnology's 'social development' applications, often cited as most applicable to developing countries. The ability of less-developed countries to engage with nanotechnology R&D is explored along with current mechanisms to facilitate partnerships and access to information. The additional analysis of health-related patents confirms that the 'nano-divide' is already here. With China constituting the bulk of patents from the South, the divide is not just between the developed and developing world, it extends to within the developing world. An assessment of participation in international nanotechnology policy and dialogue highlights low levels of developing country representation, supporting the overall argument that nanotechnology may be set to follow the path of past technologies in creating a greater global technological divide.

Background

Discussions concerning the potential implications of nanotechnology for developing countries have tended to be polarised. Whilst many see nanotechnology providing developing countries with an opportunity to promote sustainable development [1-5], others view the emerging area as an opportunity for increased exploitation of the developing world and concentration of power among corporate elites [6, Shiva, cited in, 7]. In a previous paper, we highlighted the need for discussions to show cognisance of historical trends and current barriers to technology distribution.

In 2003, Court et al. categorised 10 developing countries as either 'front-runners', 'middle-ground' or 'up-and-comers' with respect to nanotechnology activity [4]. Whilst their study highlighted a surprising level of developing country research and development (R&D) in nanotechnology, it fell short of assessing nanotechnology engagement amongst all developing countries. Early analyses of patent distribution have shown ownership concentration among a select group of countries, led strongly by the United States (U.S.), Germany and Japan [8] and strong private sector influence in patenting within the U.S. [9] but have limited their assessments to U.S. Patent and Trademark Office (USPTO) data. Whilst a number of researchers have made a point of highlighting the poor levels of participation by developing countries in international nanotechnology developments [4, 5, 10], there remains a need for some tangible assessment.

In this paper we present a synopsis of global engagement with respect to nanotechnology R&D, explore the orientation of developing country engagement, consider challenges to the creation of national nanotechnology capabilities for less-developed countries, analyse health-related nanotechnology patent activity and assess country participation in nanotechnology policy dialogue.

Assessing Global Engagement with Nanotechnology

Using the 'Google' and 'Yahoo' search-engines we individually combined the term 'nano*' with the title of every economy recognised by the World Bank in 2004[a], aiming to provide an encompassing picture of nanotechnology activity, as of October 2004. We extended our search parameters to include countries demonstrating either an interest, current research, national activities or national funding in nanotechnology (as outlined in Figure 1). Countries registering activity were then categorised by the 2003 Organisation for Economic Development (OECD) and 2004 United Nations Development Program Human Development Index (HDI) classifications[b], to assess the distribution of engagement across recognised global groupings. Our classification did not distinguish the strength or research directions of each commitment.

Table 1. Categorisation of national nanotechnology activity

Category	Requirements To Fulfil The Category
National Activities or Funding	Either: A national strategy for nanotechnology;

	Nationally co-ordinated nanotechnology activities; Government funding for nanotechnology research
Individual or Group Research Project	At least one individual or group currently conducting work identified as 'nanotechnology research'
Country Interest	An expression of interest from country governments, representatives or delegates

With patent data used in previous studies as a key indicator of country strength in nanotechnology R&D [11, 12] and the life sciences as one of the major fields of nanotechnology patenting [8], we decided to focus the second stage of our research upon health-related nanotechnology patent activity[c]. To do so we assessed data from 1975[d] – 2004, registered with the widely encompassing, European Patent Office (EPO) database[e].

Note:

a. Available at: http://www.worldbank.org/data/aboutdata/errata03/class.pdf, (for the purposes of this paper, the term 'countries' includes 'territories' recognised by the World Bank).

b. In this paper countries are classified by the January 2003, OECD 'DAC List of Aid Recipients', available at: http://www.oecd.org/dataoecd/35/9/2488552.pdf. HDI data was not available for Serbia and Montenegro, Taiwan, Afghanistan, Puerto Rico and Liechtenstein.

c. Considering that Rader notes comparability among U.S. and foreign success rates for obtaining patents from patent applications in biotechnology [13], we used both patent applications and assigned patents for our research in 'patent activity' and regularly interchanged the terms 'patent activity' and 'patents'.

d. 1975 is used as the commencement date for the research as it was the year following that in which the word 'nanotechnology' was coined [14].

e. The *Espacenet* database can be accessed at: http://ep.espacenet.com and incorporates published data from over 70 different countries.

Analysis of Data

Employing a 'basic analysis' and only registering distinct patents, we used the European Classification system (ECLA) to distinguish health-related areas on which to base our search for patents including the term 'nano*'[f]. Noting some limitations of the ECLA[g], we conducted a supplementary 'title-search'[h], combining the ten most common health-related terms identified in the ECLA search with the term 'nano*'. This produced a further list of a 197 health-related terms, gained from the patent titles, that were run through an identical process to that of the initial search (see Table 2 for examples of searched classifications and terms).

Table 2. Classifications and terms used for health-related nanotechnology patent search

ECLA Classifications	Resultant Terms	Examples of Subsequent Terms
Medical or veterinary science; hygiene; Foodstuffs; Water purification; Antibacterial paints	health*; medic*; disease*; diagnos*; detect*; drug*; delivery; therap* cosmetic*; treat*	antibacterial; antiseptic; prescription; bone; prophylaxis; pharmaceutical; genetic; vaccine; targeted; vitamin; skin

Note:

f. Based upon the data of Huang et al., 92.5% of the nanotechnology patents registered with the USPTO office between 1976-2003 included the term 'nano*' [8].

g. For example, many Chinese Patents without an abstract could not be included in the ECLA but could be identified as health-related, via their title. Furthermore, it takes up to 8 months before 90% of ECLA data is confirmed [15] yet our study of 1975-2004 data concluded in May 2005.

h. Known to give an adequate indication of patents without needing to conduct a full text search [8].

Collating of Data

The collated data was divided, based on the nationality of the patent holder(s), to give an idea of the national distribution of patents. The countries were then placed into developmental, continental and sectoral groupings to enable a broader assessment of patent distribution. Data was compared with Compañó and Hullman's 2002 EPO and Patent Cooperation Treaty nanotechnology patent analysis [12].

