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Will China's quest for indigenous innovation succeed? Some lessons from nanotechnology

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ABSTRACT

Over the past decade, the Chinese state has made major efforts to transition China's economy away from a focus on manufacturing, and towards a focus on generating indigenous innovation in R&D intensive fields such as nanotechnology. This goal has been pursued through a comprehensive industrial policy framework that aims to give preferential treatment to Chinese companies in domestic markets while also devoting significant resources towards basic and applied R&D, building science parks and research centers, funding focused venture capital funds, and recruiting prominent expatriate scientists and entrepreneurs from universities and businesses abroad. This paper, based on interviews with scientists, engineers, entrepreneurs, and venture capitalists in Shanghai, Suzhou, and Beijing, examines the strengths and weaknesses of China's push for indigenous innovation. We use the case of nanotechnology to address the pressing question of why China continues to underperform with regards to generating innovative, high-tech companies and products, despite heavy public R&D investment and the presence of one of the world's largest talent pools of potential scientists, engineers and entrepreneurs.

1. Introduction

Over the last two decades, China has succeeded in elevating several hundred million people into middle-class status. Much of this success can be attributed to China's ability to leverage low cost labor, land, and energy resources to develop manufacturing hubs focused on the production of consumer goods. In the process, China positioned itself as a manufacturing powerhouse. This success was driven by a substantial amount of process-oriented innovation, or improvements to the manufacturing process, particularly in fields like information technology. While this process-oriented innovation has contributed to China's dramatic economic growth, product innovation – the ability to create innovative products and associated brand identification – has lagged.

The Chinese government views its heavy dependence on foreign technologies and innovations as disadvantageous for China's long-term competitiveness. As a result, the Chinese Communist Party (CCP) has sought in recent years to refocus China's economy into innovation-rich, R&D heavy industries, such as nanotechnology and biological sciences [4]. In 2006, the government launched its National Medium- and Long-Term Plan for the Development of Science and Technology 2006–2020 (hereafter MLP), making indigenous innovation—as opposed to acquiring foreign technology (c.f [33])—the top developmental priority. The MLP prioritizes Chinese resources in innovation, and de-emphasizes international dependence [49]. There are a number of parallel policy areas that the MLP seeks to develop: investment in basic research; development of human capital, particularly through the luring home of expatriate Chinese scientists and engineers; building and strengthening high-tech zones and regions; and an increase in the development of new technologies or the transfer of existing technologies [15]. Given the country's limited resources, however, it also concluded that China should "do what it needs and attempt

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nothing where it does not" (*you suo wei, you suo bu wei*), concentrating its public investments where a high payoff was deemed most likely. Four "science megaprojects" (one of which is nanotechnology)[1] were therefore singled out as key areas for funding, along with thirteen "engineering megaprojects,"[2] eight "frontier technology" programs,[3] and eleven "key areas"[4] [15]: Box 2, p. 43). A Special Projects Office was created with MOST to review proposals, approve funding, and monitor projects. And when global financial markets collapsed in November 2008, China launched its 4 trillion RMB (roughly $600 billion) stimulus package, with "science and technology innovation and industrial structure adjustment" identified as one of its ten investment areas. The MLP thus seeks to transform China into a technology-focused economy by 2020, and a global leader in R&D, science, and product innovation by 2050. Key thrusts of the MLP include significantly increased public investment in basic research as well as applied R&D, building science parks and research centers, funding focused venture capital funds, and recruiting prominent expatriate scientists and entrepreneurs through such initiatives as the Thousand Talents Program and the Thousand Young Talents Program.[5]

The MLP's effort to foster indigenous innovation has been reinforced by China's 11th and 12th Five Year Plans, which – in an effort to transition from "made in China" to "designed in China" – identify a number of "strategic emerging enterprises" such as biotech and new materials, and increasing the percentage of GDP that is invested in research.[6] The 12th Five Year Plan, in comparison with the 11th, lowers annual growth targets (from 7.5% to 7.0%), reflecting a greater emphasis on more sustainable development, and places "greater emphasis upon economic development versus simply growth, scientific education … improving overall welfare [and] expanding domestic demand" [17]: 2; see also [46].

China's emphasis on indigenous innovation positions the Chinese state as a key driver of economic development. The fifteen year MLP and associated Five Year Plans constitute a strong form of industrial policy,[7] in which key areas of basic science, applied engineering, and industrial sectors are targeted for public investment at all governmental levels. The intention is to wean China from its dependence on foreign technologies, enabling domestic advances in science and technology to drive product innovation - to move China from imitation to innovation.

Can such state-driven efforts succeed? At first glance, the results of China's efforts are impressive. The MLP has resulted in the construction of numerous high-tech science parks,[8] a dramatic increase in scientific publications by Chinese authors,[9] and a substantial increase in the number of patents obtained by Chinese scientists and engineers[10]. Yet in their study of China's IT industry in Beijing, Shanghai, and the Pearl River Delta, Breznitz and Murphree [10] concluded that China's hope for economic development lies not with indigenous innovation, but with continuing what it has been doing successfully all along: focusing on the smaller-scale, incremental innovations that have enabled Chinese firms to provide specialized inputs into global production networks. They note that although Chinese firms may excel in re-engineering and improving existing products, their ability to innovate new products remains limited. This is because of what Breznitz and Murphree [10] term "structured uncertainty:" an ever-changing set of policies and goals emanating from Beijing that when combined with strong pressure to show success at the local level, have encouraged provincial and local governments to adopt lower-risk strategies that emphasize shorter-term incremental gains, rather than higher-risk (and longer-term) technological breakthroughs. While these incremental gains have clearly paid off in terms of China's impressive economic growth [85], the unpredictable nature of national economic policy discourages sustained investment in long-term, high-risk R&D activities. Breznitz and Murphree's implicit advice to Chinese planners: forget about indigenous innovation, stay the course.

Given China's current policy trajectory as well as statements from its leadership, we believe that it is highly unlikely that China will stay the course. This is because China is not only interested in increasing profit margins or sustaining economic progress, however important both may be to assuring social stability. China's long-term goals are not only about economic growth, but also about China's global standing. After a "century of humiliation" following the Opium Wars [44,92], China's leadership clearly aims to see China reclaim its international image and prestige – what is widely seen as its rightful place on the historical stage. The drive for indigenous innovation has to be understood in this context: Playing the role of economic second, to supply chains that originate in the U.S., Japan, or Europe, is no longer regarded as an option. If the theme of the Hu Jintao decade was "harmonious society" (和谐社会), the emerging theme of the Xi Jinping government has been realization of the "Chinese dream" (中国梦). In a much commented 2012 speech at the National Museum's "Road to Rejuvenation"

[1] The other *science megaprojects* are development and reproductive biology, protein science, and quantum research. It seems questionable whether or not nanotechnology is currently regarded as a science megaproject, since much of the focus and funding is on engineering applications [12].

[2] The engineering megaprojects are advanced numeric-controlled machinery and basic manufacturing technology; control and treatment of AIDS, hepatitis, and other major diseases; core electronic components, high-end generic chips, and basic software; drug innovation and development; extra large scale integrated circuit manufacturing and technique; genetically-modified new organism variety breeding; high-definition earth observation systems; large advanced nuclear reactors; large aircraft; large-scale oil and gas exploration; manned aerospace and moon exploration; new-generation broadband and mobile telecommunications; and water pollution and control and treatment.

