

Emerging Technologies and Ethics: A Race-to-the-Bottom or the Top?

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Abstract Does national success with an emerging technology require ethical sacrifices? This question is considered through the simultaneous consideration of ethics, investment, and outcomes in the nine jurisdictions that are making the largest investments in nanotechnologies—an important emerging technology. It is found that while ethical environment has no notable effect on pure and applied research, a more positive ethical environment is associated with measures associated with invention and commercialization. In summary, a *race-to-the-top* supports invention and commercialization of emerging technologies. A critical finding as it suggests that issues such as corruption and regulation could be critical in limiting the extraction of social and economic benefit from emerging technologies (like nanotechnologies).

Keywords Technology entrepreneurship · Ethics · Economic development · Government processes · Creative enterprise · Regulation · Nanotechnology · Nanoscience

Introduction

The question of whether jurisdictions must make a choice between either ethics and values or the possibility of economic growth based on early mastery of a technology is considered here in the context of nanotechnologies. This

article deals with the question of whether a race-to-the-bottom or top exists. A race-to-the-bottom suggests that standards or taxes will be lowered to try and attract and retain business or please one or more stakeholder groups. While a race-to-the-top suggests the opposite that standards or taxes will actually be increased, thereby, offending some stakeholder but satisfying others. Although the *race-to-the-bottom* is often noted as a taxation issue, many have raised concerns about *the race-to-the-bottom* in the ethics literature. These concerns include leadership issues (Raisner 1997), corporate social contracts (Cragg 2000), quality of workplace environment (Rivioli 2003), and the need for new global business principals to avoid abusive behaviors. Recently, business ethics curricula have embraced *race-to-the-bottom* concerns as part of the curricula (Crane and Matten 2005). In fact, the idea of a *race-to-the-bottom* has been proposed in many different contexts to indicate sacrifices being made to obtain an elusive economic goal (Muller 2007; Chan and Ross 2003; Wheeler 2001; Safran et al. 2001; Brueckner 2000; Pollack 1997). Others (Schneiller and Bartley 2008; Konisky 2007; Choi et al. 2004; Kvist 2004) suggest that although a *race-to-the-bottom* is often suggested, it is not supported by empirical evidence. Alternatively, the literature suggests that either a *race-to-the-bottom* or *top* could occur (Gray 2002; Brathwaite and Drahos 1999). However, Urbeinen (2010) disagrees with (Gray 2002) by suggesting that regulations are likely to lead to a *race-to-the-top*. Further support for a *race-to-the-top* is offered in a variety of contexts (Zeng and Easting 2007; Baldwin and Krugman 2004; Millimet 2003). Factors such as an open economy, innovation, and entrepreneurship are all suggested as being linked to a *race-to-the-top* (Goetz et al. 2011; Shin 2004). In this article, we question whether nanotechnology calls for a *race-to-the-bottom* with safety and human considerations being sacrificed to ensure that economic benefits are not lost to other jurisdictions

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(Marchant and Sylvester 2006). Some argue that there are circumstances under which economic globalization has led to a *race-to-the-top*, while others perceive a *race-to-the-bottom*. For example, in the regulation of biological products the European Union has taken a precautionary approach to regulation. However, the United States (US) considers these new products as being no different from products made using more traditional methods (Prakesh and Kollman 2003). While in other cases, such as STEM cell research, the US is much more conservative. Here, we are interested in the case of nanotechnology in which there are tremendous differences between countries (Walsh 2004) and many consider the role of regulation and corruption as critical to the development of this emerging field (Wilhelm 2002). Whether improvements or degradation is encouraged by opportunity is an interesting question—to pose as previous empirical studies on related topics—as previously mentioned—lend support to suggestions that the pursuit of emerging technologies could lead to either a *race-to-the-top* or a *race-to-the-bottom*.

Nanotechnology is selected as the context as it has been identified as the next Schumpeterian or Kondratieff economic cycle (Linton and Walsh 2008; Wonglimpiyara 2005; Kondratieff 1937; Schumpeter 1934). If this is so, nanotechnology will be the primary engine of economic growth for the next several decades, taking the role that the steam engine and the transistor played years ago. This possibility is supported by a variety of governments, as many countries are investing heavily in nanotechnologies (Mangematin and Walsh 2012; Nikulainen and Palmberg 2010; Romig et al. 2007). Regardless of the relative stage of economic development of a country or region, governments have been investing heavily in nanotechnologies (Motoyama and Eisler 2011; Roco 2011; Drexler 1986, 2004). This is worth noting as historically, developed countries have invested in emerging areas of science and technology; however, emerging economies that have not in the past invested in research in emerging technology are currently investing in nanotechnologies.

While nanotechnology offers a great deal of economic promise and possible societal benefits (Pandza et al. 2011; Manish et al. 2010; Anson et al. 2008; Barton 2007; Corbett et al. 2000), many concerns also exist. Materials—organic and inorganic—often possess different and possibly toxic properties at the nanoscale that are not present at the mesoscale where our past experience lies. In addition, nanotechnology generates potentially invasive solutions that are poised to affect almost every aspect of daily life. Finally, teams of biologists, chemists, physicists, and even social scientists are increasingly collaborating to generate nanoscale-based knowledge discovery and the necessary tools and equipment for R&D activities (Boardman and Ponomariou 2009; Kautt et al. 2007; Ideker et al. 2001; Kitano 2001).

However, the nanotechnology health risks are substantial as there is little understanding of the toxicology of nanomaterials (Warner et al. 2004). Consequently, the likelihood of accidental exposure to hazardous situations is substantial. This is further complicated by low public awareness (Bostrom and Löfstedt 2010) of the risks inherent in nanotechnology and a lack of understanding of the impacts of nanotechnology as can be seen in the popular press (Kjølberg 2009). In summary, nanotechnology is invasive and holds both great promise and peril.