Considering the claim that pharmaceutical giants are investing less money and people in nanotechnology than other industries [16], we felt it important to gauge the engagement from big pharmaceutical companies in health-related nanotechnology patenting. Hence, we recorded a list of the top 20 institutions patenting in this area. Due to implications of multiple holders for individually owned patents, private individuals were not included in the presented data.

In 2003, White noted that bio-nanotechnology patenting was occurring in three main areas: cosmetics and consumer health; instrumentation, focussed on general diagnostic processes; and drug delivery [17]. We therefore chose to include data on the strength of patenting within these three areas of utility.

Furthermore, with relatively little research directed towards some of the health problems affecting the majority of the world's population, we chose to analyse every title and abstract for references to diseases in order to assess one aspect of early orientation within health-related nanotechnology research. Viruses and general conditions were deemed too broad to be included in this analysis.

Excluded Data

The patent research was made difficult by factors such as one Chinese national holding over 500 health-related nanotechnology patents "by simply turning traditional plants into fine powders with particles under 100 nanometres… and claiming a new invention" [18]. Such results were excluded.

Limitations of the Study

Both the first and second stages of our research suffered from the limitation that classifying research as 'nanotechnology' has only been a recent phenomenon. Much work that occurs on the nanoscale is not referred to as 'nanotechnology' and therefore may not have been registered by our research methods. In stark contrast, it is possible that a number of individuals and companies incorrectly use the term 'nano' in the title of their work, perhaps hoping to gain from the hype surrounding nanotechnology.

The final stage of the research assessed country participation at two, key, recent international nanotechnology meetings. These were the *International Dialogue on Responsible Research and Development of Nanotechnology*[i] held in 2004, which was the first intergovernmental dialogue of its kind, and the *North–South*[j] *Dialogue on Nanotechnology: Challenges and Opportunities*[k] held in 2005, which was the first United Nations-sponsored meeting held to specifically address developing country participation in nanotechnology science and policy. As with earlier stages, categorisation occurred on a country level and used the 2003 OECD classifications. As the discussion will suggest, participation in the development of global nanotechnology policy and strategies extends well beyond representation at international conferences and meetings. Furthermore, the data limited participant assessment to one's nationality, leaving issues such as gender equity as important areas for future research.

Note:

i. The meeting report may be found at: http://www.nanoandthepoor.org Final_Report_Responsible_Nanotech_RD_040812.pdf.

j. In this paper, the term: 'South' or 'Southern' is used to refer to developing countries, whilst the term:

'North' or 'Northern' is used to refer to developed countries.

k. See http://www.ics.trieste.it/Nanotechnology/ for more details.

Global Nanotechnology Activity and Interest

In 2001 the U.S. NSF claimed that at least 30 countries had initiated, or were beginning, national nanotechnology activities [19]. This figure progressed to, "more than 40", by 2004 [8]. According to our research, this number has grown to 62 countries, 18 of them 'transitional' and 19 'developing', engaging with nanotechnology on a national level. A further 16 countries demonstrate either individual or group research in nanotechnology, 3 of which are 'transitional' and 12 'developing' (including 1 Least Developed Country (LDC)). Fourteen countries have expressed interest in engaging in nanotechnology research. Of these countries, 1 is 'transitional' and 13 'developing', including 3 LDCs (for a full, country breakdown see Table 3).

Table 3. Global distribution of nanotechnology activity by country and classification.

Least Developed	Other: Developing	Transitional	Developed
National Activity or Funding			
	Argentina; Armenia; Brazil; Chile; China; Cost Rica; Egypt; Georgia; India; Iran; Mexico; Malaysia; Philippines; Serbia & Montenegro; South Africa, Thailand, Turkey; Uruguay; Vietnam	Belarus; Bulgaria; Cyprus; Czech Republic; Estonia; Hong Kong; Hungary; Israel; Latvia; Lithuania; Poland, Romania; Russian Federation; Singapore; Slovak Republic; Slovenia; South Korea; Ukraine	Australia; Austria; Belgium; Canada; Denmark; Finland; France; Germany; Greece; Iceland; Ireland; Italy; Japan; Luxembourg; Netherlands; New Zealand; Norway; Portugal; Puerto Rico; Spain; Sweden; Switzerland; Taiwan; United Kingdom; United States of America
Individual or Group Research			
Bangladesh	Botswana; Columbia; Croatia; Cuba; Indonesia; Jordan; Kazakhstan; Moldova; Pakistan; Uzbekistan; Venezuela	Macau, (China); Malta; United Arab Emirates	Liechtenstein
Country Interest			
Afghanistan; Senegal; Tanzania	Albania; Bosnia and Herzegovina; Ecuador; Ghana; Kenya; Lebanon; Macedonia; Sri Lanka; Swaziland; Zimbabwe	Brunei Darussalam	

The most prominent figure is the number of countries engaging in nanotechnology on a national level at such an early stage of global development. Although every developed country, excluding Liechtenstein, is included in this category, the large number of developing countries is of note.

Countries Actively Involved in Nanotechnology

In China, nationally run activities in nanotechnology have existed since 1990 [20, 21] and the country "appears to be leading the world in sheer numbers of new nanotechnology companies" [22]. Brazil has approximately 300 Ph.D.-level researchers working in nanotechnology [23], whilst in India more than 30 institutions are involved in research and training programs in nanotechnology [24]. Vietnam commenced nanotechnology research in 1992 [25] and the Ministry of Science and Technology has launched a nanoscience and nanotechnology infrastructure building program from 2004-2006 [26]. In 2004, 117 participants came from all over Thailand to contribute to the development of a national nanotechnology roadmap [27]. In 2003, Maruping reported that South Africa had approximately 12 universities, 4 science councils and several companies active in nanotechnology R&D [Maruping, cited in 5]. In 2003, at least 6 groups were working on nanotechnology in the Philippines [28]. Whilst Malaysia has 6 existing research centres engaging in nanotechnology research [29].

Lesser Known Nanotechnology Players Encouraging Development

In 2004, Egypt, Bangladesh and Moldova were among some of the lesser known nanotechnology 'players' to host international nanotechnology conferences[l], perhaps as a precursor to a greater involvement in nanotechnology R&D. The International Conference on Nanotechnology: Science and Application, held in Egypt the following year, was pitched at developing country involvement and exposing young researchers from the developing world to leading researchers in the field[m].

