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Regulation and Governance of Nanotechnology in China: Regulatory Challenges and Effectiveness

Darryl S.L. Jarvis & Noah Richmond [1]

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Abstract

China's rapid economic transformation over the last 3 decades has been remarkable both in terms of its speed and scale. As the Economist magazine reported recently:

> 'In China each person now produces four times as much as in the early 1970s with as many as 400 million people being lifted from abject poverty into the ranks of an urban dwelling middle class in the space of a single generation.' (Economist, 2007).

Much of this transformation has been off the back of China's movement into low value adding manufacturing, in essence becoming the world's assembly, manufacturing, textile, and footwear hub. China, however, is rapidly moving to reposition itself and climb up the value chain.China, announcing its ambition to become a global leader in science and technology. This paper explores one such facet of this race for global leadership in science and technology, addressing China's massive investment in nanotechnology research and attempts to become a leading producer of nano-materials and nano-science knowledge hub. As the paper highlights, however, science and technology innovation are underpinned by regulatory and institutional technologies, and require adroit policy supervision of complex innovation eco-systems. Whether China is able to leverage off its increasing wealth and funnel this into global leadership in science and technology, in large measure depends on still nascent regulatory systems.

Introduction

Our ability to arrange atoms, observes K. Eric Drexler, lies at the foundation of technology (Drexler 2006: 55). It is merely variation in the arrangement of atoms that differentiates sand from computer chips, cancer from healthy tissue, and gold from bauxite. Now imagine a series of technologies that change the molecular structure of biological entities, proteins, DNA, and the building blocks that generate and control biological outcomes. Or imagine a series of technologies that are capable of engineering molecular and atomic variation in the composition of compounds to produce new materials with new properties and characteristics (Drexler 2006:12). If you can imagine all this, you can imagine *nanotechnology*: a diverse collection of academic specialisms centered around engineering and manipulating molecular and atomic structures and, in the process, creating biological and non-biological nanomaterials whose characteristics can be 'made to order'.(Drexler 2006:12-13).

Nanotechnology is the science of manipulating matter at the atomic and molecular scale. It deals with structures sized from 1-100 nanometers in dimension - one nanometer being equal to one billionth of a meter (Renn and Roco 2006: 153; see also Lindquist, Mosher-Howe and Lui 2010). Nanoscience holds vast prospects for technological innovations in areas such as electronics, through the development of nanocircuitry; molecular level semiconductors; nanotubes; new materials development in ceramics, polymers, glass ceramics and composites; and in medicine, through the development of nanoelectronic biosensors, nanoscale drug particles, and delivery systems to improve the accuracy and efficiency of drug toxicity to harmful tissue and disease - among many others. Far from science fiction, nanotechnology and the development of nanomaterials is already well advanced. Nanomaterials are currently present in over 1,300 commonly consumed products ranging from cosmetics, clothing, personal care/hygiene items, sporting goods, sunscreen, and household filtration systems and construction materials. (Project on Emerging Nanotechnologies 2010). If you consumed a McDonald's hamburger recently, the paper ring that held the burger together was glued with a nano-based resin; if you had a wound dressed with an 'Acticoat' dressing or applied 'Acnel' lotion to dry skin, then each of these products had nanomaterials incorporated into their production (Project on Emerging Nanotechnologies 2010). The US National Science Foundation estimates that USD 70 billion US worth of nano-containing items are sold in the United States each year, while the global market for manufactured goods containing nanotechnology is estimated to reach USD 2.6 trillion by 2014 (The Nanotech Gamble 2010; Lux Research 2008). Moreover, the rate of development and incorporation of nanotechnologies into all facets of consumer, industrial, and medical applications is anticipated to double every two years (Interviews, October 2010).

Hardly surprisingly, there is a race to become the global leader in nanoscience and nanotechnology. To the winner will go vast fortunes, accelerated economic development, an increasing spread of commercial spinoffs, high value adding manufacturing, and allied benefits associated with emerging hubs of intellectual capital. This paper explores one such aspirant in this international race, China. China is rapidly moving to reposition itself away from low value adding economic activity and climb up the value China, announcing its ambition to become a global leader in nanoscience and technology. As the paper highlights, however, science and technology innovation are underpinned by regulatory and institutional technologies, and require adroit policy supervision of complex innovation eco-systems. More immediately, the management of nanotechnology risks and the appropriate frameworks to balance innovation, science, and safety issues are essential if public trust in the sector is to be sustained and thus funding and investment into the sector secured. Whether China is able to leverage off its increasing wealth and funnel this into global leadership in science and technology, in large measure depends on still nascent regulatory systems. As this paper highlights, however, these regulatory technologies remain somewhat opaque, suffer from contestation and often limited institutional capacity in terms of implementation and enforcement, and are subject to problematic coordination issues that diminish the effectiveness of regulatory outcomes in the sector.