Consequently, nanotechnology is subject to government regulation and increasing discussion of corporate social responsibility (CSR) (Groves et al. 2011; Cooley 2009; O'Mathúna 2009). However, there has been limited discussion of a government's ethical obligation to prudentially investigate and develop nanotechnology's potential for job creation and increasing societal welfare (Roco 2003). Here, we consider nine jurisdictions and the role that ethics may play in relation to the development of nanotechnology science, technology, invention, and innovation.

We raise the questions which are (1) ethics and the race for economic advantage unconnected, or more specifically, (2) is there a *race-to-the-bottom*, or (3) is there a *race-to-the-top*—a positive relation between ethics and technology development. The question is investigated by considering the policies, inputs, and the environment of the jurisdictions that are the most active participants in the nanotechnology field. These nine jurisdictions vary greatly in terms of culture, development, human resources, and financial resources. Measures of environment, research inputs, and outputs are introduced. An introduction to each of the cases is offered. The data is analyzed. Statistics are utilized to examine the relationship among the environment, inputs, and outcomes. Finally, the results are discussed and the conclusions are offered.

Theoretical Development

For benefits to be extracted from science a number of steps or activities must first occur: basic science, applied science, invention, and innovation (Tornatzky and Fleisher 1990). An understanding of the underlying phenomena (theory) is typically pursued to understand the fundamental nature of the phenomena—*basic science* (Stokes 1997; Tornatzky and Fleisher 1990). While basic science provides insights to the underlying phenomena and this may offer insights into the sort of benefits that can be extracted, one must pursue further study through the consideration of how to obtain and manage certain states and characteristics that are inherent to the phenomena under study. The development of an understanding of some phenomena driven by the intent to eventually harness or obtain some direct or indirect benefit is

Applied Science (Stokes 1997; Tornatzky and Fleisher 1990). These activities for the most part are pursued in universities or government laboratories as they are of a pre-competitive nature. In the case of both Basic and Applied Science, success of outcomes is typically measured as the production of peer-reviewed publications (Stokes 1997; Tornatzky and Fleisher 1990). The potential to harness direct or indirect benefit, that is not pre-competitive in nature, is *Invention*. Invention is typically measured through the consideration of whether a patent(s) has/have been filed (OECD 2010; Breitzman and Patrick 2002; Harhoff et al. 1999; Crepon and Duguet 1997). While there are many jurisdictions that one can file patents, the most common is in the US (USPTO) or the European Patent Office (EPO). Finally, benefit is extracted once the invention is taken to market in the form of one or more products—*Commercialization* (Mangematin and Walsh 2012; Maine et al. 2012; Gans and Stern 2003; Griffin and Hauser 1996).

To consider the relationship of these different stages of value extraction from an emerging field one must consider the level of support for research for the emerging field in question—that is how much output is obtained for a given level of input. In terms of *race-to-the-top* or *bottom* scenarios further consideration must be given to the nature of the ethical and regulatory environment of a jurisdiction. Government regulation can have many effects, including subverting foreign suppliers (McGee 2008), influencing purchasing (Forker 1990), and the creation of crises (Richardson and Curwen 1995). In terms of *racing-to-the-top* or *bottom* regulation can have a major impact on such areas as welfare (Brueckner 2000), trade (Schieberg and Bartley 2008; Kvist 2004; Chan and Ross 2003), and the environment (Konisky 2007; Millimet 2003; Wheeler 2001). As it has been suggested that the uncertainties and risks associated to nanotechnology prevents governments from being able to regulate effectively and that industry will need to have a role in self management (Groves et al. 2011); considering the ability, speed, and willingness of a jurisdiction to regulate is insufficient and perhaps even a misleading measure. Instead it is necessary to consider the ability and quality of a jurisdiction to self-manage itself appropriately. That is environments in which CSR is encouraged and thrives are worth considering. In the case of a *race-to-the-top*, environments in which CSR thrives will be ideal for the pursuit of emerging technologies. In the case of a *race-to-the-bottom*, environments in which CSR is problematic will be ideal for the pursuit of emerging technologies.

Environment with Respect to Pursuing Emerging Technologies

To consider the nature of the environment in relation to the pursuit of emerging technology, it is worth considering

measures that are current, widely available, respected and offers insight into different aspects of the regulatory and ethical environment. Corruption (Transparency International 2011), Economic Freedom (The Heritage Foundation 2011), and Ease of Business (World Bank 2011) indexes were identified as meeting these criteria. The indexes overlap from the perspective that they give insights into the nature of regulation—in terms of span, nature, and effectiveness. *Economic Freedom* and *Ease of Business* provide insights into the tendency of the government not to place limitations and regulations into place that hinders business. However, regulation that is in place is clear in terms of intent and its implementation. *Corruption* (Pearce and Manz 2011; Halme and Laurila 2009; Pelletier and Bligh 2008; Emerson 2006) is indicative of regulations that are in place, but not followed consistently (Gao 2011). In a corrupt environment, regulations can be ignored through the provision of benefits to specific individuals or groups (Huang and Rice 2012). Corruption is an institutionalized form of unethical behavior—not merely the activity of a few unethical people acting in an organized way (Dunfee 1991). Corruption is the act of acculturating unethical practices, generating a set of norms, values, and ideologies that encourage unethical behavior, an integral component of these systems become institutionalized (Donaldson and Dunfee 1999). Corruption offers a system of competing ethical norms among various actors within a given economy (Goel and Nelson 2010). Corruption is widely recognized as an important contributor to a country's environment (Khera 2001; Enderle 1997). There are those that argue culture, not regulation, is the driver of corruption (Jing and graham 2008). While there is a rich literature in this area (Judge et al. 2011; Earle et al. 2010; Blackburn and Forgues-Puccio 2009; Bailey and Spicer 2007; Sah 2007; Dunfee 2006), this possibility is considered outside the scope of this research. It is also worth noting that recent studies have suggested that SMEs, if organized in clusters that create anticorruption policies, create the institutional intelligence needed to be both innovative and ethically engaged (von Weltzein Hoivik and Shankar 2011; Solleiro and Castanon 2005).

