THE BALANCE OF POLICY, PRESTIGE, AND POWER: A COMPARISON OF NANOTECHNOLOGY RESEARCH FRAMEWORKS IN THE U.S. AND CHINA

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On my honor as a University student, I have neither given nor received unauthorized aid on this assignment as defined by the Honor Guidelines for Thesis-Related Assignments.

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NANOTECHNOLOGY: A TALE OF TWO COUNTRIES

With potential applications in healthcare, agriculture, energy storage, water filtration, and much more, nanotechnology offers promise for a better future. According to the United States (U.S.) National Nanotechnology Initiative (NNI) (2018), "nanotechnology is the understanding and control of matter at the nanoscale, at dimensions between approximately 1 and 100 nanometers" (para. 1). Working at the nanoscale, scientists are able to transform seemingly ordinary materials into extraordinary ones, and extract fantastic properties from them. Many nanotechnology-related breakthroughs have already occurred, which has led to bullish attitudes towards its potential applications and uses. Taken from a report by the Rennsselaer Polytechnic Institute Nanotechnology Center, this quotation summarizes the buzz of excitement with nanotechnology near the turn of the 21st century:

> "Nanotechnology can make it all better – literally – by re-engineering the fundamental building blocks of matter. It is one of the most exciting research areas on the planet, and it may lead to the greatest advances of this century. (as cited in Sarewitz & Woodhouse, 2003, p. 67)

Despite the praise and promise of what it can be, nanotechnology is still primarily in its research and development (R&D) phase, and could be decades away from forming the fantastic products that are being dreamt about. Nevertheless, companies such as Proctor & Gamble are productizing more and more of nanotechnology research and pushing it to market (Lin & Allhoff, 2008, p. xxiv). This information comes unsurprising however, especially considering the large stake nanotechnology holds in the market. BBC Research (2016) reports that in 2014, the nanotechnology global market was valued at $22.9 billion, and is expected to grow to $90.5 billion by 2021.

With all this in mind, nanotechnology is increasingly becoming a breeding ground for international competition. As Professor Ortwin Renn and Dr. Mihail Roco, prominent leaders in the field of nanotechnology, state in the 2018 Nanotechnology Risk Government report, after the U.S. National Nanotechnology Initiative (NNI) was announced in 2000, within five years, similar nanotechnology R&D programs would spring up in about 60 other countries (p. 21). Of these countries, a clear competition has emerged between the U.S. and China, both of whom are strong leaders in the area of nanotechnology research. The U.S. and China both bolster strong government funding of nanotechnology R&D, and dominate the field in terms of research publications (Dong et al., 2016).

However, when compared, evidence suggests that Chinese nanotechnology R&D may be more *quantitatively* driven rather than *qualitatively*. According to Statnano, a comprehensive database of nano-related information, in 2018, China held 39.47% of total nanotechnology publications while the U.S. only held 14.75%. Nanotechnology research in China also appears to be of higher interest for top-tier universities compared to the U.S., where interest is spread out across various academic institutions (Kostoff et al., 2007, p. 705). But while China appears to dominate the stage of nanotechnology, the country's research is noted to generally have lower quality research than that of the U.S. One common metric to quantify the quality of research is a publication's impact factor. The impact factor is the yearly average number of citations of publications in a given journal; thus, the higher the impact factor, the higher quality the publication is generally regarded as. In a 2016 research report, between 2003 and 2013, the U.S. published 1,068 nanotech paper in journals with an impact factor >20, while China only produced 76 papers in journals with an impact factor >20 (Dong et al., p. 9). China R&D,

although notably improving with strong government intervention and regulation, is also historically noted to suffer a plethora of fraudulent cases in academia (Qin, 2017).