Science and Nanotechnology in China [2]

While the United States has led global investment into research and development in nanotechnology, China is fast emerging as a global player. By 2005, China ranked only second to the US in nanotechnology investment, ranked second in terms of the number of nano-related peer reviewed research publications (producing 15% of all global nano related research papers), and had emerged as the global leader in carbon nanotube technology and manufacture (Shapira and Wang 2009: 466; see also Liu and Zhang 2005: 397 and Liu 2008). China is also a leader in the manufacture of nano coatings, anti-corrosive nano paints (used in ship construction and oil tanks), odor eating nano coatings and plastics for refrigerators, nano filters for air conditioners, a series of nano-materials used in optics (to filter glare), and in the production of nano textiles and clothing (to enhance antimicrobial properties) (Applebaum and Parker 2008: 330). [3] Further, evidence of China's ascendency in the nanotechnology race can be found in the increasing number of product patents. Increasingly, the number of patents secured by Chinese companies has outnumbered those filed by foreign companies, reflecting the increasing ability of Chinese research on nanotechnology to be transformed into commercial applications, with 89% of Chinese nanotechnology patents filed between 1991 and 2006 stemming from invention patents (compared to 33% of all patents globally) (Appelbaum et al. 2011, 308). The synergies between investment in research and development and commercial end use in Chinese nano applications is becoming more apparent with each passing year.

China's push to become a global leader in nanotechnology reflects a national strategy aimed at leapfrogging the developmental cycle. While development of the export sector has facilitated rapid economic growth, primarily through specialization in low to medium value-adding manufacturing, sustained growth will be contingent on moving up the value chain. Leading Chinese policy makers, economic planners and influential economists all recognize the need to address China's dependence on export-led growth (interviews, MOST officials, March 2010). As the Vice President of the China National Academy of Nanotechnology and Engineering (CNANE) notes:

> 'China must break away from the mode of technology dependence and transform into independent technology innovation ... It is very clear that [in China] the leading power is in the tight grasp of foreign enterprises' (Appelbaum and Parker 2008: 319).

China's science and technology policy is thus informed by a singular rationale: economic growth situated in the context of developing indigenous scientific and technological capacity to reduce reliance on technology transfer, export-led growth, and low end manufacturing. Importantly, China sees its science and technology policy as a central pillar in its efforts to become a global leader in innovation; that is, a net exporter of ideas, innovative technologies, and commercial applications.

Developing Nanoscience and Nanotechnology in China: Policy and Regulatory Frameworks 1990-2020

Chinese domestic spending on science and technology (S&T) research and development has exploded since 1996, growing ten-fold from RMB 40 billion to RMB 461 billion in 2008 (Applebaum 2011, 305). As a proportion of GDP, China's investment into S&T research grew from 1.5 per cent in 1996 to 2 per cent in 2010, and under the Medium and Long-term Development Plan (MLP) running from 2006-2020, it will grow to 2.5 per cent of GDP. Yet despite such significant increases in the level of national investment into S&T, China still trails countries such as South Korea and Japan whose technology spending as a share of GDP stands at 3.5 per cent and 3.4 per cent, respectively.

China's science and technology programs are situated around a central policy architecture announced by Deng Xiaoping in 1986, the National High Technology Research and Development Program, known as the 863 program. The 863 Program aims at 'promoting the development of key novel materials and advanced manufacturing technologies for raising industry competitiveness' including nanomaterials (Ministry of Science and Technology of China 2008: 323). The 863 Program is implemented through successive Five-Year Plans and is the key government program behind the national research and development (R&D) capacity in support of domestic innovation. Indeed, from 1990-2002 the 863 Plan funded over 1000 nanotech projects with a total investment of USD 27 million. Similar to the MLP, the Chinese government has recognized the importance of linking S&T to economic growth through targeted research projects. To help achieve this, the 863 Program is managed by an expert responsibility system, with field-/sector-specific expert committees and panels consisting of top scientists who supervise, advise, and assess projects.

The first project adhering to the 863 Program goals was the Climbing Project on Nanomaterial Science instigated from 1990-1999 and overseen by the State Science and Technology Commission (SSTC), the predecessor to the current Ministry of Science and Technology (MOST, accessed on March 23, 2010). Given the Program's success, the government subsequently renewed its commitment to funding basic research on nanomaterials and nanostructures (i.e., carbon nanotubes) with the initiation of China's National Basic Research Program (973 Program) in 1997. This complements the 863 Program and is an evolving research agenda for nanotechnology research. Since 2006, 10 nanotechnology research projects have received a combined USD 30 Million (USD three million each) under the Program (MOST briefing paper, 2010).