Note:

l. See: www.nanotech-now.com/2004-events.htm for a list of nanotechnology conferences held in 2004 and their locations.

m. See: http://www.nanoinsight.net/ for conference details.

The Global Nanotechnology Race

Could nanotechnology promote a more equitable engagement with global science? In 1999, before the establishment of the National Nanotechnology Initiative in the U.S., Roco wrote that "the situation is unlike the other post-war technological revolutions, where the U.S. enjoyed earlier advances". A recent report by the U.S. President's Council of Advisors on Science and Technology has shown that the U.S. leads the world in the number of nanotechnology start-up companies and research output but "…is under increasing competitive pressure from other nations…" [30]. Furthermore, Haworth believes that "no one country or region of the world has a monopoly on the cutting-edge research capabilities necessary to advance materials science and nanotechnology" [Haworth cited in 31 preface]. Watanbe claims that the widespread interest is resulting in countries "…competing on a more equal basis for a slice of the action" [32].

However, Runge and Ryan note that, despite developing countries making up more than half of the 63 countries engaged in biotechnology R&D, innovation remains heavily concentrated amongst the top 5 countries, with a significant gap to the '2nd tier' [33]. Whilst global government spending on nanotechnology is relatively evenly split between North America ($1.6 billion), Asia ($1.6 billion) and Europe ($1.3 billion)[n] [30], funding among nations varies greatly. For example, whilst both the U.S. and Thailand have national nanotechnology programs, established in 2000 and 2003, respectively, Thailand's program receives approximately $2 million[o] per year [34] compared with 2005 annual funding for the U.S. National Nanotechnology Initiative (NNI), set at $982 million [35].

Furthermore, widespread national engagement with new technology does not necessarily translate to an automatic 'trickle-down effect' of associated benefits. As Chrispeels notes, with the 'Green Revolution'[p], "many governments (national or local) did not do enough to ensure an even spread of the benefits among the different types of farmers and the different socio-economic groups" [36].

Note:

n. The Lux Research data included U.S. State funding in the total for North America and incorporated figures from associated and acceding EU countries in the European estimate. The remaining governments, not covered above, contributed $133 million.

o. All monetary figures in this paper refer to U.S. dollars.

p. A movement commencing in the 1940s that focused on increasing crop yields via the application of new plant varieties and modern agricultural techniques.

Some Countries to Concentrate Nanotechnology Efforts on Materials Research

Whilst most of the international commentary on the relevance of nanotechnology to developing countries has focussed on applications to assist sustainable development in social development cluster areas[q], Chinese, South Korean, Malaysian and Thai governments will reportedly focus 2003-2007 nanotechnology funding on materials research [22]. In Thailand the initial focus has been on applying nanotechnology to 'value-add' to existing export industries and develop: waterproof, more durable silks; 'smart packaging' to monitor and maintain the state of food; more productive wine fermentation; 'self-sterilising' rubber gloves; and new car body materials [34]. With this in mind, Barker et al. suggest that "most government investments are aimed at improving national corporate competitiveness in nanotechnology" [5]. Roco believes some governments are focussing efforts towards nanotechnology because they have recognised lost opportunities at the dawn of earlier technologies such as the Human Genome Project, ICT and biotechnology [19].

Note:

q. According to the South African Nanotechnology Initiative, nanotechnology sectors can be classified into 'industrial' and 'social development', with the latter incorporating: energy; water; and health. 'The environment' crosses both sectors [37].

National Activity by Human Development Index

An assessment of national activity by HDI groupings (Figure 1) shows that the strength of developing country engagement with nanotechnology comes from countries with a medium HDI rank. China, India and Brazil lead developing country investment in nanotechnology [Rao, cited in 38], ahead of many developing countries with a higher HDI rank.

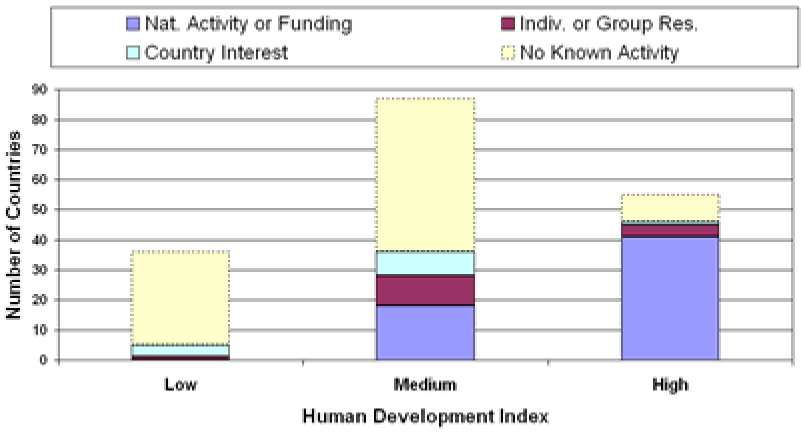

Figure 1. Global distribution of nanotechnology activity based on countries' human development groupings.

So what about the less-developed countries? It is clear that countries in the lowest bracket of either the OECD classifications or HDI rankings, have not engaged with nanotechnology on any significant level. Will this revolution promote a bigger South-South divide, whereby certain developing countries use nanotechnology to propel themselves into global trade and investment markets whilst others are left behind?

Is Nanotechnology R&D Feasible For Less-Developed Countries?

Whilst factors such as support from private enterprise will play a significant role in determining the level of nanotechnology engagement in a countries such as India or Thailand [27, 39], for many of the less-developed countries, the current barriers will present themselves at the earliest stages of R&D entry.

Challenges for Nanotechnology in Developing Countries

The correlation between lower average incomes and lower government spending on R&D [40] and healthcare [41], presents an initial challenge for nanotechnology to even be considered in less-developed countries. Infrastructure; human and policy capacity; cost; intellectual property rights; education relating to academics and the public; brain drain; trade barriers and the political context, constitute further barriers, although these are not unique to nanotechnology [42].