This study utilizes global rankings of a nation's perceived status to better understand the relation between the environments a country provides for the pursuit of emerging technologies. Three measures of nations are proposed to capture differing aspects of government and societal processes that may affect the nanotechnology development processes. These rankings involve the amount of intervention presented to companies in a jurisdiction—*Ease of Business*—which considers the extent of regulatory government activities (World Bank 2011), the amount of intervention or control on the economy a government exhibits—*Economic Freedom* (Qerimi and Sergi 2012; The Heritage

Foundation 2011; Strong 2009), and the extent of *Corruption* a state is perceived to exhibit (Transparency International 2011; Warren and Luafer 2009). We use these three measures to operationalize and better understand the differences in environment. As the context of this study is how these governmental measures affect the societal value derived from nanotechnologies as an emerging technology, this field and the jurisdiction pursuing it are now considered.

Hypotheses

To consider whether the ethical and societal environment is irrelevant to the extraction of value from a new field of science, we expect the following alternative hypotheses to be supported. A *race-to-the-top* is implied by positive relationships between outputs and *Ease of Business* and *Economic Freedom* and negative relationships between outputs and *Corruption*. Similarly, a *race-to-the-bottom* is implied by negative relationships between *Ease of Business* and *Economic Freedom* and positive relationships with *Corruption*. If there is neither a *race-to-the-top* nor a *race-to-the-bottom*, a statistically insignificant correlation between outputs and environmental variables are anticipated.

For Ease of Business

H1₀ There is no relation between Ease of Business and Pure Science output (science papers/funding).

H2₀ There is no relation between Ease of Business and Applied Science output (technology papers/funding).

H3₀ There is no relation between Ease of Business and Invention output (US Patents/funding and European Patents/funding).

H4₀ There is no relation between Ease of Business and Product Development output (Products/funding).

For Economic Freedom

H5₀ There is no relation between Economic Freedom and Pure Science output (science papers/funding).

H6₀ There is no relation between Economic Freedom and Applied Science output (technology papers/funding).

H7₀ There is no relation between Economic Freedom and Invention output (US Patents/funding and European Patents/funding).

H8₀ There is no relation between Economic Freedom and Product Development output (Products/funding).

For Corruption

H9₀ There is no relation between Corruption and Pure Science output (science papers/funding).

H10₀ There is no relation between Corruption and Applied Science output (technology papers/funding).

H11₀ There is no relation between Corruption and Invention output (US Patents/funding and European Patents/funding).

H12₀ There is no relation between Corruption and Product Development output (Products/funding).

In the case of a *race-to-the-bottom* or the *race-to-the-top* there will be a statistically significant difference between the correlations of the output variable with the measures of the local environment. More specifically for a *race-to-the-bottom* to be indicated there will be an increase in ranking (*Ease of Business* and *Economic Freedom*) as the value of the input/output ratio increases (Science—pure and applied, Invention and Product per unit of funding for all), but as score increases (*Corruption*) the value of the input/output ratios will decrease.

Alternatively, if there is a *race-to-the-top*, there will be a statistically significant difference between the correlations of the input/output variable ratio with the measures of the local environment. More specifically as the ranking increases (*Ease of Business* and *Economic Freedom*) the value of the input/output ratio will decrease (Science—pure and applied, Invention and Product per unit of funding for all) and as the score increases (*Corruption*) the value of the input/output ratios will increase.

Nanotechnology as an Emerging Technology

Since the discussion of there being “plenty of room at the bottom” over 50 years ago (Feynman 1960) futurists see that the translation of nanotechnology’s technical potential to increasingly become a driver for social and economic change. Nanotechnology promises to deliver smaller devices that consume lower levels of raw materials and demand less energy while delivering greater benefit than traditionally constructed devices. In the process, nanotechnology has the potential to create new industries, new patterns of consumption, new ways to manufacture products, and new products (Linton and Walsh 2008; Boardman 2008). It is expected that the global market for nanotechnology-enabled products will reach US\$ 2.41 trillion by 2015, 15 % of the projected global manufacturing, compared to only 0.1 % in 2006 (Global Industry Analysts 2011). In 2011, there are about 1,300 Nano-enabled commercial retail products in the commercial marketplace in nations around the globe, up from only 212 in 2006 (PEN 2011).

For these reasons, emerging technologies, such as nanotechnology, are perceived by many as a future battleground for economic prosperity (Motoyama and Eisler 2011; Roco (2011); Manish et al. 2010; Thukral et al. 2008). Since the early 2000's, nanoscience research, nanotechnology research, and development have increased steadily globally (Romig et al. 2007). In fact, nanoscience and nanotechnology has expanded drastically on all dimensions during this period—publications, patents, government funding, and private sector spending. Financial support for nanotechnology expanded to nearly US\$ 18 billion worldwide in 2009 (Hwang 2010). By the end of 2011 the total government funding for nanotechnology research worldwide will be \$65 billion, rising to \$100 billion by 2014 (Cientifica 2011). Several nations developing nanotech programs are currently undergoing an assessment of their research environment and capabilities; developing human capital; addressing institutional issues; mapping their regulatory, private, and public governance structure; and examining stakeholder issues (Groves et al. 2011). Nanotechnology promises not only economic benefits in the future, but also answers to basic needs such as clean water, renewable energy, agricultural production, and health care issues (Roco 2011). Nanotechnology is particularly interesting due to the expanding investments in technology being made by emerging economies so as to better compete with more developed nations in the future (Ratinho and Henriques 2010). By 2015, nearly \$250 billion will have been invested in nanotechnology. Consideration is now given to the nine jurisdictions that are making the largest investments into nanotechnologies.