[3] The frontier technology programs are advanced energy; advanced manufacturing; aerospace and aeronautics; biotechnology; information; laser; new materials; and ocean.

[4] The key areas are agriculture, energy, environment, information technology and modern services, manufacturing, national defense, population and health, public securities, transportation, urbanization and urban development, and water and mineral resources.

[5] The MLP aims to increase the competitiveness and competencies of Chinese companies through more controversial economic tactics as well, such as the forced transfer of foreign technologies to Chinese companies in exchange for access to Chinese markets [54,56]. These approaches have drawn recent criticism from the United States government, as well as several prominent multinational corporations that have a market presence in China [54,56].

[6] The plans also call for increased emphasis on consumption-led growth (as opposed to continued reliance on high levels of public investment), green development (reducing carbon emissions per unit of GDP), and – ominously, in view of the U.S. Chamber of Commerce – industrial upgrading through "re-innovation" of foreign technology.

[7] A report commissioned by the U.S. Chamber of Commerce, entitled *China's Drive for Indigenous Innovation: A Web of Industrial Policies*, regards the MLP as a "a blueprint for technology theft on a scale the world has never seen before" [54] [55]: 4).

[8] China's Ministry of Science and Technology (MoST), Department of International Cooperation (CISTC), lists 48 science parks on its website (http://www.cistc.com/englishversion/China_ST/China_STAdd2.asp?); UNESCO lists 80, compared with 22 for Japan and 72 for the United States (http://www.unesco.org/new/en/natural-sciences/science-technology/university-industry-partnerships/science-parks-around-the-world/).

[9] China ranked second to the U.S. in number of scholarly publications in 2010 [106], although the quality of Chinese (as measured by impact) is another matter (see, for example, [86]; regarding the "clubbing effect" on Chinese citations).

[10] In 2014 China's State Intellectual Property Office (SIPO), now the world's largest, received 868,511 utility model patent applications [27]; the U.S. Patent and Trademark Office received 579,782 utility model patent applications [88].

exhibition, soon-to-be President Xi[11] set forth the path that will likely characterize his decade as China's leader: "I believe that realizing the great revival of the Chinese nation is the greatest dream of the Chinese nation in modern times" [96].

In this paper we assume that China will continue its effort to become a global innovator, seeking to create breakthrough products with global brand name recognition. If China's leadership hopes to succeed, it will need to reduce the uncertainty - structured or otherwise - in its state-driven innovation system. In what follows, we examine some of the principal barriers to China's quest for indigenous innovation.

We focus on nanotechnology for two reasons. First, nanotechnology is believed to have great commercial promise as a platform technology that will enable breakthroughs in a wide range of fields, including targeted drug delivery, ultra-light carbon-based materials, greatly enhanced water filtration, highly efficient low-cost energy production, and high-speed computing. As a result of its promise, nanotechnology has received considerable public investment in the U.S., Europe, and China in the last fifteen years.[12] Second, as an emerging technology that is one of the four science 'megaprojects' identified in China's MLP, it provides a useful case study for China's innovation potential. While China's success in IT was largely the result of its ability to build on already established technologies [10], with nanotechnology China launched its national effort at roughly the same time as the U.S., Europe, Japan, and other advanced economies. As a nascent technology, China sees itself in a race to become a leading innovator, rather then engaging in second-tier innovations, however successful they may be. Nanotechnology therefore serves as a useful case study to address whether China's substantial public investment in R&D activities and infrastructure, combined with its vast pool of potential scientists, engineers, and entrepreneurs, has resulted in the innovations envisioned by China's leadership.

In terms of patent applications in nanotechnology, China's performance has been impressive. Fig. 1 shows the share of the top four countries in terms of global nanotechnology patent family counts.[13] In 2013, China accounted for 26.6% of nanotechnology patents worldwide; the U.S., 16.4%; South Korea, 13.2%; and Japan, 9.3%. The growth of China (and of South Korea to a lesser extent) and the decline of both the U.S. and Japan are the most significant changes in the last ten years. Our research also finds that two-thirds (66%) of China's nanotech patents are from the academic sector, while only a sixth are corporate (and roughly another sixth are from government).

Fig. 2 shows that in China, the share of carbon nanotubes, surfaces and substrates has become more prominent among China's top ten patent areas.[14] These are all areas, however, that are fairly low on the nanotechnology value chain. Although they include nanomaterials that are typically incorporated into final products, those products – even when highly innovative – are typically not Chinese brands. China may well have emerged as a world leader in graphene and carbon nanotube research, but providing even breakthrough inputs mainly benefit the (non-Chinese) firms that make the final products.[15] In fact, as one study notes, "the increase in production by Chinese firms will exacerbate global oversupply, with a profound effect on global prices and margins" [42].

What, then, constitutes truly innovative indigenous innovation? In the next section we develop a model that addresses this question, before turning to our field interviews, in an effort to see how Chinese nanotech firms measure up.

2. A model for indigenous innovation

2.1. Industrial policy

In the present research, our key question has to do with the appropriate role that the state, at all levels, can play in creating conditions that foster innovation. Governments seeking to create or strengthen innovation systems often utilize instruments such as taxation, regulation, and infrastructure development to achieve their desired ends [37]. Where the state has been a flexible partner in national innovation, making decisions based on input from industry while providing government guidance, state-driven development may prove successful [30,71]. State agencies can also act as venture capitalists, funding platform technologies, innovative firms, and science parks [28,29]. The question remains, however, just how flexible the state can be in such partnerships, particularly when politics intervene. This has been a major concern in China, where innovation occurs within the framework of national five- and fifteen-year plans, as well as provincial and local plans, and Communist Party officials have their hands in virtually all-economic decisions [9].

Late innovating countries have an advantage over early innovators in that they do not have to navigate the missteps of their more developed peers. In this way, they can leapfrog early stages of innovation [72,79]. China did just this with its Information Technology (IT) industry. By jumping into the high-tech field, the Chinese were able to quickly (from about the 1980s to the 2000s) become a leading producer of IT products. Yet most of their contribution to the global IT market came at the producer rather than the designer portion of the value chain [10,73]. This is of concern to China's leaders, who believe that product innovation is the key to lifting the Chinese people out of poverty and into middle-class status.