The Cost of Setting Up Nanotechnology Institutes

Differing figures have been provided as to the financial and infrastructure demands of nanotechnology innovation. The cost of establishing nanotechnology institutes has been claimed at approximately $5 million in both Vietnam [43] and Mexico [Rao, cited in 38], whereas the new national nanotechnology facility in Costa Rica, including a ‘clean room’, was reportedly built for “about $50,000”, and will be equipped for an extra several hundred-thousand dollars [44]. Rao claims an Atomic Force Microscope, a fundamental tool for characterisation at the nanoscale, costs approximately $1.5 million [Rao, cited in 45], whereas the ETC Group puts this figure at $175,000 [42]. Salvarezza believes that the ability for nanotechnology research to be conducted with relatively inexpensive items such as computers and scanning probe microscopes means that it “becomes an attractive field for research and development in third world countries because it can be done with modest resources and relatively low funding” [46]. Furthermore, Welland challenges the contemporary belief that drug research has to be capital intensive, claiming that pocket-sized, drug factories “could theoretically end the control of large companies over manufacturing” [Welland cited in 47]. On the other hand, Waga believe that as scientists work with matter on a smaller scale approaching the nanoscale, more sophisticated and expensive equipment is required [48].

As with most emerging technology, one cannot generalise about nanotechnology innovation being ‘expensive’ or ‘inexpensive’. Rather, nanotechnology innovation encompasses a wide spectrum of R&D activity, from less sophisticated powders all the way through to highly complex quantum computers. Existing resources, niche areas for development and program aims will all play a role in any countries’ national assessment prior to engaging with nanotechnology R&D.

Facilitated Partnerships and Access to Information

Partnerships between countries are crucial for successful developing country engagement with nanotechnology. The U.S. NSF suggests that there is scope for ‘win-win’ in the pre-competitive stages of international nanotechnology R&D [31], although this acknowledges, in part, that the situation becomes ‘zero-sum’ when the research moves to the commercialisation stage. The NSF also sees ground for leveraging investments and educating young investigators [31] and that “research groups in different countries and regions can bring complementary expertise to solve common problems for the ultimate benefit of society as a whole” [Haworth in 31 preface]. In 2002, the NSF had already developed partnerships with India and the Asia Pacific Economic Cooperation group [31] and, since then, has been integral in the development of national nanotechnology initiatives in Vietnam and Costa Rica [44, 48].

European Commission Partnerships

Similarly, the European Commission (EC), believing “a wider critical mass is beneficial” [49], has encouraged widespread participation in nanotechnology. In promoting their Sixth Framework Programme, the EC highlighted the possibility of funding for developing country nanotechnology projects [49]. Simultaneously, the EC negotiated bilateral nanotechnology partnerships with Argentina, India, Chile, China, Russia and South Africa [50].

Asia Pacific Partnerships

Regional partnerships in the Asia Pacific are meeting with some success for developing countries. The Asia Nano Forum involves 13 countries including China, India, Hong Kong, Singapore, Thailand, South Korea, Indonesia, Malaysia and Vietnam. Similarly, the APNF offers opportunities for Asian countries to engage in dialogue on collaboration and has already held international nanotechnology meetings on issues as widespread as human resources development and environmental protection and pollution.

Partnerships for Countries in the Bottom Third of the HDI Rankings

Apart from South Africa and India, we have found no evidence to suggest any official R&D partnerships including countries in the bottom third of the HDI rankings. Yet, with nanotechnology research underway in Pakistan, Bangladesh and Botswana and expressions of interest from Kenya, Senegal, Swaziland, Ghana, Tanzania and Afghanistan concerning an engagement with nanotechnology, the opportunity exists for nanotechnology partnerships to promote emerging science in some of the less-developed countries. In Africa, where nanotechnology research "has been largely academic and disparate" [51], regional partnerships and pooling of resources, both virtual and physical, may offer geographical and cultural advantages over trans-continental partnerships and present the operative strategy for African engagement in nanotechnology R&D.

In 2003 the World Bank provided $1/4 million for a 'nano science and technology observatory' as part of the Brazilian Millennium Institute in nanotechnology [52]. However, noting the inappropriateness of a 'developed world model' for nanotechnology innovation in developing countries [39, 53], caution must be taken to ensure nanotechnology is not viewed as a means by which developing countries are to replicate the development path of the industrialised nations. Such understanding was demonstrated at the UNIDO-sponsored, '2004 Technology Fair of the Future'. This event incorporated nanotechnology and "allowed least developed countries to present their technology needs, to identify mechanisms to match needs and trends and to determine their potential role in global value chains" [54].

Barriers to Global Partnerships

One barrier to global partnership is that clear information concerning national nanotechnology activity and global resources, remains unavailable or beyond the access capability of many. Reports outlining international activity in nanotechnology, such as the 'Lux Report', currently cost in excess of $4500[r]. The Global Nanotechnology Network, formed out of the 2001 'Workshop on International Collaboration and Networking', seeks to address this situation by facilitating information exchange, collaborations and access to critical resources in the field of nanotechnology [55].

Note:

r. See: https://www.globalsalespartners.com/lux/order.asp?retrysecure=1 for cost details.

Scientific Publishing

With scientific journals becoming increasingly unaffordable for developing countries [56], examples such as the online *AzoNano Journal of Nanotechnology* offer a unique and important step towards open-access information in cutting-edge science, technology and policy, via financial incentives for authors and reviewers. The associated website[s] provides a free database for many issues and research papers related to nanotechnology. Another site, managed by SciDev.net[t], offers efficient, free access to nanotechnology updates compiled by some of its 300 researchers posted around the world. This group has agreements with some of the most prestigious journals, such as *Science*, allowing them to post articles on their site, free of charge.

Electronic education offers one avenue to bridge the gap between differing academic expertise internationally [57], particularly those that have a growing ICT infrastructure and reasonably inexpensive bandwidth costs. In 2004, Dr Joe Shapter from Flinders University, in Australia, conducted an Internet link-up between Australia and New Zealand, hosting an online, real-time nanotechnology demonstration involving the use of atomic force microscopy. This opens the way for an interactive, online method of international training for teachers in countries lacking such expertise [58].