Summary of Nine Jurisdictions with Largest Investments in Nanotechnology

A synopsis of each of the jurisdictions is provided in Table 1. The commitment of each jurisdiction to nanotechnology is provided then information relating to each investment into nanotechnology is summarized by year since 2000 in Tables 2 and 3 (utilizing data from Cientifica (2011)).

China and Nanotechnology

As China has grown to become the second largest economy in the world (2010), investment in R&D has increased substantially (Wong 2011). The government's intent is to have innovation drive future development in China. Since 1999, R&D expenditures have expanded at a 24 % annual rate (Liu et al. 2009) and nanotechnology is one of the strategic priorities.

The Chinese National Nanotechnology Development Strategy for 2001–2010 was developed by the Chinese National Steering Committee for Nanoscience and Nanotechnology formed in 2000. Between 2005 and 2007, the government spent about US\$ 893 million and the private sector US\$ 348 million (Lux 2008). Between 2006 and 2010, China invested US\$ 760 million in its nanotechnology industry (Institute of Nanotechnologies 2011). Chinese nanotechnology research involves about 70 academic institutes, 50 universities, 20 research institutes, and more than 100 firms. The large majority of these research centers and firms are located in Beijing, Shenyang, Shanghai, Hangzhou, and Hong Kong. China's top nanotechnology research institutions are the Chinese Academy of Sciences, Tsinghua University, Fudan University, Jiatong University, University of Science and Technology of China, Njing University, Peking University, Shandong University, Zhejiang University, and Shanghai Jiao Tong University. As the largest concentration of Chinese nanotechnology centers are concentrated in Beijing and Shanghai most public funding is allocated to these two regions (Dillemuth et al. 2011). The Pentagon estimates that in 2007, China spent close to US\$ 139 billion in military projects related in some way to nanotechnology (Vance 2008). The number of nanotechnology patents in China has increased from 4,600 to 12,000 in 2009 (Institute of Nanotechnologies 2011; Preschitschek and Bresser 2010).

Germany and Nanotechnology

A number of worldwide studies illustrate Germany's rapid advance in the field of nanotechnology research, development, and early stage commercialization (Lux 2011;

Table 1 General indicators of size, economic activity and R&D for jurisdictions studied [population in millions, GDP \$ in trillions, R&D% of GDP—Batelle (2010) and International Monetary Fund (2011)]

Indicator	Cn	Gr	In	Jp	Ru	SK	Tw	UK	US
Population	1,340	81	1,120	127	142	49	23	62	312
GDP rank	2	4	9	3	11	15	24	7	1
GDP (\$)	5.88	3.29	1.63	5.46	1.48	1.12	0.43	2.42	14.53
R&D Rank	2	4	8	3	10	5	13	7	1
R&D (%)	1.4	2.3	0.9	3.3	1.0	3	2.3	3	2.7

Jurisdictions considered: *Cn* People's Republic of China, *Gr* Germany, *In* India, *Jp* Japan, *Ru* Russia, *SK* South Korea, *Tw* Taiwan, *UK* United Kingdom, *US* United States of America

Table 2 Annual government research expenditures on nanotechnology—in US\$ millions (Cientifica 2011)

Years	Cn	Gr	In	Jp	Ru	SK	Tw	UK	US
2000	5	120	7	250	5	5	5	20	250
2001	5	250	7	720	5	120	5	20	500
2002	5	250	7	700	5	210	5	70	700
2003	5	300	7	800	5	230	75	140	800
2004	200	350	7	850	5	240	150	220	1,250
2005	210	375	20	850	5	260	150	140	1,500
2006	650	450	25	700	15	300	150	130	1,600
2007	750	500	80	720	200	310	150	150	1,700
2008	950	700	80	770	1,600	350	150	220	1,800
2009	950	600	80	800	1,750	375	190	220	2,000
2010	950	700	80	850	1,800	400	200	210	2,200
2011e	1,300	775	80	900	1,900	420	200	210	2,100
Totals	6,000	5,370	480	9,110	7,295	3,220	1,430	1,750	16,400

Jurisdictions considered: *Cn* People's Republic of China, *Gr* Germany, *In* India, *Jp* Japan, *Ru* Russia, *SK* South Korea, *Tw* Taiwan, *UK* United Kingdom, *US* United States of America

Table 3 Annual government research expenditures of nanotechnology—adjusted for PPP—in US\$ millions (Cientifica 2011)

Years	Cn	Gr	In	Jp	Ru	SK	Tw	UK	US
2000	10	100	10	200	10	10	10	10	250
2001	10	200	10	600	10	200	10	10	500
2002	10	200	10	600	10	300	10	50	700
2003	10	250	10	650	10	310	100	100	800
2004	250	275	10	700	10	320	200	200	1,250
2005	300	300	80	700	10	320	200	120	1,500
2006	1,100	400	90	600	10	400	200	120	1,600
2007	1,800	500	120	600	300	420	200	120	1,700
2008	1,900	500	120	650	3,000	450	200	120	1,800
2009	1,850	550	120	700	2,700	475	250	120	2,000
2010	1,800	550	120	650	2,600	500	300	120	2,200
2011e	2,300	650	120	650	2,500	650	300	120	2,100
Total	11,340	4,475	820	7,300	11,170	4,355	1,980	1,210	16,400

Jurisdictions considered: *Cn* People's Republic of China, *Gr* Germany, *In* India, *Jp* Japan, *Ru* Russia, *SK* South Korea, *Tw* Taiwan, *UK* United Kingdom, *US* United States of America

Cenitifica 2011; Preschitschek and Bresser 2010; Sargent 2008). Germany leads the European Union in nanotechnology research, development, and early stage commercialization. Germany has the highest value of EU and government-funded projects, as well as the most companies active in nanotechnology. German government policy focuses on sustainability and technology development. The country is considered well above average in commitment to nanotechnology (Sargent 2008).