Using China as an example, there is a clear need to better analyze and understand the current research systems behind nanotechnology. At its current rate, nanotechnology is becoming an imminent ubiquity to our daily lives, and with its dangerous power comes the increasing importance to better analyze nanotechnology at its most critical phase: preliminary research and development. By performing a case study on Chinese R&D systems for nanotechnology while comparing and contrasting to that of the U.S., we will be able to point out major issues in our current system, and help create more safe, sound, and responsible academic frameworks for nanotechnology to grow in.

Proper analysis will first require a fine-tuned understanding of relevant stakeholders for nanotechnology, and then an evaluation of how they interact with each other. This is best done through the Social Construction of Technology (SCOT) perspective, which emphasizes nanotechnology R&D to be an artefact that exists within the social context of relevant stakeholders and gatekeepers (Bijker et al., 2001). By using a SCOT perspective in both the U.S. and Chinese landscapes, with an emphasis on the latter, the report addresses current issues surrounding nanotechnology R&D, and gives suggestions for improvement. Although SCOT is commonly performed through an analysis of equally-weighted, relevant stakeholders, government intervention is scrutinized in this report due to the critical role it plays in China. A loosely coupled technical project draws parallels to the role of government intervention through investigating the rise of electronic waste (e-waste) in China. Similar to the case of academic fraud in nanotechnology R&D, China is attempting to solve their growing dilemma of e-waste management with stricter government regulations, but still suffers from ineffective enforcement.

In order to address this issue, the technical project focuses on designing a plant using novel processes, which can effectively and safely transform e-waste into precious metals and energy.

UNDERSTANDING THE ISSUE: SOCIAL CONSTRUCTION OF TECHNOLOGY

Of the many methods used to study the intersection and interaction between society and technology, this paper explores the use of SCOT because of its unique approach that is highly applicable to the given case study. SCOT argues against technological determinism and believes that technology is an artefact, shaped via interpretive flexibility from the social groups surrounding it (Bijker, 2001). This framework is henceforth more useful for our case, where we investigate how different relevant stakeholders shape R&D institutions surrounding nanotechnology. Nanotechnology R&D, in many other situations, can and should be considered with technological determinism, which treats the technology as an actor within a complexly knitted system that can shape social structures and values (i.e. using an Actor Network Framework). But in our present case, this perspective does not offer any novel insight to our research question, and thus, we only focus on inspecting our technology via social determinism.

As can be seen on the following page, nanotechnology R&D can be considered as an artefact at the center of a SCOT framework (see Fig. 1). In this figure, the nanotechnology R&D artefact, held by the researcher itself, is influenced by governmental pressures, an academic network, the consumer market, international competitors, patent offices (i.e. those concerned with IP), and private businesses, which together comprise a non-exhaustive list.