Note:

s. www.azonano.com.

t. www.scidev.net

Health-Related Nanotechnology Patent Activity

Our assessment of health-related nanotechnology patents registered 1256 distinct results, showing that 35 countries have a share in the global distribution (as shown in Figure 2). The three leading countries are the U.S. (32.8%), China (20.3%) and Germany (12.9%), with the top 7 countries holding 88% of the overall patent share. Compañó and Hullman's study of general nanotechnology patents from 1991-99 shows a similar concentration among the top 7 country holders (92.1%) [12]. However, unlike their study where the only transitional or developing countries ranking in the top 15 holders were Israel and Russia [12], our research showed that in health-related nanotechnology, patent participation extends to the transitional countries of South Korea (3.9%), Israel (0.9%), Russia (0.5%), Taiwan (0.3%), the British Virgin Islands (0.2%), Hong Kong (0.2%), Hungary (0.2%), Poland (0.2%), Singapore (0.2%), Bermuda (0.1%) and Slovenia (0.1%). Furthermore, developing country patent holders include China (20.3%), India (0.5%), Brazil (0.1%), and Serbia and Montenegro (0.1%).

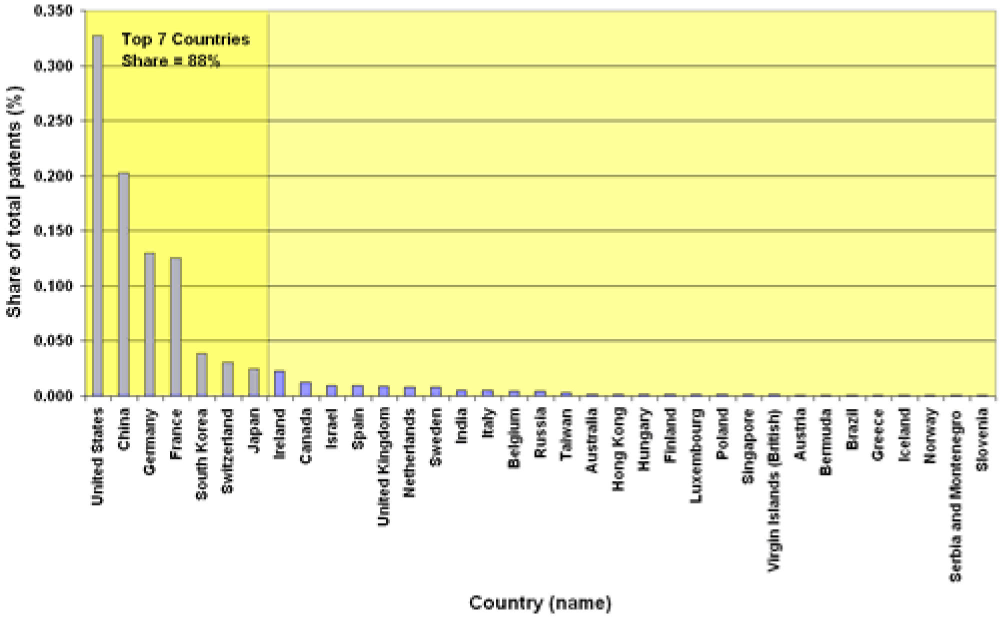

Figure 2. Distribution of health-related nanotechnology patent activity (1975-2004), by country.

World Leaders in Nanotechnology Research

Whilst commentators have suggested that the U.S. "does not dominate nanotechnology research" [31] or "…have a commanding lead as it was for other S&T (science and technology) megatrends" [59], it would appear that the U.S. has a very strong position in health-related nanotechnology. However, the 2004 data shows China catching up to the U.S. in health-related nanotechnology patenting, with 123 patents, compared with 128 for the U.S. Third placed Germany produced 39 patents (See Figure 3).

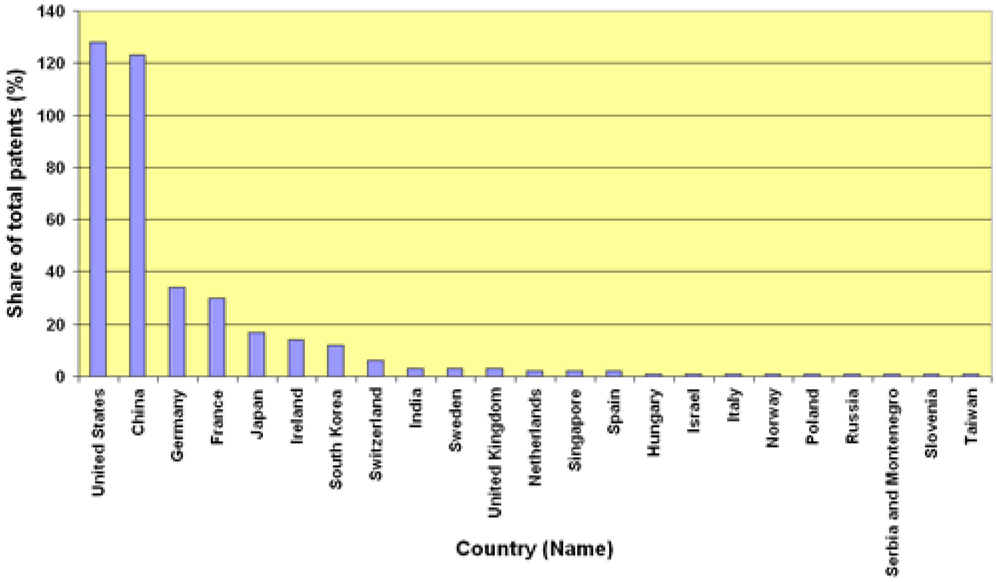

Figure 3. 2004 Distribution of health-related nanotechnology patent activity by country.

Health-Related Nanotechnology Development in China

Challenging a 2003 report that stated Chinese domestic studies in biomedicine lagged behind those in developed countries [60], the present data suggests that China will use health-related nanotechnology to leverage its position in the 21st century knowledge economy. The strength of China's patenting defies the general statistic that less than 2 per cent of all the world's patents are granted to scientists in the South [6] but obscures weak levels of patenting among the other developing countries.