The German Ministry for Education and Research (BMBF), the federal body governing nanotechnology in Germany started by focusing on basic research in the early 1990's. However in 2001, the new focus on a national sustainability strategy favored application of nanotechnology as

it met eleven of twenty-one measures and three of the four guiding principles of the strategy. The German Nano Initiative – Action Plan 2010–2015 focuses on nanotechnology applications in energy, health, food and agriculture, mobility, communication, and security.

India and Nanotechnology

While India has become the world's leader in export of IT services over the last two decades, India lacks a micro-electronics manufacturing industry. Investments in nanotechnology R&D are aimed at ensuring that another great manufacturing opportunity is not missed. For this purpose a series of programs have been developed: (1) Nanoscience

and Technology Initiative (NSTI) from 2001 to 2006, (2) the Nanoscience and Technology Mission (NSTM) in 2007, and (3) the Nano Mission Initiative from 2007 to 2012. The Nano Mission Initiative was launched with a budget of US\$ 44 million over a 5-year period aimed at building capacity in nanotechnology related skills and research (Manish et al. 2010). India's Nano Mission Council will implement a Nanotechnology Regulatory Board to regulate nanotechnology-based products: water filters, biomedical products, chemicals, paints, as well as health and wellness. Funding is growing at a much slower rate than the other cases considered in this article.

Japan and Nanotechnology

In 1981, the Exploratory Research for Advanced Technologies (ERATO) initiated a government commitment to the advancement of research and development into nanotechnology. This early start was probably in part due to the prominence of Taniguchi (1974) who is considered by many to have named the field of nanotechnology. The Ministry of International Trade and Industry (MITI), Science Technology Agency (STA), and Monbusho (Ministry of Education, Science, Sports, and Culture) joined in the funding of basic research on nanoscience through Science and Technology Law 130.

Nanotechnology research and development is also active in the corporate sector. In 2004, investment by private funders reached US\$ 18 billion. Industrial research is concentrated at Hitachi, NEC NTT, Fujitsu, Sony, and Fuji Film. Finally, a growing number of small firms are developing nanotechnology in Japan.

Russia and Nanotechnology

Between 1980 and 2008, Russia dropped from 7th place to 14th place in scientific publications. There has also been little activity over this time in patent development. Furthermore, corporate R&D as a percentage of total R&D has fallen to 10 % in Russia compared to over 60 % in Germany (Gokhberg and Kuznetsova 2011). Russia is implementing R&D policies to assist in diversifying away from reliance on heavily oil and gas toward a more knowledge-intensive, innovation-driven economy (Liu et al. 2009). There is a desire to redevelop the Russian traditions of basic and applied research that existed in the days of the Soviet Union (Swiss Business Hub Russia 2011). In 2006, a commitment to build a new nanotechnology industry was made. Russia has allocated US\$ 11 billion to support nanotech research (Swiss Business Hub Russia 2011; Lux Research 2011). In 2009, 82 % of investments in nanotechnology R&D was subsidized by the federal government.

RusNano is the program used to promote, finance, and plan the development of the Russian nanotechnology industry. By late 2010, RusNano had funded 94 nanotechnology projects for a total amount of 7.2 billion euros. As well as funding homegrown nanotechnology foreign firms like US-based IPG Photonics are being funded if they commit to manufacturing in Russia. RusNano is investing in 19 regional nanotechnology commercialization centers. Finally, RusNano is involved in over 36 educational programs: including an entrepreneurship program with MIT Sloan School of Management (MIT 2010). It is worth noting that a willingness to invest in the commercialization of academic nanotechnology research is a departure from previous local practice.

South Korea and Nanotechnology

South Korea is betting heavily on nanotechnology to improve its high tech competencies. The continual improvement in funding, publications, and nano-enabled commercial output is to the point where some observers (Lux 2008) see South Korea as having surpassed the US in the race for commercializing nanotechnology-based products. Between 1997 and 1999, South Korea had a respectable 1.8 % of world publications (Hullman and Meyer 2003) due to the tripling of its publication output in the science and engineering of nanotechnology. This trend has continued, Korea's share of worldwide nanotechnology publications is now >3 % (Wong et al. 2007). Furthermore, Lux (2008) has estimated that South Korea will spend more than \$500 million on government-funded nanotechnology R&D. South Korea spends more on R&D as a percent of GDP than any other country in this study. The national strategy focuses on Nanotechnology as a critical provider for the next generation economy. South Korea has been active in developing nanotechnologies with other countries, most recently with Russia, Singapore (Institute of Nanotechnologies 2011), and Thailand (Asian Scientist 2011).