While China embarked on its path toward greater innovation in the mid-1980s, these efforts were stymied by low investment, weak industrial R&D, and incomplete patent protections [99]. The move from a master-planned economy to a more open, market-oriented one has been gradual, filled with national and local experimentation and the development of linkages with international investors [61]. According to Liu et al. [49], the majority of China's early innovation policies were developed by one agency, the Ministry of Science and Technology (MoST), which was more effective in developing ties to local and regional government than other

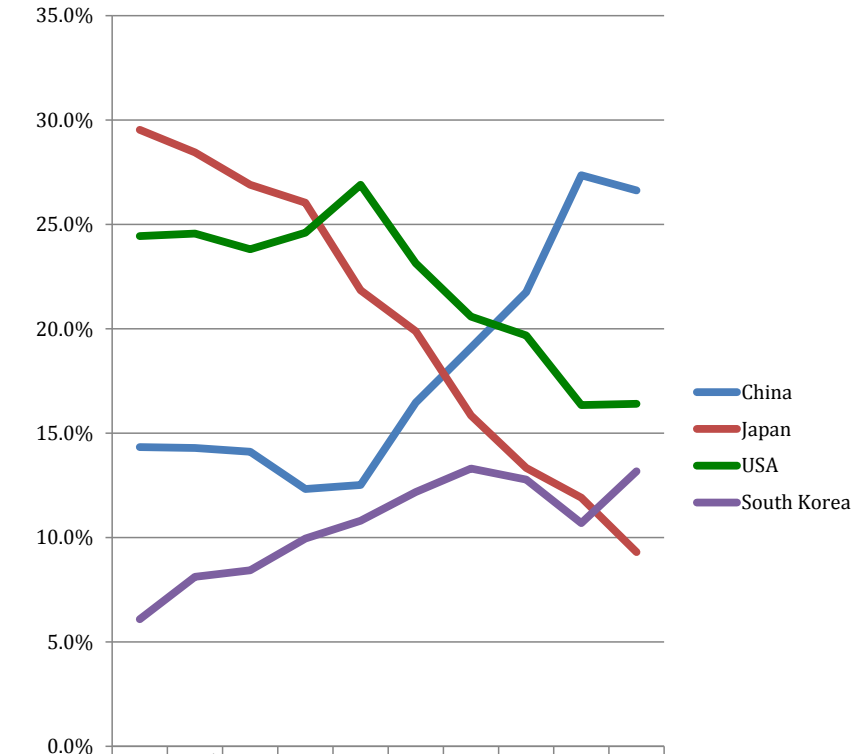
[11] Xi was elected General Secretary of the Chinese Communist Party on November 15, 2012; the "Chinese dream" speech was given two weeks later (on November 29). He was elected President of the People's Republic of China on March 14, 2013.

[12] Nanotechnology is defined by the U.S. National Nanotechnology Initiative (NNI) as "science, engineering, and technology conducted at the nanoscale, which is about 1–100 nm … [enabling] scientists to utilize the unique physical, chemical, mechanical, and optical properties of materials that naturally occur at that scale" (http://www.nano.gov/nanotech-101/what/definition, http://www.nano.gov/nanotech-101/special). The U.S. launched the NNI in 2000; every other developed economy, and most emerging economies, immediately followed suit. It is estimated that by 2014, global public spending on nanotechnology will have reached $100 billion, with China surpassing the U.S. in 2011 when adjusted for purchasing power parity ($2.25 billion v. $2.18 billion) [20].

[13] This analysis draws on the Center for Nanotechnology in Society (CNS) nanotechnology patent dataset with about 106,000 patent families based on EPO's PATSTAT Spring 2014 database and the definition of nanotechnology developed in Ref. [5]. The dataset for China comprises 6288 patent families with patent documents that report assignee address in China, including all patent offices and the PCT system, between 2004 and 2013.

[14] Further analysis shows that most of the patents related to substrates are in the IPC class H01 (Basic Electric Elements), also suggesting increasing activity in areas such as electrodes (cathodes, anodes), electric batteries, and other battery parts.

[15] Examples might include the Italian company Bianchi – maker of high-end bicycle frames that incorporate CNTs – or the French company Babolet – maker of high-end tennis rackets, that incorporate graphene.



	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013
China	14.3%	14.3%	14.1%	12.3%	12.5%	16.5%	19.1%	21.8%	27.4%	26.6%
Japan	29.5%	28.4%	26.9%	26.0%	21.8%	19.9%	15.8%	13.3%	11.9%	9.3%
USA	24.4%	24.6%	23.8%	24.6%	26.9%	23.1%	20.6%	19.7%	16.3%	16.4%
South Korea	6.1%	8.1%	8.4%	10.0%	10.8%	12.2%	13.3%	12.8%	10.7%	13.2%

Fig. 1. Country share in nanotechnology patent applications between 2004 and 2013.

national level agencies. Sectors with significant government investments tended to have strong linkages between industry and basic researchers, laying the foundation for future growth [60].

Existing research into China's state-driven innovation attempts have reached mixed conclusions. Some have found that China's emphasis on indigenous innovation has come at the expense of firms' ability to transfer technology and expertise from foreign sources, limiting their innovation capacity [107]. Breznitz and Murphree [10] found that China's tangle of policy-making and regulatory agencies created an environment of 'structured uncertainty' that impeded the risk-taking required for genuine innovation to occur. In their view, China should downplay indigenous innovation and focus instead on what it does best: incremental 'second tier' innovations that have been the backbone of China's success in IT. However, some research has concluded that China's emphasis on high-tech regions has not been entirely effective, as it has been accompanied by contradictory policies, top-down control from Beijing, and an emphasis on exports that have forced many companies to rely on foreign technology rather than indigenously developed technology [101].

2.2. Cultural challenges

Studies of innovation in China have pointed to several dimensions of Chinese culture that hinder the nation's high-tech growth potential: a business culture based on *guanxi* that invites corruption, an educational system based on rote memorization, enormous publishing pressure that sacrifices quality for quantity (and often results in plagiarism), and a research culture that embodies a strong work ethic but discourages innovative thinking [95,103].

2.2.1. Business culture and Guanxi (关系)

Guanxi, traditionally speaking, refers to one's connections and relationships and the reciprocal obligations among those who belong in one's network, but is often facilitated through "*songli*" (送礼), or gifts or bribes [69]. *Guanxi* is fundamental to the conduct of business in China because it allows individuals to bypass a system full of ambiguous bureaucratic rules and regulations and facilitates access to financial, natural, and human resources [64,81,87,98]. On the other hand, *guanxi* is often linked with corruption, bribery, and an overall lack of ethics [50,80], which are widespread despite harsh policies adopted by the Xi government to discourage such practices [104,38,39,8,93]. Companies that find themselves in the favor of powerful politicians are often provided with lucrative government grants, tax incentives and contracts [10].

To remain effective, *guanxi* networks must be continuously cultivated through costly and lengthy meals often involving excessive consumption; many businessmen and entrepreneurs claim to be "spending more time courting well-connected officials in order to secure protection and access to rents than they do pursuing their business" ([10,45]: 47). As a result, domestic Chinese venture capital firms and small or medium enterprise (SME) owners focus significant time and energy towards *guanxi* activities that keep them in favor of prominent government officials [34]. Furthermore, the almost mandatory nature of *guanxi* may