Health-Related Nanotechnology Development in India

With India touted as "likely to become a leader in nano technology within the next five to ten years" [Pillai, cited in 61], the country remains behind the rest of the world by about 6 years in nanotech patenting [Sastry, cited in 45]. Yet these results come at a time of great transition for developing country patent regimes in light of required accession to the Trade Related Aspects of Intellectual Property Rights Agreement. Furthermore, Indian research has been strengthened by a number of domestically-based, international nanotechnology healthcare conferences. In both 2003 and 2005, an international workshop on 'Nanotechnology and Healthcare' saw a wide range of researchers and industry professionals, including Nobel laureates, gather in India to discuss applications of nanotechnology in frontier areas[u]. These conferences flanked 'The First World Congress on Nano-biotechnology' in 2004, and "Nanobiotechnology: Implications on Food, Health and Nutrition Security", in 2005.

Note:

u. See http://www.sastra.edu/nthc/ for more details.

Distribution of Health-Related Patents by Continent

When we look at the distribution of health-related patents, by continent (shown in Figure 4), we see little separating Europe (36.7%), North America (34.2%) and Asia (28.8%). The large involvement of Asia suggests that nanotechnology may be the first widespread technology in which Asian countries have a foundational role. Competition, arising from a relatively evenly distribution of patents across the three continents will probably lead to a more rapid development of nanotechnology but may do little for partnership outside these regions. Few or no patents are held in Oceania (0.2%) South America (0.1%) and Africa (0%). This furthers our earlier claims that a 'nano-divide' may exist within the developing world highlighting the continental divide in health-related nanotechnology patenting.

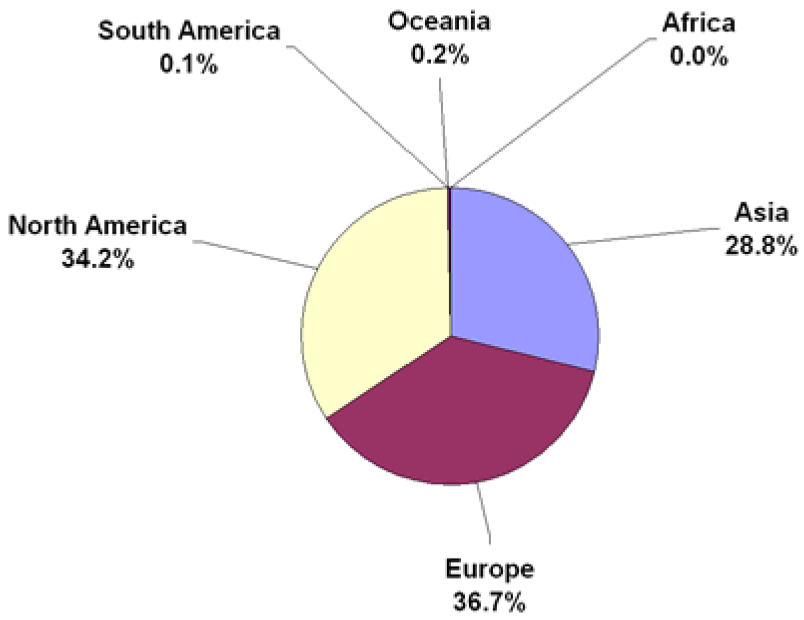

Figure 4. Global distribution of nanotechnology health-related patent share, by region.

Patent Ownership by Sector

With respect to sectoral ownership, 77% of patents are held privately, 16% by universities, 5% by government and 2% by independent, not-for-profit organisations (outlined in Table 4).

Table 4. Distribution of health-related nanotechnology patent activity, by sectors.

Sector	Share (%)
Private	
Company	54
Individual	23
University	16
Government	5
Independent, Not-For-Profit	2

This data is consistent with the belief that "independent public research is becoming extinct" [6]. As Chrispeels notes, research contributing to the Green Revolution was conducted in the public domain and included free distribution of resultant technologies, "without concerns for the intellectual property rights of those who produced them" [36]. However, in the 21st century there is an increasing difficulty of public sector researchers to access technologies to fulfil their missions [62].

The top 20 holders account for 28% of the patents (Comprehensive data is shown in Table 5), with the top 10 institutions holding 22% of the total. The difference here, as compared with biotechnology, is that many of these are multinational corporations (MNCs), engaging right from the 'beginning' [63].

Table 5. Top 20 institutions with health-related nanotechnology patent activity.

Rank	Top 20 Institutions	Patents	Country
1	L'Oreal	109	France
2	Elan Pharma International	38	Ireland
3	Nanosystems (ISRA Visions Systems Group)	31	United States
4	Henkel	28	Germany
=5	Cognis Deutschland	15	Germany
=5	Sanofi-Aventis	15	France

7	Amorepacific	14	South Korea
8	Vesifact	13	Switzerland
=9	Japan Science and Technology Agency	11	Japan
=9	GlaxoSmithKline	11	U.Kingdom
11	Rohm and Haas	10	United States
=12	Centre National De La Recherche Scientifique	9	France
=12	Eastman Kodak Company	9	United States
=14	Ciba Specialty Chemical Holdings	8	Switzerland
=14	The Regents of The University of California	8	United States
=16	Diagnostikforschung Institute	7	Germany
=16	University of Texas	7	United States
=18	Alfatec Pharma	6	Germany
=18	Max Planck Gesellschaft	6	Germany
=18	Novartis	6	Switzerland

Of the top 10 pharmaceutical companies on the U.S. market (according to NDCHealth figures[v]), Sanofi-Aventis, GlaxoSmithKline, AstraZeneca and Merck have all engaged in nanotechnology patenting. Two further drug giants: Elan Pharma International and Novartis, hold strong patent positions in health-related nanotechnology.

Yet, highlighted by a recent report claiming pharmaceutical giants are investing less money and people in nanotechnology than other industries [16], a number of big pharma companies are noticeably absent from health-related nanotechnology patenting. These include the top pharmaceutical manufacturer in the U.S.: Pfizer, along with Johnson and Johnson, Bristol-Myers Squibb, Abbott Labs and Amgen. Nordon suggests this offers a situation similar to that in biotechnology, “allowing new competitors to take root” [Nordon, cited in 16].