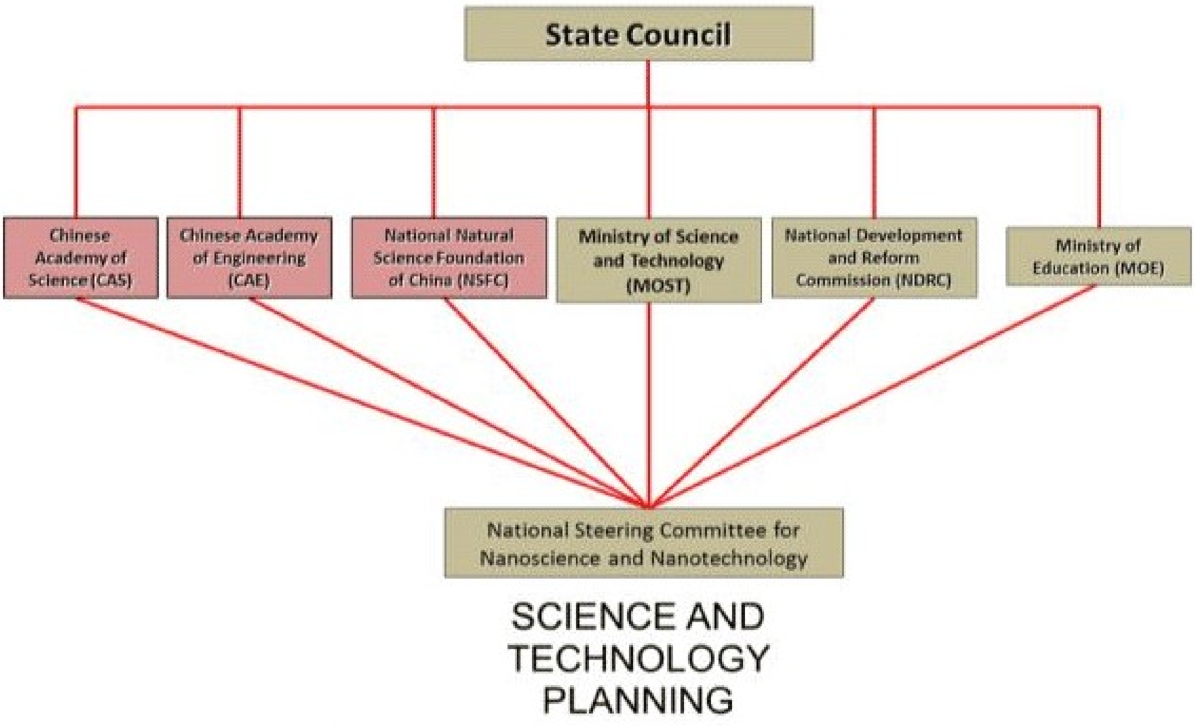
The 973 Program also supports fundamental research that enhances domestic capacity and knowledge on nanotechnologies while complementing the 863 Program in applied research. Two other notable projects under the 973 Program concern the standardization of procedures and assessment/test protocols which form the basic framework for the regulation of nanomaterials. The first, the standardization for the key measurement techniques in nanotechnology is led by Professor Jiang Chao at the National Center for Nanoscience and Technology (NCNST), and the second, the Controlled Synthesis of Nanometer-sized Reference Materials for Metrology and Measurement: Scaling-up and Standardization of Nanofabrication Methods, is led by Professor Wu Xiaochun also at the NCNST (interviews, NCNST officials, March 2010; interviews MOST officials, March 2010). Each is a standards-based series of protocols designed for benchmarking nanoscience research and findings.

In addition to nanotechnology research funding, the 10th Five-Year Plan (2001-2005) also addressed priorities for the commercialization and development of nanotechnology (interview, MOST, March 2010). The government disaggregated nanotechnology development between short (development of nanomaterials), medium (development of bio-nanotechnology and nano medical technology), and long-term projects (development of nano electronics and nano chips). The Five-Year Plan prioritized bridging the gap between nanotechnology research and market demand to form a complete national innovation system. The 11th Five-Year Plan (2007-2012) in turn places emphasis on innovative technologies, including the development of new materials for information, biological, and aerospace industries, and commercializing the technology for 90-nanometer and smaller integrated circuits.

As part of China's longer term S&T policy objectives, the MLP 2006-2020 is a follow-up to the Five-Year Plan and designed to provide China with the necessary technical capacity for sustained technology innovation that contributes to national economic development and China's ambitions to become a global leader in S&T research (MLP 2006-2020). Indeed, the MLP 2006-2020 plan calls on S&T to address current development bottlenecks such as environmental degradation and energy efficiency and thus avert negative externalities associated with accelerated growth. Importantly, under the MLP, nanotechnology development is given priority status and is identified as one of science's 'megaprojects' (MLP 2006-2020). It calls for R and D to be undertaken on nanomaterials and devices, design and manufacturing technology, nano-scale complementary metal-oxide semiconductor devices, nano drug carriers, energy conversion and environmental purification materials, and information storage material. Between 2006 and 2008, the MLP funded 29 nanotechnology projects in 22 universities and research institutes across the country, totaling USD 38.2 million (MLP 2006-2020).