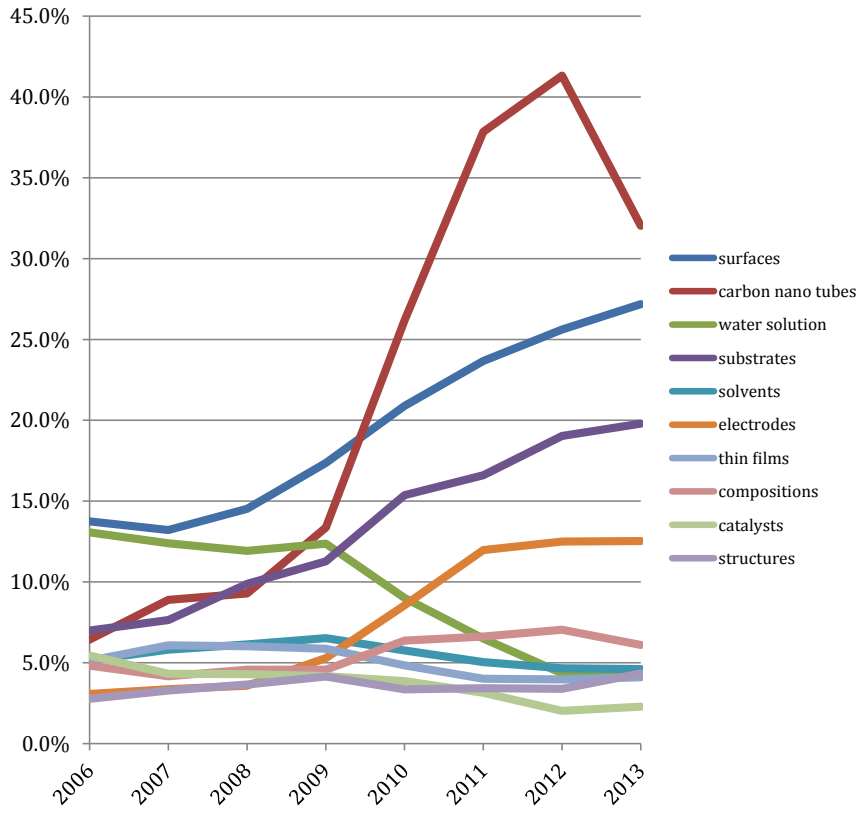


Fig. 2. Percentage of patent families that relate with the top-10 topics in Chinese nanotechnology patenting activity between 2003 and 2014 (3 year moving average).

discourage Chinese entrepreneurs and researchers from returning from abroad, as the activities associated with *guanxi* are often viewed as time-consuming and unhealthy.

China's weak formal legal system for protecting intellectual property (IP) rights forces companies and entrepreneurs to rely on *guanxi* networks to protect essential IP [1,68,102]. This discourages innovation and creates an additional disincentive for foreign investors looking to enter the Chinese market, further impeding the kinds of collaborations that can foster innovation [11,34]. Additionally, companies that choose to do business with entities outside their established *guanxi* networks risk having their IP stolen and rebranded as a competing product [1,10].

Relatedly, Chinese courts unevenly enforce contractual agreements. Even when courts do resolve contractual disputes, the winning party is rarely awarded damages corresponding to the original contractual obligations [11]. Contracts are typically viewed as loose agreements and are even viewed as secondary to *guanxi* relationships, some of which can actually involve the judges charged with arbitrating contract disputes [11].

The Xi government is well aware of these problems, and has launched a major anti-corruption drive over the past several years. According to official statistics, as of December 2014 the "Eight Points" campaign had disciplined more than 102,000 party officials, one-third of them "severely." These officials range from local bureaucrats to top figures in the Chinese Communist Party [47]. While the campaign enjoys widespread popular support in China, it has also greatly amplified uncertainty in an economic system that historically has run on bribery and *guanxi* relations. As a result, many government officials are reportedly "sitting on their hands, delaying decisions and failing to grant approvals for investment projects, either out of fear that they could be caught up in a future corruption probe or because, without a bribe, they simply lack any incentive to act" [25]. Such "political paralysis," according to a Merrill Lynch report, was depressing investment, slowing economic growth, and discouraging innovation [51]. One survey of local officials by Caixin, a Beijing-based media group, found that two-thirds of those surveyed "were reluctant to make decisions for fear of 'doing something wrong' …. Whatever can be delayed will be delayed" (as reported in Ref. [31]).

2.2.2. Education policy

Education has long been popularly viewed as the only way to improve one's social standing in China. This belief can be traced back to the beginning of the imperial civil service examinations during the Sui Dynasty (581-618AD), in which individuals were given the opportunity to climb the social ladder and receive respectable, high-ranking government jobs regardless of their social status as long as they were able to pass the examination [26,59]. As the only method to improve one's life, scholars spent years, even decades, studying and preparing for the exam. The view that education is the only way to a brighter and more prosperous future is still ingrained in contemporary China.

The Cultural Revolution (1966–1976) proved to be highly detrimental to China's educational system. Its emphasis on agricultural labor, which included the forced relocation of student-aged youth to rural communities, all but eliminated a generation of scholars. Since then, China has made remarkable strides in improving its education system. The number of undergraduate students enrolled in Chinese universities has increased dramatically in the past decade, from approximately 4.1 million in 1999 [57] to more than 23 million in 2011 [58]. The total number of Chinese universities and colleges also increased dramatically during this time, from 1071 to 2762 [57,58].

Despite these vast improvements, however, many believe that

the Chinese educational system remains broken. It is limited by a strong cultural tradition that emphasizes rote learning and test taking instead of innovative thinking. For instance, government policy may be insufficient to convince parents and students to engage in extracurricular activities, sacrificing time that might be better spent preparing for the *Gaokao* (高考), China's college entrance exam, which serves as the determining factor in whether a student is accepted into a college or university [53,82]. The exam takes place over the course of 2–3 days with tests on Chinese, English, mathematics and a variety of other subjects. It is based primarily on the memorization of facts [23]. China's focus on teaching students through memorization and theory rather than analytical thinking has been criticized as a major hindrance to creativity – and, more broadly, to China's innovative capacity [18,43,67].

The Chinese central government recognizes that the current educational system is not conducive to facilitating indigenous innovation in China, even though Chinese students outperformed the rest of the world on international standardized tests[16] [36,62,63]. There is growing recognition that a rote memorization system, with classes designed for examinations, may produce excellent test-takers but does not result in creative individuals with strong analytical and critical thinking capabilities. In 1998, China launched Project 985 to address these concerns. Nine universities have received funding through Project 985 to modernize their academic and research programs. While this project did not call for an overhaul of educational philosophy, it provided funding for research centers and other facilities, conference travel, and attracting top scholars[17] [106].

China's recently implemented National Plan for Medium and Long-Term Educational Reform and Development (2010–2020) further calls for relaxation of central control on academic institutions, and adoption of more flexible enrollment and admission policies, such as including letters of recommendation and extracurricular activities in determining a student's college admission [58]. The Plan also seeks to emulate the U.S. education system by creating a set of experimental universities in which students will choose their own majors and offer classes that will be more discussion-based.

Despite being named a "historic reform" by the Chinese government, problems of bribery and corruption remain (and are perhaps even encouraged by) in the new policy. This can be especially troubling during the admissions process, where "accepting a bribe is very common in admissions work, but the bribe might not always involve cash. It has been an open secret in all universities that the admissions job is a lucrative post" [24]. Parents fear that under the new policy, bribery and corruption will be even more rampant as teachers will have more power in controlling whether a student is admitted into college [74,91].