The concern that health-related patents will be ‘locked up’ extends beyond ‘big pharma’ because, with nanotechnology, patents can cross over many industrial sectors [Mooney, cited in 64]. Two of the top 20 institutions with health-related patents (Eastman Kodak and The Regents of the University of California) are also two of the greatest assignees for general nanotechnology patents [8]. Considering that legislative prohibitions, such as the non-patentability of living material, do not stand in the way of nanotechnology, the ETC Group believes that convergence at the nanoscale will become the “operative strategy for corporate control” in 21st century healthcare[63].

In an era when, both within and across countries, health-related decisions are increasingly based upon ‘economic return’ [65], the additional concern is that nanotechnology R&D will be oriented towards the needs of Northern markets [5], thereby exacerbating the 10/90 gap[w]. For example, though heralded in the literature as an application aimed at a predominantly developing country issue[x], Starpharma’s manager of drug development confirmed that their HIV microbicide gel is likely to be aimed at commercialisation on the U.S. and Australian markets by 2010 [McCarthy, cited in, 67]. Such examples provide a good opportunity to more carefully consider suggestions that official development assistance and United Nations’ specialised agency programs assess an incorporation of nanotechnology-based applications [5, 68].

Note:

v. Available at: http://www.ndchealth.com/press_center/pressreleasearchive.asp.

w. Whereby, only 10% of spending on health research and development is directed at the health problems of 90% of the world’s people” [66].

x. See, for example: [5].

Assessing Patents by Utility

Assessing patents by utility, we notice the strong emphasis on therapeutic applications. A large number of patents relate to cosmetic and sunscreen applications, providing initial evidence for Barker et al.’s concern that nanotechnology may be directed at applications most applicable to the North [5]. However, the great majority of therapeutic patents are focussed on new drug delivery mechanisms, already highlighted as an important application for the developing world. Furthermore, a number of applications describe the combining of nanotechnology with traditional medicine for therapeutic benefit. The strength of therapeutically-related patents, compared to diagnostic-related patents challenges Tegart's suggestion that nanotechnology applications could encourage detection outpacing response capability [2].

Table 6. Categorisation of health-related nanotechnology patents, by utility.

Application	Number of Patents	(%)	Examples
Therapeutic	775	52	Drug delivery mechanisms, vaccines, nutraceuticals, bone scaffolds
Diagnostic	270	18	Sensors, biomarkers
Consumer health	449	30	Cosmetics, sunscreens, antibacter ial/antiseptic/antimicrobial coatings, water purification systems

Patents Classified by Disease

An assessment of all titles and abstracts for cited diseases shows that patenting is strongest for non-communicable diseases (see Figure 5 for a list of the 10 most cited diseases). By citation, cancer is receiving the greatest focus, propelled by funding such as the $144 million committed to nanotechnology cancer research in the U.S. [69]. Yet cancer's burden, in terms of overall numbers, is greatest in the developing world [70]. Hepatitis is the second most cited disease, yet the majority of patents relate to Hepatitis B which is most prevalent in the developing world [71]. Non-communicable diseases include osteoporosis, beri-beri, stroke and diabetes mellitus. Yet, much of the projected doubling of diabetes mellitus cases by 2025 will stem from increases in developing countries [72]. Influenza, acne, AIDS and vaginitis represent the remaining communicable diseases and are conditions prevalent in both the developed and developing world. Numerous references to various waterborne diseases, staph infections and viruses such as HIV were not included in this research but would have shown HIV/AIDS receiving a greater focus than represented in our disease citation data.

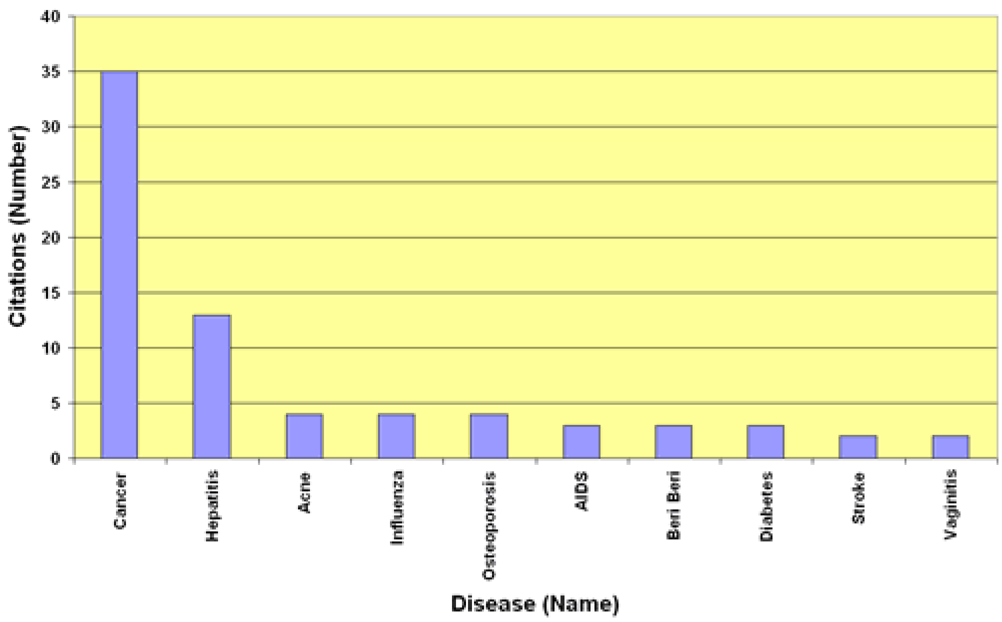

Figure 5. The 10 most cited diseases in health-related nanotechnology patent abstracts.

With a growing recognition that "…health differences between countries will be narrowed" [73], one challenge is to ensure that developed world research into areas such as cancer, hepatitis and AIDS does not limit research into developing country applications. As discovered with 'Golden Rice', "when it came time to prepare this new rice for those countries and people for whom it was intended… many of the techniques used by the researchers were patented…" and these barriers took a great deal of time and effort to overcome [62].

The research shows very little focus on neglected diseases. Two of the worlds greatest killers, malaria and tuberculosis, are noticeably absent from any significant level of nanotechnology patenting. In one respect, this could mean that little research being undertaken in these areas has been transferred to the commercial setting. However, what is more likely is its signifying that these diseases are receiving attention disproportionate to their global impact.