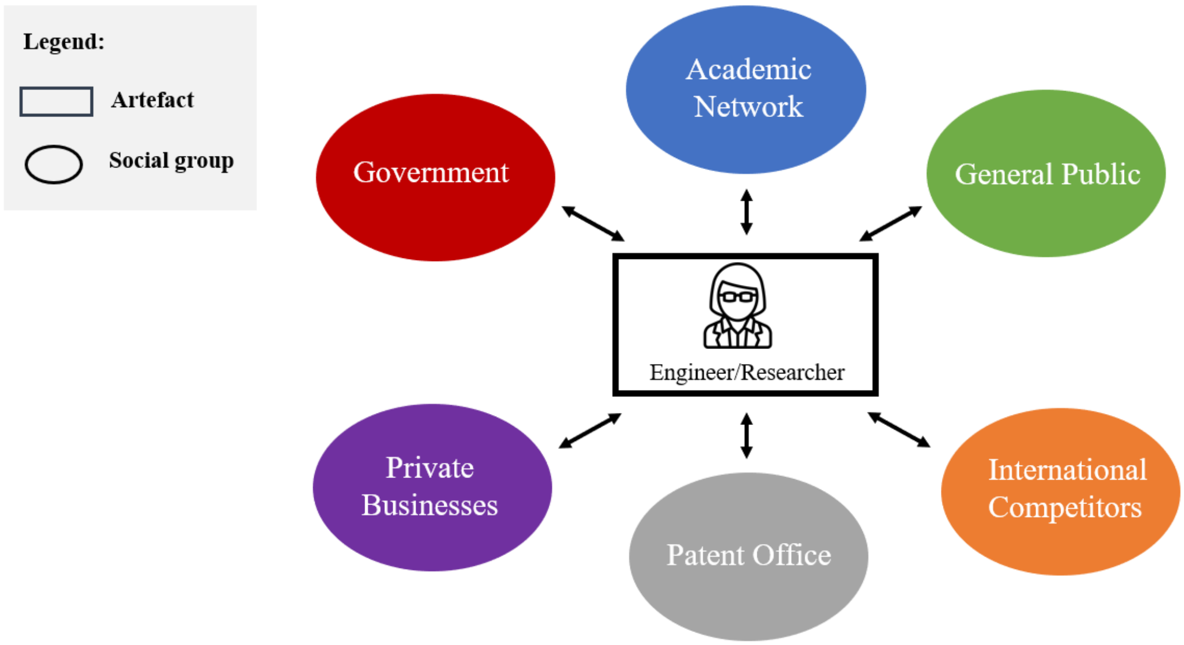

Figure 1: SCOT framework for nanotechnology R&D: At the center is the engineer/researcher, who is responsible for interacting with and protecting the interests of relevant social groups. (Ho, 2019)

THE FRAUD AND FAME OF ACADEMIA

To begin our analysis, we first investigate the academic institutions which enable the development of nanotechnology in the U.S. and China. For China, its education system was originally a source of pride. In the 1940s at the onset of the People's Republic of China, through the 1970s to post-Mao China, massive effort has been made towards expanding education across the country (Tao et al., 2006). However, China's academia has recently developed into a system influenced by academic fraud, discredited research, and a culture of performance evaluations that emphasizes and rewards *quantity* above all else (Han & Appelbaum, 2018). For example, in 2017, major publisher Springer retracted over 100 Chinese papers from one journal after discovering they had been using fake peer reviews to boost the quality of their work (Jia, 2019, para. 10). Events like this, among many others, has led to a notable decline in the reputation and quality of China's research. A lack of academic discipline also exacerbates this issue by encouraging scientists to continue fraud without fear of any immediate consequences. As Professor Zhang Lei (2017), a professor of applied physics at Xi'an Jiaotong University, states when comparing research discipline in China vs. the U.S., "In America, if you purposely falsify data, then your career in academia is over … But in China, the cost of cheating is very low. They won't fire you" (as cited in Qin, para. 18).

In the United States, research is also well known for its share of scandals over the past few decades of nanotechnology research. In 2002, research and scientific development company Bell Labs Innovation (now named Nokia Bell Labs) dismissed nanotechnology physicist Jan Hendrik Schön after he was discovered falsifying his data (Brumfiel, 2002, para. 2). Even more recently, Harvard scientist and nanotechnology expert, Charles Lieber, was arrested in 2019 for concealing more than $2 million in Chinese backing for undocumented research. The Lieber case is not the only unique instance on undocumented and fraudulent research in the U.S., with similar events occurring at MD Anderson Cancer Center and the Los Alamos National Laboratory (Viswanatha & O'Keeffe, pp. 2-3). Clearly, both countries exhibit their fair share of fraud and immoral behavior in the lab. But despite the mounting cases of research scandal on both sides, these fraudulent practices are noted to be handled more quickly and efficiently in the U.S. than in China, and may be because of how investigations are organized.

Recently, the Chinese government has undergone a major shift in handing off the responsibility of deterring and examining scientific misconduct to its new Science Ministry ("China sets a strong example on how to address scientific fraud," 2018). Before, many investigations in China were handled by the institution itself, a notably ineffective system with institution personnel having "little to gain and a reputation to lose" by self-conducting these investigations ("China sets a strong example on how to address scientific fraud," 2018, para. 5).