To help oversee the various nano projects the National Steering Committee for Nanoscience and Nanotechnology (NSCNN) was established in 2000 to coordinate and streamline all national research activities. The NSCNN is directed by Dr. Chunli Bai and it consists of MOST, the Chinese Academy of Sciences (CAS), National Natural Science Foundation (NSFC), the National Development and Reform Commission (NDRC), the Ministry of Education (MOE) and the Chinese Academy of Engineering (CAE) (interviews, NSCNN, March and October 2010). The NSCNN membership excludes other regulatory bodies such as health, environment and worker safety ministries. The NSCNN is chaired by the Minister of MOST and includes twenty-one scientists from universities and research institutions and seven officials from government agencies (see Figure 1). The preliminary results of our interviews suggest that the approval of research grants by the NSCNN depends primarily on demonstrating the commercial utility of projects, and that NSCNN is focused predominantly on commercialization objectives.

Figure 1: Policy and Key Regulatory Agencies for Nanotechnology in China



Source: Interviews, March & October 2010.

Managing nano-based risks in China: Regulatory responses

As the complexity of nano-based research (pure and applied) has increased in line with increased government funding, and as the number of industrial applications for nanomaterials has grown, China has moved to identify measurement, handling, exposure, toxicity, and safety standards. Nanotechnology standards are reviewed by the National Nanotechnology Standardization Technical Committee (NSTC), and the Technical Committee 279, a nanomaterial-specific sub-committee under the Standardization Administration of China (SAC). It is housed within the NCNST. The SAC/TC279 serves as the coordinating body for the purposes of drafting essential nanotechnology standards including terminology, methodology, and safety in the fields of nano-scale measurements, materials and nano-scale biomedicine.

The NSTC-TC also develops test protocols and technical standards used by manufacturing firms. The Committee oversees applied research for industry and metrology, and laboratory measurement instruments in particular. SAC/TC279 is also constructing a database for nano-material toxicology studies to assist in the establishment of safety standards for nano-material production, packaging, and transportation. The NSTC-TC has five core research working groups: 1) micro-fabrication, 2) nano-metrology, 3) health, safety and the environment, 4) nano-indentation testing and 5) scanning probing microscopy (see Figure 2) (interviews, March 2010). Standards are usually published, administered, and enforced by TC279's parent agency, the General Administration of Quality Supervision, Inspection and Quarantine (AQSIQ) (interview, NSTC, October 2010). Technical standards are distinguished between GB (mandatory), GB/T (voluntary) and GB/Z (technical guide).

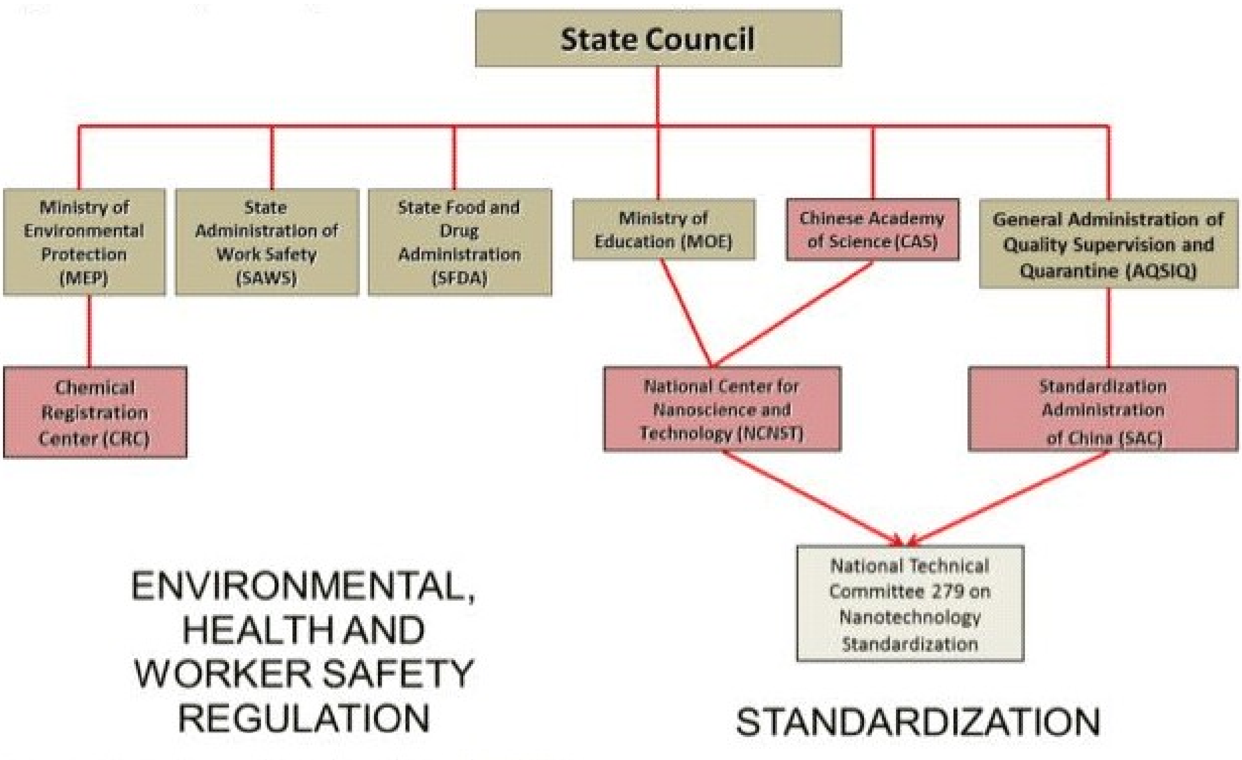
Of the published nanotechnology standards, 17 are voluntary. However, during interviews it was evident that the distinction between voluntary and mandatory standards is unclear: complying with voluntary standards often ensures market access for nano products and thus voluntary standards tend to be treated as mandatory by commercial operators. Under this regime, there are multiple standards relating to various nano-related issues. Ten standards, for example, are concerned with new testing methodologies and protocols, five apply to product specifications, and two standardize older terminology. There is only one standard provided by the industry, which is GB/T 22925-2009. It was established by the China Association of Textile Industry (CATI) that provides specifications for nanotechnology-treated clothes (for a complete list of standards see Appendix 1).