One final challenge to innovative thinking in China's educational system may result from the Xi government's recent efforts to reign in "western thinking" in China's universities. In January 2015 the Party issued a document titled "Suggestions on further strengthening and improving ideological propaganda among tertiary institutions under new circumstances," which called for "turn [ing] our universities into a stronghold for learning Marxism" through "management of the use of western teaching materials." The CCP was instructed to "strengthen its control over ideology and firmly secure its leadership in grasping ideological control among tertiary institutions" [90]. These efforts are intended to restrict the relative autonomy currently enjoyed by Chinese universities, shifting their focus to more ideologically acceptable teaching rather than research. The latter is to be conducted in research centers, to be established by the CCP, the Chinese Academy of Science, and the Chinese Academy of Social Science [21]. While it is clearly too soon to tell what effect this will have on innovation, it does not seem likely to encourage the cultivation of the kind of critical thinking and experimentation that are necessary for indigenous innovation to succeed.

2.2.3. Research culture

While a research culture that encourages critical thinking would seem to be a key component of innovation, China experiences significant barriers to the development of such a culture. While scientific merit and peer review are customary in receiving smaller grants, large megaproject funding is run by various governmental agencies. In a highly controversial (in China) editorial published in *Science* in 2010, the Life Science Deans at China's top two universities, Peking and Tsinghua, pointed out that [77]: 1128)

> … to obtain major grants in China, it is an open secret that doing good research is not as important as schmoozing with powerful bureaucrats and their favorite experts … [scientists] spend too much time on building connections and not enough time attending seminars, discussing science, doing research, or training students (instead, using them as laborers in their laboratories). Most are too busy to be found in their own institutions. Some become part of the problem: They use connections to judge grant applicants and undervalue scientific merit.

China's researchers are imbued with a strong work ethic and are often found working 10–12 h days. Outside scientists have observed that Chinese students "work extremely hard and [for] very long hours … [but they] haven't been trained so much in using their knowledge to generate new ideas and find new solutions" [70]. Despite this strong work ethic, the long hours do not necessarily result in creative or original thinking thanks to several factors. From an early age, Chinese students are discouraged from creative thinking taught through rote memorization. They are also taught to conform to social norms and to avoid questioning authority figures: laboratory culture remains largely defined by respect for the authority of the senior professor who runs the lab, which limits new ideas.

Chinese academics and researchers are under strong and growing pressure to publish at a "world-class" level. Many universities offer their faculty financial incentives for SCI publications, though some offer higher incentives for higher quality journals [35,89]. Some universities have switched to a "position allowance" system in which roughly 20% of an individual's pay is solely determined by his/her performance, and some have implemented financial penalties if certain quotas are unmet by academics [89]. All of these measures have led to a significant increase in publication pressure, which has resulted in the previously noted dramatic increase in Chinese scientific publications. But the increase in quantity has not been matched by a corresponding increase in quality, and in many cases publication pressures have led to increased plagiarism [22,32,100]. This is a direct result of the

[16] In both the 2009 and 2012 PISA assessment tests, students from Shanghai, China scored significantly above the Organization for Economic Co-operation and Development (OECD) average in all three test subjects, ranking first among all participating countries [62,63].

[17] The original nine universities selected to partake in Project 985 were Fudan University, Harbin Institute of Technology, Nanjing University, Peking University, Shanghai Jiao Tong University, Tsinghua University, University of Science and Technology of China, Xi'an Jiao Tong University, and Zhejiang University. There are a total of 39 universities that are funded by Project 985. (The Central People's Government of the People's Republic of China. 2009. Background information: what is Project 985. http://www.gov.cn/fwxx/2009gk/content_1314252.htm).

incentives that pressure Chinese academics to publish as many publications as quickly as possible [40,95].

2.3. Venture capital

Availability of venture capital is associated with the historical success of high-tech centers such as Silicon Valley, and innovative companies such as Apple and Google that benefited from early-stage venture capital financing [76]. The American venture capital industry is mature, with a rich history extending more than fifty years, during which venture capital companies have developed increasingly sophisticated strategies for managing investment risks, interacting with startup companies, and exiting ventures.

China's recent push for indigenous innovation not only calls for the "re-innovation" of foreign technologies, but also for the importation and adaptation of successful business models that were developed in established economies [55,56]. Given the magnitude of the economic impact of venture capital in Western economies, developing and sponsoring an indigenous Chinese venture capital industry has been a prominent economic growth strategy of the Chinese government for the previous decade [1,105].

China's approach to venture capital, however, has followed a dramatically different path than the "Silicon Valley model" that originated in the U.S and Europe [84]. In the West, the venture capital industry is dominated by private venture capital funds, and the managers of these funds view venture capital activities as a vehicle for generating investor profit. Accordingly, the positive impacts that these investments have on the competitiveness of a society as a whole are not investors' direct goal. In contrast, the venture capital industry in China has to date been dominated by public, government-backed venture capital funds that are utilized as a tool to promote high-tech development [84]. While government investment technically could favor far-from market innovations that might pay off in the long term, in China the companies that routinely receive large government contracts or grants tend to be less creative and innovative [10]; instead, they are the ones most focused on cultivating relationships with local officials. Moreover, the resulting access to "easy money" (based on personal connections) places these beneficiaries in a position where the companies are never truly faced with an "innovate-or-die" set of circumstances [34], a key hurdle that has driven many of the world's most innovative firms.

Private venture capital companies that choose to operate within China are also plagued by the lack of an established, consistent legal framework for protecting investors and entrepreneurs [7,68,108]. This weak regulatory environment leads private venture capital firms in China to adopt a more conservative investment strategy than venture capital companies operating in established markets [48,102]: they tend to invest in companies that are already marketing tangible products that are headed by well-trusted founding teams [1]. These problems are compounded by the central government's legal authority to seize the assets of SMEs that are determined to be operating in industries that are either viewed as the domain of large state-owned enterprises (SOE), or relevant to its interpretation of Chinese national security concerns [1,10]. This power is open to abuse by government officials aiming to increase their own personal wealth or political influence [34]. The end result of these challenges is that privately owned Chinese venture capital firms largely refrain from filling one of the most valuable economic roles adopted by Western venture capital firms: investing in early stage, highly innovative ideas that are far from market.

This discussion points to the interaction of policy, economic, and cultural factors that shape China's efforts to become a nanotechnology innovator. The Chinese state is faced with the need to create and enforce honest and open legal systems, an educational system that encourages open and experimental thinking, and talent cultivation through grants, competition, and other initiatives. The private sector must increase innovative capacity through expanding private venture capital opportunities. And both the public and private sectors must ferret out corruption, beginning with cultural norms that place the cultivation of relationships (particularly with CPP officials) over norms that would benefit sound research priorities and business decisions (Table 1).

3. Method and data

We draw on five years of interviews with Chinese academics, entrepreneurs, and government officials, in which we investigated the degree to which the central government's heavy emphasis on R&D investment has resulted in innovative breakthroughs. Much of our research has focused on small startups, particularly nanotechnology-related incubators in Suzhou Industrial Park. Since 2006 we have conducted dozens of interviews in China, primarily in Beijing, Shanghai, Zhejiang, Hangzhou, and Suzhou. Interviewees have included university professors; members of the Chinese Academy of Sciences (CAS) and its institutes; government officials at the central provincial and local levels; and business owners and managers.