Taiwan and Nanotechnology

Taiwanese investment into nanotechnology started early, but was insignificant until 2003. Taiwan invests a much more significant amount as a percent of GDP in nanotechnology research than any other country in this study. The initial focus of Phase 1 (2003–2008) was to develop knowledge and industry. The second phase focused on nanoelectronic and optoelectronic technology, nanoscale instruments, nanotechnology for energy and environmental applications, and nanoscale biomedical research. Taiwan has made attempts to utilize Eskowitz's triple helix (Johnson 2008) by linking the university, government, and industry to address nanotechnology research development

and initial commercialization. Taiwan is considered to be one of the most adept jurisdictions in exploiting emerging technologies (Cientifica 2011), due to their relative level of success.

The United Kingdom (UK) and Nanotechnology

UK policy makers' state that Nanotechnology is a key to the redevelopment of technology-based knowledge economy in the UK (Knowledge Transfer Network 2010). Certainly, the UK has a great number of nanotechnology-based activities. A number of UK centers of research excellence have been involved with both of the European Union's framework bio-nanotechnology initiatives—for example: Nano for Life and Frontiers. Furthermore, the UK is one of the first countries to see the economic development potential of nanotechnology as well as one of the first countries to see its potential peril and call for its regulation in the workplace and in the society (Winans 2011). The UK has spent well over one billion dollars to foster the responsible growth of nanotechnology. By 2011, the UK ranked second only to Germany in the number of Nanotechnology-based companies in Europe (Winans 2011). The UK is one of the top 10 countries in terms of commercializing emerging technologies (Cientifica 2011) and is poised to focus on nanotechnology-based commercialization. The greatest focus for nanotechnology within UK firms is specialty chemicals, sensors, coatings and inks, medical devices, and drug delivery (Knowledge Transfer Network 2010).

The US and Nanotechnology

The United States announced the National Nanotechnology Initiative (NNI) in 2000, the first integrated national nanotechnology research program in the world. NNI invests across 13 US government departments for nanotech research. Between 2003 and 2008, US investments in nanotechnology did not keep pace with the rest of the world (18 % increase in the US vs. 27 % increase in others jurisdictions). Elements of the NNI have been adopted by at least 60 countries (Roco 2005). The US NanoMetro Map (PEN 2011) highlights more than 1,200 companies, universities, government laboratories, and other organizations that are involved in nanotechnology research, development, and commercialization—this is double the number of participants 2 years earlier. Nevertheless, country commitment to nanotechnology is evaluated in the US as below average (Sargent 2008). However, a study found that each year since 1990, US assignees have accounted for approximate two-thirds of all nanotechnology-related patents in the USPTO database (Li et al. 2007). The NNI today has numerous programs to accelerate nanotechnology development in support of US Policy through the Office of Science and

Technology Policy (OSTP) which the NNI states is “intended to enable the rapid advancement of science and technology in the service of national economic, security, and environmental goals by focussing resources on critical challenges and R&D gap” (NNI 2011).

Having provided overviews of policy and activities in different jurisdictions methodology and supporting data are considered.

Method

The study of nine jurisdictions is employed to generate an understanding of differences and similarities in the various locations regarding research inputs, outputs, and measures that represent the ethical environment of the jurisdiction. Purposive sampling was utilized in the selection of nine jurisdictions that have both substantial activity in nanotechnology research and accessible and verifiable information on programs and budgeting. The nine locations have been chosen because they have invested in nanotechnology to a higher degree than others. Moreover, there is data available that is internationally verifiable—whereas some other locales do not have investment data that can be verified. Finally, these countries have made nanotechnology a national policy imperative and have very different policies and index relationships. These nine jurisdictions, importantly, have significant variation on measures associated to the presence/absence of an ethical environment. Secondary source data is utilized in this study for the nine candidates: China, Germany, India, Japan, Russia, South Korea, Taiwan, UK, and USA.

To control for differences in the investments between countries the output measures for all four of the different stages—science, technology, invention, and commercialization—are adjusted based on the magnitude of the investment (see Table 2) and purchasing power parity (PPP) (see Table 3). Basic science output is based on the number of peer-reviewed articles on the subject nanoscience (c) appearing in Scopus (www.scopus.com). Applied Science output is based on the number of peer-reviewed articles on the subject nanotechnology (NSB 2010; Youtie et al. 2008; Kostoff et al. 2007; Kostoff et al. 2006; Grupp and McGee 2004) appearing in Scopus (www.scopus.com). Invention output is based on the number of patents that appear in the US and European patent office databases (Motoyama and Eisler 2011; Preschitschek and Bresser 2010; Lee et al. 2009; Chen et al. 2008; Leydersdorff 2008; Youtie et al. 2008; Li et al. 2007). Information for the European Patent Office was collected for each jurisdiction using the search term: **nanot* or nanop* or nanom* or nanoc* or nanos* or nanob* or nanoim* or nanof*** in the full text AND **country or jurisdiction of interest** as

Table 4 Output data utilized: Basic Science—nanoscience publications, Applied Science—nanotechnology publication, Invention—USPTO and EPO patent counts, and Commercialization—product count

Metric	Cn	Gr	In	Jp	Ru	SK	Tw	UK	US
Nanoscience publications	1,790	697	613	1,209	268	399	258	475	1,852
Nanotechnology publications	6,655	4,328	1,921	4,546	1,092	3,060	1,568	3,379	18,937
USPTO	945	4,769	509	12,869	300	3,469	2,411	2,114	54,216
EPO	194	5,361	5	9,333	91	1,040	229	900	14,469
Product count	55	168	2	51	0	126	30	83	587

Jurisdictions considered: *Cn* People's Republic of China, *Gr* Germany, *In* India, *Jp* Japan, *Ru* Russia, *SK* South Korea, *Tw* Taiwan, *UK* United Kingdom, *US* United States of America

Table 5 Data on environment of different jurisdictions utilized (World Bank 2011; Heritage Foundation 2011; Transparency International 2011)

Years	Cn	Gr	In	Jp	Ru	SK	Tw	UK	US
Ease of business	79	19	134	20	123	8	25	7	4
Economic freedom	135	23	124	20	143	35	25	16	9
Corruption	3.6	8	3.1	8	2.4	5.4	6.1	5.4	7.1

Jurisdictions considered: *Cn* People's Republic of China, *Gr* Germany, *In* India, *Jp* Japan, *Ru* Russia, *SK* South Korea, *Tw* Taiwan, *UK* United Kingdom, *US* United States of America

the applicant. Information for the US Patent Office was collected for each jurisdiction using the search term: ((nano\$ AND (((((((2011 OR 2010) OR 2009) OR 2008) OR 2007) OR 2006) OR 2005) OR 2004) OR 2003) OR 2002)) AND ICN/[country or jurisdiction of interest].