The regulatory regime for the management of nanotechnology chemicals (still being implemented at the time of writing) will likely manage risks comparable to those identified under the EU's REACH regulation. Under REACH (the Registration, Evaluation, Authorization and Restriction of Chemical substances), all chemicals imported or produced in the EU are subject to the same regulatory oversight, requiring companies to submit chemical data to the European Chemical Agency (ECA). Part of the required data includes safe handling guidelines to manage the risks of chemical substances and providing data on the environmental, health and safety properties of chemicals. Presently, chemical regulation in China follows the EU approach in that companies must apply to a central oversight authority, the Chemical Registration Centre of the Ministry of Environmental Protection (CRC-MEP), for a registration certificate prior to manufacture/import of new chemicals. In this application process, companies must supply toxicological and other data to the CRC for all new chemical substances not listed on the Inventory of Existing Chemical Substances Manufactured or Imported in China (IECSC) (Article 8). Registration requirements and enforcement guidelines are set out in the Provisions on the Environmental Administration of New Chemical Substances made effective in September 2003 (Articles 14-18). Penalties for producing chemicals without obtaining registration include paying a fine and being prohibited from registering new substances in China for three years. Falsification of documents and chemical material data during random inspections is also punishable by the same penalties (Article 25).

In the area of health and safety, China has a complex regime to manage and oversee the use and manufacture of chemical substances. This also applies to nanotechnology with multiple ministries including the Ministries of Health, Communication, Public Security, and multiple administrative organs including the State Food and Drug Administration (SFDA), State Administration of Standardization (SAS), State Administration of Work Safety (SAWS), and AQSIQ - all having some control over Environment, Health and Safety (EHS) aspects of chemicals. This implies potential coordination difficulties and calls for inter-ministerial /inter-agency coordination to improve the management of potential regulatory gaps. It also makes it harder to establish a clear, predictable and simplified regulatory environment for companies to operate in.

In 2009, the government revised the chemical substance rules in order to incorporate risk assessment, risk management and data submission requirements similar to REACH. These requirements include measures to mitigate hazards and exposure in labeling, packaging, transporting, and disposal of new chemicals. The 2009 amendments (English version from: SOCMA 2009; see also Freshfields, Bruckhaus, Deringer 2009) also require eco-toxicological test data to be drawn from testing organizations at Chinese laboratories. Some concerns have been raised, namely that the technical infrastructure and testing labs might not be of sufficient quality/capacity to generate timely and OECD-acceptable chemical test data. Yet the 2009 amendments demonstrate the MEP's commitment to adopt the precautionary principle for managing risks. They may also be applicable to nanotechnology since notification will be required for chemical substances manufactured and/or imported under one kilo tonne per year, although with the caveat of reduced data submission requirements. Day-to-day enforcement of chemical production and food safety regulations fall directly onto local governments, though national agencies reserve enforcement power. In all cases, local governments are charged with supervisory and administrative responsibility. This may be problematic when local governments inconsistently implement/interpret national laws.