In comparison, the U.S. already has an assemblage of national organizations and self-regulation initiatives. As noted in The National Academics of Sciences, Engineering, and Medicine (2017) publication “Fostering Integrity in Research,” federal agencies exist in the U.S. and have ultimate power over investigations of research conduct, such as the Department of Health and Human Services and the National Science Foundation (NSF), but research institutions are still primarily held responsibility for preventing and detecting misconduct (p. 88). It is through this healthy mix of national and self-regulation that results in an environment which promotes much stricter research practices and a better sense of accountability among researchers. With national enforcement, researchers are forced to understand the potential consequences of their actions. But with an overall system of self-regulation, the researchers are also empowered to build upon and explore the idea of ethics in their work. China is still suffering the blows from their previous research scandals, but this new wave of national enforcement and regulation provide hope for improved research standards in China.

GOVERNMENT SUPPORT SYSTEMS

Given the huge government support by the U.S. and China to incorporate nanotechnology initiatives into programs and policy strategies for future scientific developments, it is no surprise both nations are frontrunners to the great nanotechnology race. According to Gao et al. (2015), the U.S. government started the first nanotechnology program, the National Nanotechnology Initiative, and former President Obama proposed a $1.5 billion investment in it in 2015 (p. 13). The U.S. has also made it a point to focus. on strengthening nanotechnology development in secondary schools and institutions of higher education, such as through the Nanotechnology in the Schools Act of 2007, which is focused on “preparing United States students for careers in nanotechnology” (Sec 2.a.6). Similar to the U.S., the Chinese government houses program initiatives like the Nanoscience Basic Research Program, and invested $1.6 billion for research in the field of nanotechnology in 2009 (Gao et al., 2015, p. 13). China does not try to engage with lower academic institutions as formally as the U.S., besides a few events which expose primary and secondary school students to observe nanotechnology research at higher universities (Hu, 2012). However, this is changing as the Chinese government has more recently developed a special fund called the Young Scientists' Innovation Fund, which supports funding for researchers younger than 35 years of age (Qiu, 2016, p. 151).

Beyond the influx of cash and programs toward nanotechnology initiatives, a major point of consideration is the inclusion of ethical thought into government mandates for each country. For China, Mingyan Hu (2012), a philosophy professor at the Party School of the Central Committee of the Communist Party of China, points out that China has no government policy documents on nanotechnology which addresses ethical considerations (p. 2). In contrast, in the 21st Century Nanotechnology Research and Development Act of 2003, the National Technology Program was made to explicitly address appropriate ethical considerations in U.S. nanotechnology research. This is an especially disconcerting fact when looking at nanotechnology R&D in China. When considering any type of technology, it is paramount to consider ethics of design and usage among the many other features. In fact, according to Ellul's "Seventy-Six Reasonable Questions to Ask About Any Technology," moral and ethical questions make up two of the nine major categories. Not fully addressing this area, while also pushing for development and commercialization of nanotechnology, leads to huge unsettling questions on the future of nanotechnology in China.

THE PRESSURE OF MONEY

In light of the huge market share nanotechnology holds, it is unsurprising how strongly commercialization influences much of its R&D. According to a forum from the 2016 Sixth International Conference on Nanoscience and Technology, many nanotechnologist scientists, who both operate in the U.S. and in China, agree that China is primarily focused on commercialization (Qui, p. 149). Among the forum members is Dr. Yang, an expert on nanomaterial energy research at the University of California at Berkeley, who actually describes China's desire to rapidly commercialize as a major weakness of Chinese nanotech research (p. 150). While Dr. Yang does not conduct research within China, he does regularly collaborate with the Suzhou Institute of Nano-Tech and Nano-Bionics, and is thus well-versed with research practices in both countries. Professor Chunli Bai, President of Chinese Academy of Sciences in Beijing, also backs up this claim, stating most Chinese researchers are keen to follow "trendy research areas" (as cited in Qiu, 2016, p. 150).