Commercialization output is based on the number of products listed in the nanotechnology product database (Nanotechnology products 2011). In an effort to ensure that the data is as accurate and repeatable as possible, searches were conducted during the revision process. In the case of publication counts and products counts the most recent data collection was on Dec 16, 2011 and for patent counts a query was last run and recorded on Oct 11, 2011. The output data (prior to division by investment adjusted by PPP) is summarized in Table 4. The three measures of environment, Corruption, Ease of Business, and Economic Freedom, are summarized in Table 5.

Results

There is a strong correlation between the three different measures of ethical and regulatory environment. More specifically, *Ease of Business* and *Economic Freedom* have a strong positive ($r = 0.94$, $p = 0.00018$) correlation—they both increase and decrease simultaneously. As *Corruption* increases both *Ease of Business* ($r = -0.89$, $p = 0.00142$) and *Economic Freedom* ($r = -0.94$,

Table 6 Summary of correlations used to test the various hypotheses

Correlation (statistical significance)	Ease of business—rank	Economic freedom—rank	Corruption—score
Science publications/funding	0.38 (0.32)	0.19 (0.62)	−0.13 (0.73)
Technology publications/funding	−0.08 (0.83)	−0.22 (0.57)	0.26 (0.50)
US patents/funding	−0.69 (0.039)	−0.79 (0.012)	0.74 (0.022)
European patents/funding	−0.065 (0.059)	−0.72 (0.029)	0.88 (0.002)
Product development/funding	−0.69 (0.038)	−0.68 (0.043)	0.69 (0.039)

All values that are statistically significant at a level of 5 % or better have been placed in a bold font

$p = 0.0002$) decrease due to the strong negative correlation. Hence, a *Race-to-the-Bottom* involves an increase in *Corruption* accompanied by decreases in *Ease of Business* and *Economic Freedom*. While a *Race-to-the-Top* involves an increase in *Ease of Business* and *Economic Freedom* accompanied by a decrease in *Corruption*. The associated correlations are considered in Table 6.

From the perspective of the hypotheses, the results are summarized in Table 7 and follows below:

For Ease of Business

H1₀ There is no relation between Ease of Business and Pure Science output (science papers/funding).

Supported—no race-to-the-bottom or top.

H2₀ There is no relation between Ease of Business and Applied Science output (technology papers/funding).

Supported—no race-to-the-bottom or top.

H3₀ There is no relation between Ease of Business and Invention output (US Patents/funding and European Patents/funding).

Table 7 Implication of correlation to racing toward the top or bottom for different stages of science, technology, and innovation

	Ease of business—rank	Economic freedom—rank	Corruption—score
Basic science Publications/funding	No race	No race	No race
Applied science Publications/funding	No race	No race	No race
Invention US patents/funding	Race-to-the-top	Race-to-the-top	Race-to-the-top
Invention European patents/funding	No race	Race-to-the-top	Race-to-the-top
Commercialization Product development/funding	Race-to-the-top	Race-to-the-top	Race-to-the-top

Partially Supported and Not Supported—race-to-the-top.

H4₀ There is no relation between Ease of Business and Product Development output (Products/funding).

Not Supported—race-to-the-top.

For Economic Freedom

H5₀ There is no relation between Economic Freedom and Pure Science output (science papers/funding).

Supported—no race-to-the-bottom or top.

H6₀ There is no relation between Economic Freedom and Applied Science output (science papers/funding).

Supported—no race-to-the-bottom or top.

H7₀ There is no relation between Economic Freedom and Invention output (US Patents/funding and European Patents/funding).

Not Supported—race-to-the-top.

H8₀ There is no relation between Economic Freedom and Product Development output (Products/funding).

Not Supported—race-to-the-top.

For Corruption

H9₀ There is no relation between Corruption and Pure Science output (science papers/funding).

Supported—no race-to-the-bottom or top.

H10₀ There is no relation between Corruption and Applied Science output (science papers/funding).

Supported—no race-to-the-bottom or top.

H11₀ There is no relation between Corruption and Invention output (US Patents/funding and European Patents/funding).

Not Supported—race-to-the-top.

H12₀ There is no relation between Corruption and Product Development output (Products/funding).

Not Supported—race-to-the-top.

Discussion

Emergent technologies like nanotechnologies offer greater risk than more traditional technologies. Emerging technologies often result in new innovation models (Walsh et al. 2002) and business models (Allarakhia and Walsh 2011) resulting in greater upside and downside risk. While some suggest that emerging technologies require more proactive regulatory action (Prakesh and Kollman 2003), increasing complexity and technology convergence complicates proactive regulation (Tierney et al. 2012). The belief that *race-to-the-bottom* policies are more effective in quickly generating benefit is investigated by the authors in this study. We found that this is not the case.