Figure 2: Risk Regulation of Nanoscience and Nanotechnology in China



Source: Interviews, March and October 2010.

Nano safety regulation in China: Environment, Health and Safety (EHS) risk

In 2001, CAS researchers recognized the environmental and toxicological effects of manufactured nanomaterials by signaling their concern of the EHS risks of nanomaterials. Because of their findings, the Laboratory for Bio-Environmental Effects of Nanomaterials and Nano-safety (LBENN) was established in 2003. It is currently based at the Institute of High Energy Physics, the CAS and the NCNST. MOST provides research funding while CAS provides support for capital costs and equipment for EHS research. LBENN employs researchers in the fields of chemistry, biology, nanosciences, and toxicology. In the area of nanosciences, the objectives of LBENN are to first establish a methodology for the detection of nano particles in vivo and determine their biological, environmental and toxicological effects, and then establish protocols for the safe use and handling of nanomaterials and nanotubes for medical and consumer use. These studies are funded by the 973 Program under a Five-Year Nano-safety Project, namely, the Health and Safety Impacts of Nanotechnology, Exploring Solutions (Zhao et al.2008: 1000-1002). The studies on EHS risk of nanomaterials also support another objective, which is the development and drafting of regulatory frameworks for research and industrial activities in nanotechnology (Zhao et al. 2008: 1001).

Presently, there are more than 30 research organizations in China that have initiated research activities studying the toxicological and environmental effects of nanomaterials and nanoparticles and developing techniques for recovering nanoparticles from manufacturing processes (interview 2010). For example, the CAS, Beijing University and the Chinese Academy of Medical Sciences are conducting toxicology studies on nanomaterials intended for medicines. In our interviews, we were told that a generational divide exists among researchers; younger scientists discount EHS risks and are more motivated towards commercial goals, whereas older researchers take a more precautionary stance. One senior interviewee suggested that safety is not usually an important factor in nanomaterial research, except when it involves medical applications.

In 2006, the State Food and Drug Administration (SFDA) revised its medical device regulations to require medical devices made with nanometer biological materials and medical instruments made with nanometer metal silver material to be classified as Class III medical devices (OECD 2010). This means that devices are subject to stricter control and safety oversight than other medical devices, including more detailed pre-market approval procedures. This was the first published case of nano products that were subject to special regulatory requirements. Given that research funding for nanotoxicology studies is distributed by MOST, and research conclusions are communicated back to the organization, it is not clear how MOST handles its competing objectives of promoting technology development and taking EHS risk research seriously. Driven by a strong need to commercialize research and contribute to economic growth, MOST, and researchers funded by MOST, have strong incentives to underestimate the risks of new technologies.

Conclusion: Regulatory Effectiveness and Governance Gaps

While the full impact of China's push for leadership in nanotechnology and nanomaterials is yet to be realized, policy planning, regulation, and management of the sector reveals much about the state of the sector, Chinese public attitudes towards nanotechnology, and, in turn, how the discourse and management of possible nano risks are framed and approached by public agencies and regulators. While nanotechnology holds enormous potential for commercial gain, cutting edge technological innovation, and the development of an innovative knowledge economy, the risks associated with nanotechnologies and nanomaterials on human health and the environment remain largely unknown. Recent laboratory experiments on carbon nanotubes suggest that they could be as dangerous as asbestos fibres (Greenemeier 2008; see also Falkner 2008; Scheufele *et al*, 2007). More importantly, nano toxicity is thought to display an inverse relationship to particulate size: the smaller the particulate matter, the more toxic such particulates tend to be (The Project on Emerging Nanotechnologies 22 September 2010). However, the precise dimensions of these risks, especially with longer term exposure or exposure through nanomaterials engineered in chemical composites and utilised in industrial and chemical applications, have yet to be determined. For this reason, nanotech-specific safety regulations, toxicity, and exposure levels have not been formalised, nor a commonly accepted international safety regulatory framework established (Breggin *et al*. 2009).

Science has historically approached new technologies by invoking the 'precautionary principle'. Broadly stated, the precautionary principle assumes that if a technology or policy has a suspected risk of harm (to individuals, the public or the environment), or absent scientific consensus about the extent and magnitude of these risks, the burden of proof that the technology or policy is not harmful falls to its proponents. In China and the case of nanotechnology, however, the extent to which the precautionary principle guides the adoption of nanotechnologies and the use of nanomaterials appears problematic. Several interrelated factors contribute to this.