Global Participation Nanotechnology Dialogue

Court et al have suggested that the greatest lesson nanotechnology can learn from biotechnology is that there should be a democratic and more widespread participation in discussions concerning society [4]. To avoid a 'Genetically Modified Organism-style' backlash but simultaneously ensure legitimate handling of public concerns, developing country representatives must play a significant part in global nanotechnology discussions.

Forty-three participants from 25 countries gathered in the U.S. for the first intergovernmental dialogue on *Responsible Research and Development of Nanotechnology* (IDRDN) and 106 participants from 18 countries assembled in Italy for the *North-South Dialogue on Nanotechnology: Challenges and Opportunities* (NSDN).

Table 7. Breakdown of country representation at the *International Dialogue on Responsible Research and Development of Nanotechnology* and the *North-South Dialogue on Nanotechnology*

Developed Countries			Developing & Transitional Countries		
Country	IDRDN	NSDN	Country	IDRDN	NSDN
United States	7	10	South Africa	2	5
Italy	1	72	Argentina	1	2
Japan	5	1	India	1	2
United Kingdom	1	3	Mexico	2	
Taiwan	3	1	South Korea	2	
Canada	3		Brazil	1	1
Australia	1	2	Czech Republic	1	
France	2		Egypt		1
Slovenia		2	Israel	1	
Belgium	1	1	Malaysia		1
Germany	1	1	Nigeria		1
Switzerland	1	1	Romania	1	
Austria	1		Russia	1	
Ireland	1		Uruguay		1
The Netherlands	1				
New Zealand	1				
Total	30	92	Total	13	14

Both conferences demonstrated a strong presence from the host nation, with Italy contributing 67% of the overall NSDN participants. Developing country representation, in both dialogues, was weak, contributing to 30% of the IDRDN constituency and 13% for the NSDN. Furthermore, in a breakout group at the IDRDN, titled 'nanotechnology and developing countries', only 3 of the 13 representatives were from developing countries (Argentina, South Africa and Mexico). Moreover, participants in this group commented that the allocated time for their discussions (less than two hours) was insufficient [42].

China's Absence from Discussions

Whilst South Africa played a leading role in developing country representation at both events, Chinese delegates were notably absent from both meetings[y]. A lack of Chinese engagement in international nanotechnology dialogue weakens efforts to ensure nanotechnology is developed responsibly and for the benefit of those most in need.

Note:

y. Although a Chinese paper was distributed at the NSDN.

Concerns for Some Developing Nations

With many development groups tending "…to stay away from the emerging nanotechnology debate" [5], there is significant concern that developing country voices will not be heard in the international development of nanotechnology. This was highlighted by a session on nanotechnology held at the 5th World Social Forum in Brazil . Furthermore, representatives from India, Nepal, Sri Lanka, Pakistan and Bangladesh, as signatories of the 'Dhaka Declaration', wrote of their concern for the loss of traditional methods and potential health risks associated with nanotechnology [74].

Attempting to Address The Lack of Cohesion in Global Nanotechnology Policy

Some attempts have been made to address the lack of cohesion in global nanotechnology policy. The International Association of Nanotechnology claims to address important global issues such as: nomenclature & terminology; safety; standards; intellectual property; regulation; ethics; society and the environment [75]. The International Council On Nanotechnology (ICON) is the "only global organization aimed at providing… meaningful and organized relationships among diverse stakeholders" [76]. The International Nanotechnology and Society Network "consists of researchers exploring the connections between society and the possible upcoming changes provided by nanotechnology research" [77].Yet all three examples are U.S.-based, posing logistical and, perhaps, political challenges to an incorporation of truly global perspectives. Furthermore, major environmental groups invited to participate in ICON, have protested that the sole funding for the group comes from industrial members [78, 79]. Hence the need for a permanent United Nations' committee on nanotechnology to ensure debates occur outside the national context but include a truly global range of national perspectives.

Conclusions

Our research has shown a more widespread developing country engagement and interest in nanotechnology R&D than previously documented although this, itself, will not promote a more equitable engagement with global science. Early signs are that developing countries will direct nanotechnology R&D to 'value-add' to export markets, rather than use nanotechnology to promote sustainable development. The considerable absence from countries with a low HDI signals that the 'nano-divide' is already here and exists just as strongly *within* the developing world as between the North and South. Although some examples are provided of developing countries inexpensively establishing national nanotechnology programs, one cannot generalise about the cost of nanotechnology innovation. Considerable barriers exist for less-developed countries seeking to engage with nanotechnology R&D on a national level. Some of these barriers are uniform but entry costs will vary from country to country depending on factors such as the selection of research directions.

A number of international nanotechnology partnerships and alliances have been established. At the moment, partnerships look set to promote some of the more industrialised developing countries, leaving behind many of the less-developed countries interested in nanotechnology. The challenge for people in policy circles investigating the engagement of developing countries with nanotechnology is to constantly assess whether their work is helping reduce technological dependency in both hard and soft forms. A combination of regionally- and internationally-facilitated access to resources and information may prove crucial for developing countries geographically isolated from nanotechnology infrastructure and R&D.

Viewing the overall picture of health-related nanotechnology patents, we see that control lies firmly with the industrialised countries of the North, although China is ensuring strong representation from the developing world, relative to its general patent input. The U.S. holds a strong lead in health-related nanotechnology patenting. However, the 2004 data indicates that China is placing pressure on U.S. dominance. Ownership rests firmly with the private sector, following a relatively earlier MNC engagement with nanotechnology than witnessed with biotechnology. The research is primarily oriented towards therapeutic applications, particularly drug delivery mechanisms, with great interest in cancer and hepatitis. Many of the diseases and conditions cited in the patents hold increasing relevance for the developing world although it must not be assumed that such research can, or will, be transferred.

Global participation in the development of nanotechnology policy and directions appears limited to U.S.- and European-led efforts with the notable absence of China from key international meetings. As it is currently placed, nanotechnology is in danger of replicating the inequitable trends of biotechnology with respect international participation in dialogue.

Overall, there are some encouraging signs that certain developing countries could play a significant role in the global development of nanotechnology. Yet, in light of increasing, market-based barriers and limited country participation on a number of levels, early signs are that nanotechnology will promote a greater global technological divide.

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