Our 2012 research visit included six sets of interviews in Shanghai and six sets of interviews in Suzhou Industrial Park. We identified these individuals by finding relevant government officials from official documents, prominent scientists and academics from their publications, and searched local business directories where available for private sector interviewees. Using this list, as well as research team contacts and recommendations from interviewees, we then conducted a snowball sample. This method was effective at opening doors to additional businesses, and persuading government officials to speak with us. Additionally, many academic interviewees brought several additional contacts to our interviews because their experience made them good candidates for our research. To validate the data we collected from different interviews, we used a semi-structured interview approach in which the same larger-picture questions were asked of all participants.

Of the Shanghai interviews, two sets were with university professors and officials, one was with a quasi-government development agency, and three were with businesses. Suzhou interviews reflected a similar pattern, including two interviews with governmental or quasi-governmental developmental agencies, two with university professors and officials, and two with startups at different phases of their business cycle. Shanghai and Suzhou are singled out in the present paper largely because of their prominence in nanotechnology and bio-nanotechnology. Additionally, Shanghai is China's banking and financial center, and is emerging as a center of high-tech production [2]. Suzhou, fifty miles west of Shanghai, has long been a center of trade and commerce, assured by its strategic location on the Grand Canal, 1100 miles of waterways completed during the 7th century.

In 1994, the Chinese government signed a Joint Agreement with Singapore to develop a large area to the Southeast of the city as Suzhou Industrial Park (SIP). This unique, joint program emphasized Singaporean norms of transparency and efficiency in public administration and urban planning, enabling the Chinese to "learn how to modernize the Singapore way" [66]. SIP's tenants range from multinational corporations to high tech startups in a high-tech ecosystem designed to foster innovation. Its approximately 188 square miles includes eighteen universities (many with Western partners), 148 Fortune 500 companies, and over 150 nanotech startups. The latter include two nanotechnology incubators, bioBay and Nanopolis – quasi-governmental agencies that cultivate

Table 1
Policy, economic, and cultural factors that shape China's efforts to become a nanotechnology innovator.

	Public sector	Private sector
Policy	IP and other friendly legal regimes Educational reform	
Economic	Broad and open public investment	Invest in longer-term R&D Increase opportunities for private venture capital
Cultural	Reduce corruption Foster self-directed, open research environment	Reduce corruption

entrepreneurs through grants and other subsidies as part of a coordinated effort between the local and central government [83]. SIP has grown considerably; in 2012, its GDP was 176 billion, a 10.8% increase over 2011 [19]. Local government has strongly emphasized nanotechnology within SIP with the hopes that the "cluster development" of nanotechnology will bolster surrounding economy and industries [19]. As the largest industrial park in Jiangsu Province, these effects ripple across the province's economy, which may explain its continued growth rate - 10.1% in 2012, making it the second largest economy in the country [52].

In order to protect the confidentiality of respondents, we do not provide names and organizational affiliations, but identify respondents by letters A through O (Respondents A, B, and C were interviewed in 2007; all others in 2012). The organizational types for each respondent are identified in Appendix A.

4. Emerging innovation patterns

4.1. The role of government policy

Our respondents agreed that the Chinese government views process innovation as crucial for the continued growth and success of the Chinese economy, especially at a time when attracting private capital can be a challenge. However, government policies can be inconsistent across levels and over time, contributing to uncertainty and discouraging potentially innovative yet risky projects. The Chinese government to some extent assumes the role of risk taker, shifting that burden from companies to itself (Respondent K). This is seen in the dominant role that government-run venture capital plays in the market, relative to its role in other advanced industrial economies. State entities are often the only parties willing to invest in projects with a long-term investment horizon. The state is willing to take on these risks because it is concerned that the market will not foster innovative products. This is not an unfounded concern: there is a perception in the Chinese nanotech community that during the early 2000s there was a disconnect between nano-related research and manufacturing (Respondent I). Without a clear return on investment, private capital – in China or elsewhere – is unwilling to support long-term research.

The Chinese government has adopted three related strategies to counteract this trend: regional strategies and competition, directed manufacturing and research, and regional economic zones like Suzhou Industrial Park.

4.1.1. Regional strategies

One key source of uncertainty is the devolution of policy to the provincial and even municipal level, particularly with regard to nanotechnology. The Shanghai government, for example, has targeted nanotechnology as a key growth area through grants to corporations and universities (Respondents D, E, and F). Similarly, the Suzhou government has used its authority over Suzhou Industrial Park to promote nanotechnology, with the goal of making nanotechnology one of the primary industries in the park (Respondents M and N). In both of these cases, the government utilizes quasi-governmental agencies to serve as coordinators between corporations and universities, as well as sources of funding. The Shanghai Nanotechnology Promotion Center (SNPC), which defines itself as a hub for nanotechnology in the Shanghai area, is perhaps the most prominent such quasi-governmental agency in the region. Accordingly, it holds networking and academic conferences; publishes academic journals and other papers; coordinates facility sharing, in which companies with specialized equipment rent their equipment out to other companies for a minimal cost; and conducts training programs (Respondents D, E, F, and I). In Suzhou Industrial Park, on the other hand, nanotechnology efforts flow through agencies like Nanopolis or bioBay. Nanopolis provides grants for entrepreneurs through annual competitions. These grants take the form of investments in the company, in which Nanopolis holds a small share of the company, much like venture capital, although it focuses on longer time horizons (Respondents M and N).[18] Such regional and local government programs can reduce the risk that otherwise might result from uncertainty.

Regions also compete against each other, a process that can be shaped by policies emanating from the central government in Beijing. For instance, while Suzhou was building up Suzhou Industrial Park, Shanghai was building the Shanghai Nanotechnology Promotion Center. Similarly, centers for nanotechnology research were established in Beijing and Guangzhou [6]. Companies accordingly move from one region to another, as regional governments lure them with new opportunities and resources. Although regions are given considerable latitude, the central government places limits on the extent to which regions can set agendas and will penalize them if they see their policies as being at odds with Beijing's. Before 2009, for instance, reportedly four-fifths of Shanghai governmental grants were for research.[19] After 2009, the central government required a shift in emphasis to grants more aimed at applied science that might facilitate commercialization. This change occurred because basic research funding was going largely to foreign firms that had the capacity to conduct such research, which ran contrary to China's policies calling for indigenous innovation (Respondent G, Respondent H). Such policy changes, whatever their motive, contribute to uncertainty in the research environment. Furthermore, they are often exacerbated by rapid turnover in local party leadership, since new leaders often bring new policies. On the one hand, because the central government appoints governors or provincial party secretaries, it can appoint people with the express purpose of reining in a region whose policy innovations have strayed too far from Beijing's vision. On the other hand, when new leaders come into office, current

[18] Similar agencies exist in Beijing and Guangzhou, although the basic structure differs. For example, the primary nanotechnology center in Beijing, the National Center for Nano Science and Technology (NCNST), is housed in the Chinese Academy of Sciences and so is fundamentally a research center, not an incubator or services organization like those in Suzhou or Shanghai (Respondent B).

[19] We take sustainable long-term commercial investment to be a category distinct from investment in basic research. Long-term commercial investments are still focused on developing a specific commercial product from the beginning of the investment. Basic research refers to funding that is allocated to the investigation of a fundamental scientific problem that may ultimately lead to a range of commercial returns, without emphasizing a specific application.

programs may be upended as the new governor implements his policies (Respondent O). This uncertainty can make investors less willing to take on risk, requiring the government to assume that role, while giving entrepreneurs pause.