In comparison, Yang claims that the U.S. focusses on more basic research and is less motivated by the commercialization of its nanotechnology (as cited in Qiu, 2016, p. 150). This conflicts with other reports, which state that the U.S. has the most companies involved in nanotechnology research, manufacturing, and engineering (Gao et al, 2015, p. 17). This might be reasoned by considering the differences between purely academic nanotechnology R&D vs. nanotech company R&D divisions. Because the majority of Chinese nanotechnology research is carried out by universities rather than specialized industry R&D divisions, Chinese universities are more inclined to focus on commercial viability. Research funds, which must be applied for in academia, are also given by government-initiated research institutions such as the National Steering Committee for Nanoscience and Nanotechnology (NSCNN) in China, which are known to determine funding off of demonstrating the commercial utility of projects (Jarvis & Richmond, 2011). Thus, the U.S., which houses a diverse mix of industry R&D and purely academic institutions, can afford to focus upon more free and basic research, trusting that commercializing will come later. Yang in this case, points out the superiority of U.S. research, stating that research in America switches to commercial products "when the time is right" (as cited in Qiu, 2016, p. 150). China could benefit from allowing diversification of its R&D institutions, but should foremost decrease its commercialization pressure that the government places upon its researchers and engineers.

PUBLIC PERCEPTION AND SENTIMENT

Misinformed Trust

Despite the potential fears and dangers of this unknown tech, nanotechnology in both countries has continued to be revered as a revolutionary innovation by the public. In Sarewitz and Woodhouse's work, "Small is Powerful," they exemplify public awe towards the possibilities of nanotechnology by discussing the development of a new generation of sensors and the radical evolution of organisms on the nanoscale (p. 65). The consensus is similar in China, where there is a strong agreement that nanotechnology, like nanomedicine for example, is the future (Qui, 2016, p. 149). This overwhelming approval comes despite the vast majority of people not fully understanding the technology itself. In a 2008 study conducted by Peter D. Hart Research Associates on over 1,000 adult Americans, they found that while 42% of the public had heard "nothing at all" about nanotechnology and 29% heard "just a little," only 6% said that they perceived the "risks will outweigh the benefits" (pp. 5-6). A similar situation can be assumed in China as well, where nanotechnology leaders like Bai express the need to better educate and inform the public on nanotechnology (as cited in Michelson & Rejeski, 2008, p. 291). With generally uninformed public approval, it is very likely that this will translate into economic action and additional market pressures. In China, nanotechnology is not just an extravagant new technology to invest in, but is also a new commercial means to increase national economic well-being through indigenous scientific growth, and a decrease in dependence on export-led growth and low-end manufacturing (Jarvis & Richmond, 2011, para. 6).

The dangers of this misinformed approval are obvious: with increasing public approval and a lack of clear understanding, we may be motivating a powerful technology to develop in unethical and immoral ways. Therefore, it would be beneficial to have increased nanotechnology education programs throughout both countries. As Michelson and Rejeski state in their comparative writing on nanotechnology governance in the U.S. and China, these efforts are critical and must be "supported by both government and industry," and will most likely require a blend of traditional and modern media outlets to educate the public (p. 292). It is certainly no easy task, but public engagement and education is crucial to ensure that research, often times pandering to whatever public sentiment dominates, is truly done for the greater good.