First, the discourse framing China's pursuit of nanotechnology is tied intimately to a national political agenda. As one of China's four science-based 'megaprojects', nanotechnology occupies an iconic policy space that is highly politicised. Far from an exclusively science-based initiative, nanotechnology in China has thus to be appreciated in relation to centralised 'command and control' economic planning. Nanotechnology research and development thus operates under the burdens of expected national economic transformation, the delivery of substantial commercial outcomes, the development of a knowledge-based economy, a reduction in China's technology dependence, and the flagship of China's ambitions to assume global leadership in science and technology. Public perceptions of nanotechnology thus tend to be shaped in relation to sustaining and increasing national economic well-being, the prospective assumption of global leadership in cutting-edge technologies and science, and improving the quality of life for Chinese citizens.

Second, the framing of nanotechnology in such overtly nationalist and aspirational contexts diminishes the political space for dissent or for the public to raise questions about safety issues, or risks associated with the impact of nanotechnology on human health and the environment. Rather, public perceptions of nanotechnology tend to be celebrated in concert with a 'rising China' and as evidence of China's destiny to assume a global leadership role. This is equally true for an increasingly large segment of the science community in China, whose livelihoods are aligned with pure and applied nano research and commercialization efforts, and who also harbour national aspirations for Chinese leadership in science and technology. These dynamics portend to longer term tensions about the desire to use nanotechnology and nanoscience as flagship programs to champion China's emerging role on the world stage, while constructing regulatory modalities of governance that create effective risk management regimes to avert potential harm from nano-toxicity.

Third, the command and control style approach to national economic planning and the development of nanotechnology creates elite, technocratic processes, limiting the spaces for wider consultation or public participation about the role, desirability, potential applications, and impact of nanotechnology. In a sense, the public are shut out of the policy spaces around which science and technology policy is determined, or where risks and questions about potential harm from such technologies can be assessed. As observed by the head of China's National Steering Committee for Nanoscience and Nanotechnology (NSCNN), the peak body overseeing nanotechnology in China, nanotechnology is highly technical, requires specialist knowledge, and the public don't have the technical capacities or knowledge to understand the technologies or assess potential risks (interview, 16 January 2010). Indeed, it was suggested that excluding the public or civil society groups from participation in reviews and debates was advantageous, since they might react inappropriately or form misperceptions about potential nano risks due to technical deficiencies and a poor grounding in nanoscience. Involving the public or wider non-science-based communities in discussions was thus seen as a potentially risky consultation process (see also Satterfield et al. 2009).

Fourth, the 'knowledge deficit' problem, which in other national contexts sees the science community engage in outreach and education activities to raise evidence-based knowledge about new technologies, tends not to operate in China and the nanotechnology sector. In part this derives from a hierarchical technocratic system where there is a collusion of interests between central planners and the nanoscience community, but also in part because public perceptions toward science and scientists are deferential, with scientists highly respected and revered for their contributions to China's national economic advances. Such perceptions thus tend to reinforce the relative autonomy of the nanoscience community as the professionals most able to manage and assess the risks of nanotechnology (see also Brown 2009). Such attitudes tend to moot vocal opposition, limit potential avenues for engagement between the science community and public /civil society groups, and lessen the incentives for scientists to disseminate evidence-based knowledge to the public.

Fifth, these political-social hierarchies tend to be self-reinforcing. Absent external, public scrutiny, or the ability of civil society to engage critically with evidence-based risk assessments of nanotechnologies, concerns about the potential risks of nanotechnologies or exposure to nanomaterials are left to the science community to explore. However, the patron-client relationship that operates between central planners and the nanoscience community creates disincentives to design research programs focused on the risk impacts of nanotechnologies. Indeed, two senior Chinese nanoscientists, when interviewed about possible conflicts of interest, admitted that younger scientists have incentives to under-report or downplay possible negative impacts of nanotechnologies. As they explained, funding streams for R&D are predominantly driven by the prospects for commercialization. Apart from establishing standards for nano toxicity, researchers were incentivised to open nano research avenues and not close them down through highlighting potential risks or downsides (interview, 16 January 2010).

Considerations such as these render the emergence of an effective regulatory regime able to manage nanoscience-based-risks in China problematic. The relatively closed nature of the nanoscience community and an absence of outreach or public engagement create regulatory modalities that might better be characterised as self-governance or closed governance regimes. While this is not totally unusual in science-based regulation due to the technical nature of the domain, in China where nanoscience is conflated with national economic planning and key economic objectives focused on commercialization and international leadership, perverse incentives operate that might compromise the effectiveness of risk-based regulation. This has possible longer term implications for regulatory legitimacy in the sector, especially in the context of public risk perceptions about nanoscience and nanomaterials. Indeed, the effective side-lining of civil society engagement in the regulatory process was highlighted in numerous interviews with nano researchers who generally endorsed the need for greater civil society engagement but principally as a means to 'educate' the public so that they did not develop misperceptions about the risks associated with nanoscience and toxicity. Chinese researchers, for example, lamented the inability to communicate the benefits and risks of nanoprojects and ideas with the public. During interviews, they argued that Chinese society is relatively conservative and reluctant to adopt new technologies, and hinted at concerns about growing public risk perceptions of nanoscience and increasing levels of mistrust of government agencies, standards, and quality assurance regimes. Off the back of recent food scandals, contaminated baby formula, and a spate of similar quality assurance failures in domestic food manufacturing, the nanoscience community thus appears increasingly sensitised to issues of regulatory legitimacy. It remains to be seen, however, how or if this will transform the culture of regulation surrounding nanotechnology (interviews, October 2010).