The results are consistent in suggesting that early stages of discovery of scientific researches—basic and applied academic researches—are unaffected by the context in which they are conducted under. More specifically differences in ease of business, economic freedom, and corruption are not drivers or inhibitors of success for research—either basic or applied. As pure and applied research rely heavily on the activity of individual or small teams of individuals, it is perhaps unsurprising that this is not an important factor. The absence of structural or ethical impediments does not appear to be helpful for the scientific discovery process—basic and applied research—at least in the terms of publications. While this does not prove the absence of a *race-to-the-bottom* or the *top*, it does suggest that this is the case for nanotechnologies and perhaps other emerging fields.

However, a different finding is present as we consider the move away from research toward actual products. The measures of invention (European and US patents) and development and introduction of products (products) show a positive relationship between high rankings for jurisdictions suggesting that for inventions and commercial products there is a *race-to-the-top*. While one might argue that an environment that lacks all constraints (including ethical barriers) may allow for rapid product development through the provision of an environment where anything goes, the

opposite is found to be the case. It is likely that the presence of clearly defined rules, higher levels of disclosure, greater levels of trust, and reduced costs (associated to lower levels of corruption) results in the appropriate set of ethical rules and guidelines providing the best outcomes for development of commercial products. For example, the presence of appropriate intellectual property rules, procedures, and protections raises the likelihood that products are developed and brought to market as the inventors believe that they are likely to appropriate the value associated with their effort. While in a *race-to-the-bottom* environment, scientists are not hindered from publishing; however, inventors are hesitant to commit resources to products as they are unlikely to benefit from their investment and effort.

Clearly, consideration of a single class of emerging technologies from the perspective of a few metrics is insufficient evidence to base the development of regulations and systems of ethics. However, these findings do provide evidence of a strong positive relationship between commercial success in an emerging technologically based industry and a *race-to-the-top*. This calls for further research into what aspects of the ethical and regulatory environment lead a jurisdiction to better support the extraction of economic and social benefits out of emerging technologies. Given that there is evidence of a statistical relationship, future research should take a more qualitative approach to capture the hidden richness of relationships and identify specific mechanisms that will efficiently provide suitable precautions while enabling the harvesting of benefit.

Implications to Theory and Practice

Based on the metrics considered in this article the evidence is that the ethical and regulatory environments are irrelevant to the production of scientific and technological results. However, as one moves away from pure and applied science to invention and commercialization then the effect of the environment becomes apparent. It is suggested that the findings reflect a *race-to-the-top* as environments that are open are the most successful per unit of funding. For example, the existence of corruption creates artificial barriers to invention and commercialization. Economic Freedom and Ease of Business also result in greater success in invention and commercialization. While many would suggest that this is indicative of an environment where *anything goes* and as such supports a *race-to-the-bottom* what we see is that jurisdictions with *Economic Freedom and Ease of Business* work to reduce the number of societal barriers that firms and individuals face. However, the fewer rules that exist are more likely to be adhered to. That is *Corruption* is a significant issue in the

absence of Economic Freedom and Ease of Business. However, *Corruption* is associated with the presence of a large number of regulations, requirements, and/or rules.

Economic Freedom and Ease of Business are in line with a *race-to-the-top* when regulations are few, but the regulations put in place are carefully crafted creating simple and obvious relations. For example, a carbon tax clearly makes the generation of carbon dioxide less attractive and in doing so helps to eliminate the economic negative externality (societal penalty) associated with green house gases. While, funding or requiring specific technologies to be utilized forces certain invention and commercialization paths to be followed that may be influenced by good intent, but is also susceptible to special interests and corruption. An interesting possible explanation of the empirical results is that our lack of understanding on what the right sort of regulations, safeguards, and constraints are required results in the decision that are made to constrain the economy are made naively allowing for corruption, emotions, and special interests to govern. Hence, the appropriate path to protect society from the negative externalities that the development of emerging technologies can have is to put regulations in place where they are clearly warranted (such as lab safety), ensure funding and scientific capabilities to gain a better understanding of possible societal impacts on the technology (toxicity, risk, effects on existing systems), and to ensure that the rules and regulations that do exist are followed strictly and consistently. A jurisdiction that fails to provide an appropriate ethical environment may be able to have substantial activity in the pure and applied sciences. However, inventors and entrepreneurs are likely to either not attempt to develop their ideas and products at all or move to another jurisdiction as they move toward the commercialization stage.

Conclusions

The argument that economic development is supported by a *race-to-the-bottom* is not supported by this study of the pursuit of emerging technologies in different jurisdictions. We find that racing in either direction (*top* or *bottom*) appears to be irrelevant to the production of scientific and technical results, the important factor here is funding. However, as we move toward invention and commercialization the presence of *Corruption* (*race-to-the-bottom*) is problematic. *Economic Freedom and Ease of Business* support invention and commercialization. As examples of *Economic Freedom and Ease of Business* may suggest to some that one allows business to do anything, it is important to note that these measures are strongly related to having a clear and consistent set of rules and regulations that allow decisions to be made that reflect societal needs

and requirements of the host jurisdiction. In the absence of knowledge and understanding of the technical risks and societal implications of emerging technologies, attempts to regulate or control are bound to failure as their formation will not be driven by the solution of an identified threat or problem. Hence, ideally emerging technologies are developed to offer economic and social benefits in an environment that incorporate economic freedom with ease of doing business, but that this is moderated by an integrated, but independent, programs of research to identify potential negative side effects of a technical nature—such as toxicity—and a societal nature—such as damage to communities (e.g., Hightower (1973) and Rogers (1995)). Hence, this article call for an increased integration between scientific research and the study of the risks, benefits, threats, and opportunities associated with it. In doing so, the economic and social benefits of emerging technologies can be enjoyed, while the risks to individuals, society, and the environment can be minimized.

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