The Danger of National Pride

An additional, and potentially dangerous, factor for both countries in spurred nanotechnology growth is also the public sentiment towards international competition. For the U.S., while it has more recently grown to be better accepting of Chinese influence, China has grown to become more prideful and distrusting of the U.S. From an Opinion Survey in 2017 about Chinese and U.S. citizen opinions, 80% of surveyed Chinese citizens believed that China should trust the U.S. a little or none at all, while 61% of Chinese believe the U.S. is trying to "prevent China from becoming a great power" (Committee of 100 (C100), p. 8). In contrast, 54% of surveyed Americans think the U.S. should trust China, and 66% of Americans desire a collaborative relationship with China (C100, 2017, p. 8). These findings align with China's *rising-star* attitude in seeking to be the best, and not just exclusively in academics. In Richard Engel's MSNBC special, "Made in China," an interview with local Chinese citizens revealed the public sentiment towards being the best: as local Sandy Zhang succinctly states, "we want our country to be #1," and for the U.S, "#2." Although this is only the opinions of one person, it does reflect the many Chinese citizens who hold similar beliefs in their national pride and the fierce competition China has with the U.S. The nanotechnological landscape offers a rich and unique opportunity to capitalize on this belief of "#1" through increased nanotechnology-related publication output, higher research funding, and an abundance of commercial nanotechnology products for China. But as can be seen from before, while these rapid advancements might be a point to boast, it may also be what is leading the nations' academic institutions and universities into decline. In order to truly take time to stop and reevaluate one's country, may also require the relinquish of national pride, something that the Chinese people may have trouble adapting to.

A SYSTEM IN CONTEXT OF NANOTECHNOLOGY R&D

Considering all of the previously outlined issues which contribute to the hindrance of nanotechnology R&D, there are a greater number of concerns with the current research framework in China than the U.S. To better illustrate the problems that have been identified, we use a System in Context Model of the nanotechnology R&D in China, as developed by Professor Bernard Carlson. This can be seen below in Figure 2.