Appendix 1: List of Nanotechnology related Standards in China

No.	Name	Issuer	Effective Date
GB/T 13221-2004	[Nanometer powder-Determination of particle size distribution-Small angle X-ray]	AQSIQ	2005-04-01
GB/T 19345-2003	[Nanometer powder-Determination of particle size distribution-Small angle X-ray]	AQSIQ	2004-05-01
GB/T 19346-2003	[Measuring method of magnetic properties at alternative current for amorphousand nanocrystalline soft magnetic alloys]	AQSIQ	2004-05-01
GB/T 19587-2004	[Determination of the specific surface area of solids by gas adsorption using the BET method]	SAC	2005-04-01
GB/T 19588-2004	[Nano-nickel powder]	AQSIQ	2005-04-01
GB/T 19589-2004	[Nano-zine oxide]	AQSIQ	2005-04-01
GB/T 19590-2004	[Nano-calcium carbonate]	AQSIQ	2005-04-01
GB/T 19591-2004	[Nano-titanium dioxide]	AQSIQ	2005-04-01
GB/T 19619-2004	[Terminology for nano materials]	AQSIQ	2005-04-01
GB/T 20307-2006	[General rules for nanometer-scale length measurement by SEM]	AQSIQ	2007-02-01
GB/T 21510-2008	[Antimicrobial property detection methods for nano-inorganic materials]	AQSIQ	2008-08-01
GB/T 21511.1-2008	[Nano-apatite/Polyamide composite - Part 1: Designation]	AQSIQ	2008-08-01
GB/T 21511.2-2008	[Nano-apatite/Polyamide composite - Part 2: Technology requirements]	AQSIQ	2008-08-01
GB/Z 21738-2008	[Fundamental structures of one dimensional nanomaterials - High resolution electron microscopy characterization]	AQSIQ	2008-11-01
GB/T 22458-2008	[General rules of instrumented nanoindentation test]	AQSIQ	2009-05-01
GB/T 22462-2008	[Nano Sub-micron scale film on steel - Quantitative depth profile analysis - Glow discharge atomic emission spectrometry]	AQSIQ	2009-06-01

GB/T 22925-2009	[Nanotechnology-treated clothes]	China Association of Textile Industry	2009-12-01
GB/T 23413-2009	[Determination of crystallite size and micro-strain of nano-materials-X-ray diffraction line broadening method]	AQSIQ	2009-12-01
HG/T 3791-2005	[Suspension poly (vinyl chloride) resins via vinyl chloride and nano-calcium carbonate in situ polymerization]	NDRC	2006-01-01
HG/T 3819-2006	[Nano-synthetic hydrotalcite]	NDRC	2007-03-01
HG/T 3820-2006	[Methods of test for Nano-synthetic hydrotalcite]	NDRC	2007-03-01
HG/T 3821-2006	[Nano-powder of magnesium hydroxide]	NDRC	2007-03-01

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[2] Readers familiar with the governance of nanotechnology in China will appreciate the paucity of information available (especially in English). More obviously, the newly emerged state of the field and the rapidly changing institutional environment that oversees the sector, adds to the problems of researching the sector. We have attempted to overcome these limitations by conducting field research and undertaking a series of interviews with leading authorities in the nanotechnology arena. Interview subjects were identified on the basis of our mapping of the regulatory and governance agencies responsible for development and oversight of the nanoscience and technology sectors, including environmental agencies, occupational health and safety, and with the assistance of peak authorities such as Ministry of Science and Technology where ultimate regulatory authority for nanoscience resides. Interviews were conducted in March and October 2010. We are indebted to our interviewees for their time, candidness, and insights. However, the opinions expressed in this paper (as well as any possible inaccuracies) are those of the authors.

[3] Carbon nanotubes (fullerenes) are derived from graphene, rolled into sheets and then tubes. They have a length to diameter ratio of up to 132,000,000 to 1, a magnitude much greater than conventional materials which endow them with unique strength, and properties such as thermal and electrical conductivity, making them ideal for incorporation into electronics and optics. See Cess Dekker (1999) "Carbon nanotubes as molecular quantum wires," *Physics Today*52: 22-2. See also Richard P. Appelbaum and Rachel A. Parker (2008), China's Bid to become a Global Nanotech Leader:

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