4.1.2. Directed manufacturing and research

While there are some grants for basic research (for example, through the National Natural Science Foundation), our interviews showed that these are neither as plentiful nor as easy to obtain as grants for commercialization. In fact, university faculty have found that their basic research grants are less likely to be approved if they do not have some path to commercialization and a private partnership (Respondent G). While this can promote product development in the short run, it can also run counter to China's quest for indigenous innovation because it discourages the years of basic research that are typically required for innovative breakthroughs. The pressure on local governments to prioritize short-term results over long-term innovations can accordingly hinder the development of long-term innovation capacity (Respondent A, 2007). While central government funding for basic research has the potential of supporting innovative efforts that are far from commercialization, as we noted above, such funding is often based on personal ties with government officials, rather than project merits.

While companies conducting research can apply for government funding, they face a low likelihood of success; at the same time, they can make quick money by producing products the government wants. Both central and regional governments publish an annual list of products or services they would like to see produced; producers are then commissioned to create these products. The government monitors progress over the course of the commission, which can last several years (Respondent I). The government uses this process to identify gaps that it believes the market will not adequately cover. At the same time, the government is focusing on cultivating the talents of promising entrepreneurs. However, the result is that "companies that get government funding [are no longer] hungry," meaning that they have a stable revenue stream, so they do not devote resources toward developing competitive products. "Commissions," one entrepreneur said, "do not develop companies" (Respondent H). Instead, our interviewees claimed, this enriches company founders but does not positively influence the Chinese economy. First, since the focus is on developing specific products, these policies do not develop companies' innovative capabilities over the long term. Second, because these companies lack an innovative drive, they see no need to cultivate or spend the money to hire talent away from foreign companies, which can pay more and target basic research (Respondent H). If directed manufacturing lists were cutting edge, and developed through a public-industry partnership, these problems might be eliminated. However, these lists are largely about creating indigenous versions of existing products at lower prices (Respondent H). This has a long-term negative effect on the Chinese nanotechnology industry, reinforcing trends toward incremental innovation and away from basic research or development of new products.

4.1.3. Economic zones

The third approach taken by the Chinese government is the development of private/public industrial centers, with a characteristic example being Suzhou Industrial Park (SIP). As described above, SIP was initially adopted as a joint Chinese/Singaporean venture to integrate Singaporean management and efficiency norms into a Chinese industrial center. Singapore currently has a minority stake in SIP, but continues to provide technical advice and serves on SIP's advisory board [19]. The resulting ecosystem resembles the 'triple helix' models of industrial policy, in which government, universities, and entrepreneurs work in close proximity to develop a collaborative environment of rapid innovation. The Beijing and local governments play a key role. The national government exempts income taxes for SIP companies for their first three years, and reduces it by half for the following three. More locally, the SIP government established an IP Protection Bureau to help companies register patents and protect their IP (Respondents M and N).

A major distinguishing characteristic of these industrial parks is the presence of quasi-governmental agencies that identify and develop promising early stage businesses, like Nanopolis in SIP. Nanopolis is an incubator for nanotechnology companies in SIP. It has high standards for admission, but once companies gain access, they are showered with benefits. Applicants are selected through a two-stage competition: the first stage assesses scientific feasibility while the second judges competitors on their business plan and leadership potential. Winners receive up to 10 million RMB and rent and employment subsidies. This investment is similar to that of a venture capitalist, although Nanopolis prefers to fund projects at the very early stages, with the hope that the company will be able to buy out the government's stake at a reduced rate later. Consequently, Nanopolis funds projects with somewhat longer-term growth horizons that may be neglected by private capital (Respondents L, M, and N).

Nanopolis offers other advantages. Winners also gain access to infrastructure and equipment, monthly workshops in nanotechnology, management, and business, additional venture capital, and promotion abroad at trade shows. Since Nanopolis reports directly to the central government, it is relatively immune to the shifting winds of ambition and competition that can create uncertainty in other areas. Nanopolis sees these services as part of its effort to create a nanotechnology community within SIP, wherein researchers within universities, small startups, and multi-national firms interact in a collaborative innovative environment (Respondents M and N).

Yet this generally positive picture is softened by the tradeoffs inherent in Nanopolis or other government backed incubators. When Nanopolis invests in a company, commercialization is emphasized, which can pull high-level researchers away from basic research. Although Nanopolis' emphasis on shared resources and a collaborative environment help young companies prosper, our impression is that the similarly strong emphasis on commercialization discourages basic research, which may prove detrimental to China's ambitions in the long run. Nonetheless, the stability of this structure seems to reduce uncertainty and promote nanotechnology development.

4.2. Cultural issues

While government policies play a mixed role in fostering innovation, widely shared cultural norms in business, education and research that discourage independent, innovative thinking are also problematic.

4.2.1. Business culture

Deep-seated business norms, such as *guanxi* are difficult to dislodge through policy; instead, they require changing the expectations and incentives of those in the system, from entrepreneurs to officials. One respondent found that government funding, although supposedly based on peer review, is frequently dependent on connections (Respondent C). Others said that contracts for the procurement lists described above were similarly awarded based on connections.

Repatriating successful Chinese innovators, entrepreneurs, and businessmen is seen as a solution — one that is being actively pursued by governments at all levels. National government

programs such as the Thousand Talents Program and the Thousand Young Talents Program have been somewhat successful, at least in Shanghai and Suzhou Industrial Park. Roughly half of the twenty business people we interviewed in 2012 were returnees; their individual time abroad ranged from several years to well over two decades in the United States, Singapore, and Britain. Despite the small sample size, our findings suggest that Chinese returnees play a very important role in the overall innovation process in China. The returnees we interviewed were a combination of academics and entrepreneurs who carried basic research knowledge and culture as well as entrepreneurship experience. The reason for returning, as stated by several interviewees, was the opportunity to engage in new, more innovative projects. Most stated that because of the economic downturn in the United States since 2008, there were fewer jobs, funding, and opportunities in general, whereas the opportunities afforded by the Thousand Talents and similar programs teased at a brighter future free from constraints imposed by market vacillations.

On the other hand, government-sponsored repatriation programs do not assure success. One interviewee stated that though there are more people returning to China, he "believes that people would rather stay in the US because of the business culture there." This respondent also stated that conducting business in the United States is more straightforward than China. This is because "one must spend a lot of time on *guanxi* … *guanxi* can facilitate the progress of a company but it is a necessary evil to do business in China because it is extremely hard … physically to take people out and be forced to drink, to give 'face'" (Respondent K). The talents programs can also suffer from corruption – for example when non-Chinese foreign scholars are being recruited with promises of laboratories, colleagues, and funded research projects [41]. Moreover, according to one U.S. National Science Foundation study, interest is limited, only ten percent of Chinese students who receive a U.S. science or engineering Ph.D. report a desire to return to China, while many of China's top science and engineering undergrads leave for other countries to pursue their graduate studies. While there was an apparently an uptick in returnees (especially among the less qualified) during the height of the economic recession that began in 2007, now that the US economy has improved, the economic incentive to return to China has diminished. Once they return, expats often find it difficult to find a place in the Chinese system, in part because they have difficulty adapting to the absence of freedom they had grown accustomed to while studying to working abroad, and in part because they lack the *guanxi* networks that have been central to success [13,75].