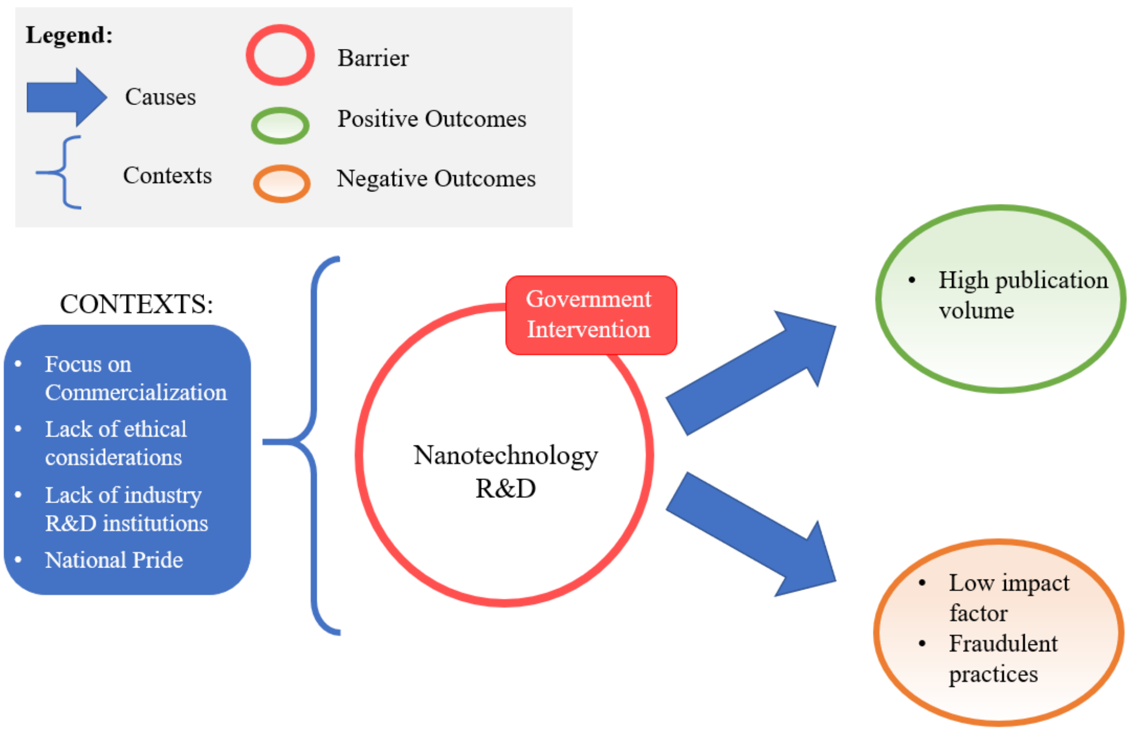

Figure 2: System in Context Model of Nanotechnology R&D in China: the Chinese government serves as a barrier to nanotechnology R&D. This barrier results in both positive and negative outcomes (Ho, 2019).

With this model, we can clearly visualize government intervention to be the barrier to nanotechnology R&D, reinforced by several contexts of the environment. Despite the self-regulation initiatives in China for researchers to monitor their own work, the government can still be considered an overbearing force that consistently promotes the idea of research as a means to increase commercial power and national pride for the country above all else.

Researchers and institutions that exist within this barrier are then forced to pump out work that panders to the government's objectives, unfortunately resulting in a decline of research quality and a narrow view of what nanotechnology can be. As can be seen in the figure, this still results in positive consequences, with China leading the world in nanotechnology research in high publication numbers. In order to address this issue, we will need to pull our findings from the SCOT framework of nanotechnology R&D that was previously employed. In this framework, government intervention is another stakeholder who participates with nanotechnology R&D. We must consider the researcher/engineer as the true center of this model, who has the power to control the outcome of this powerful technology, and must consider the interests of all its relevant stakeholders. The responsibility of the stakeholder should be to guide and support the engineer in their endeavors by providing space for ethical thought, and a balance of motivations. By adopting the SCOT model, we can provide a potential solution to address the major issues outlined the System and Context Model for Chinese nanotech R&D.

THE TIP OF THE ICEBERG

Nanotechnology provides an exciting new opportunity to develop life-changing innovations, and is one that should not be squandered by leading countries such as the U.S. and China. Both countries have clearly made nanotechnology a national priority and have invested huge capital into their research programs, actions that have contributed to their rise as global leaders in nanotech. However, while U.S. researchers are able to conduct more basic research because of their diverse assortment of dedicated R&D industry divisions and purely academic institutions, China relies solely on academic institutions and are therefore more susceptible to market pressures in academia. Government intervention may be seen as the barrier to nanotechnology R&D because of its power over the engineers and researchers. By allowing the government to focus on commercial utility of research, which is only exacerbated by national pride and lack of ethical considerations, China endangers the fundamental mindset of its researchers who have already begun to turn to fraudulent practices. The research scandals that have already surfaced are not unique to China, with many similar cases occurring in the U.S., but are worsened by a system which lacks strong accountability and ethical thought. Therefore, China may benefit from drawing inspiration from the U.S. in several ways: to diversify their research institutions, focus less on commercial utility and more on free research, and to foster a better sense of collaboration in research, nationally and internationally. Already, China is undergoing major shifts in its research frameworks, such as developing its Science Ministry for the first time, but only time can reveal how these changes will be received by its engineers and researchers.

Overall, we are still only at the tip of the iceberg for nanotechnology. It is a technology not yet fully understood, but is one that many are desperate to tap into and reap its benefits. Talent and funds make up the fundamental components of research, but by themselves are not sufficient in providing an adequate framework to conduct completely sound and ethical research. To better foster the correct environment, we need to be cognizant of how we are framing the need and how different stakeholders interact, which may require us to draw inspiration from research frameworks of countries across the ocean. Neither the U.S., nor China, nor any other country, can be considered as a perfect model in how they structure and support nanotechnology research. But as the U.S. and China are both countries at the forefront of radically changing the world with their work, they have the best opportunity to begin a new era of thoughtful collaboration, well-informed decisions, and ethical scientific exploration.

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