4.2.2. Education and research culture

Several interviewees stated that true innovation is not yet happening in China. One interviewee believed that the "barrier [to innovation] is cultural – you see when you go to kindergarten [in China] the little kids just sit there; in the US the kids are everywhere. The Chinese cannot think so diversely. You have to obey your supervisor. [There is] a psychological barrier to think[ing] of new things" (Respondent O). Many respondents believed that a foreign education is much better than a Chinese one; this undergirds the continuing desire of many Chinese to study abroad. Accordingly, Chinese policymakers have adopted a series of reforms to try to increase the desirability of a Chinese education.

Soochow University, located in SIP, is one of the test universities for some of these reforms. As one of the seventeen experimental universities taking part of the National Plan for Medium and Long-Term Educational Reform and Development (2010–2020), students at Soochow are allowed to choose their own courses and discipline. Courses are taught in English, in a Western style, and students are highly encouraged to study abroad. The end goal, according to one respondent, is to encourage critical thinking. Yet he felt that this is potentially problematic since the government "do[es] not [want to] encourage students to challenge authority, not challenging politics, just to challenge science and technology" (Respondent O). He believes that the government would not tolerate innovative or original thinking if it led to a questioning of the central government as well. This may in turn circumscribe the effectiveness of these programs.

Even if this approach does take hold, there are other challenges to cultivating the critical thinking norms that lead to innovation. Across the Chinese universities we visited, we found that Chinese students work extremely long hours, but seldom on research of their own design or choosing, with doctoral students reluctant to question authority figures. The graduate students with whom we spoke reported that they typically work from 8am to 10pm, weekends included – and that unlike the practice in most Western universities, their dissertation topics were given to them by their advisors. This reduces the agency of those students, and limits their capacity to develop future innovative research projects.

Similarly, one academic felt that the central government recognizes that the current education system is not conducive to research and innovation, which explains the millions of dollars spent on educational reform and programs such as the Thousand Talents Program: Beijing hopes that the returnees can change the culture with their presence. However, he was concerned that although "the faculty is changing the educational environment [in China] … at the same time, the faculty members themselves are being changed by the Chinese environment" (Respondent O).

All of the faculty members we interviewed felt intense pressure to publish and win funding. Faculty members at one Shanghai university stated that professors are required to publish at least three papers a year, with at least one in a high-impact journal. Publication requirements extend to graduate students as well (Respondent G). While pressure to publish is not necessarily undesirable, too much pressure can reduce the incentive to develop long-term research portfolios and can encourage cheating. According to a recent article in *Science*, China's "publication bazaar" enables scholars to outsource their writing (for a hefty fee) to services that "not only prepare and submit papers for a client: they furnish the data as well" ([40]: 1038).

4.3. Venture capital

Venture capital investments have grown rapidly in China over the past two decades. In 1998, the Chinese government adopted measures to support the growth of VC funding. Between 1994 and 2011, VC investments grew at an annual rate of 20%, reaching $12.8 billion in 2011 – primarily VC investments by provincial and local governments. What little research has been done on this topic has concluded that Chinese government VC efforts, which are more likely to be based on *guanxi* connections, have been less successful then private efforts, as measured by return on investment [97]. China's chief policy organization, the State Council, announced in January 2015 that, to foster innovation, it would provide $6.5 billion for a new VC fund aimed at supporting startups in emerging industries. While the details remained to be worked out at the time of this writing (August 2015), such a large infusion of public money has raised concerns that such relatively "easy money" – in which personal connections may prove important – could result in poor private investment in government-picked key industries [94].[20]

[20] GSR Holdings, a Chinese VC firm, announced in July 2015 that it was creating a $5 billion fund in hopes of acquiring stakes (or complete ownership) of foreign technology, Internet, and biotech firms seeking entry into the Chinese market [16].

The demographics and motivations of the Chinese venture capitalists who are working at publicly owned funds appear to significantly differ from those of private-funded venture capitalists in the United States and China. Private venture capitalists tend to be highly experienced business professionals who aim to maximize a fund's return on investment over the shortest time horizons possible. This is in contrast to the large number of idealistic, young Chinese venture capitalists managing state-backed venture capital funds. In fact, some of the venture capitalists we interviewed had only recently finished their training at universities, typically relatively prestigious foreign universities (Respondent J; Respondents M and N).[21]

It appears that a genuine interest in seeing the Chinese economy become world-class and self-sufficient drives many of these public fund Chinese venture capitalists (Respondents M and N). Consequently, they attempt to focus on identifying longer-term commercial investments that will enrich society (Respondent J; Respondents M and N). At face value, the investment model espoused by publicly owned venture capital funds in China appear to offer great promise for promoting long-term, sustainable commercial innovation within the Chinese economy. However, identifying candidates for longer-term investments is inherently a higher risk activity than making predictions about short-term gains. As a result, publicly owned venture capital funds could ultimately provide lower economic gains than more traditional private venture capital companies.

Additionally, venture capitalists that manage publicly backed venture capital firms in China are salaried employees that are charged with investing the state's money. Thus, both the risk assumed by and compensation packages offered to them are significantly lower than for private venture capitalists. Managers of large government-backed venture capital firms do not realize personal fortunes when portfolios skyrocket (Respondent J). Therefore, many of these publicly-funded venture capitalists are financially motivated to follow a lower risk investment strategy that focuses on enabling steady economic growth and the development of a "harmonious society," rather than placing high-risk bets in an attempt to discover the next Apple or Google (Respondent J; Respondents M & N).

China also has a number of successful indigenous private, profit-driven venture capital firms. These firms are typically headed by venture capitalists that are older and more experienced than their counterparts in the state-funded venture capital firms. While these funds typically enjoy larger returns on investment than the publicly-backed venture capital funds [97], one particularly successful venture capital manager was concerned that the short investment horizons expected by privately-backed venture capital firms will lead to less sustainable or broadly beneficial growth (Respondent J).

5. Concluding remarks

As an earlier study conducted by one of the present authors concluded, "research is high and the market is far away" [14].[22] We have found that while there are many hints of progress, they have yet to turn China into the nanotechnology innovator it hopes to become. Few products can be described as breakthrough or revolutionary; many mirror the functionality of existing products. Moreover, there is a deficit in the basic research that drives long-term innovation. We argue that China will be unable to achieve its goal of becoming a world-class product innovator unless it fully implements and standardizes policies that encourage the growth of its emerging technology sectors. Our study provides only a snapshot into China's innovation system and does not constitute China's efforts in all areas of scientific research.

Xi's desire to realize the "Chinese dream" – to restore China to its rightful place in history – strongly suggests that China will not stop its pursuit of indigenous innovation in science, technology, and ultimately their commercial applications. China clearly has not been hesitant to adopt policies that have the potential to increase its innovative capacity. It has developed grant programs and incubators like Nanopolis, encouraged experimentation at the provincial level, and offered incentives for expatriates to augment Chinese research with their expertise and business practices. Many of these practices show promise. Peer reviewed grant programs, like the Nanopolis competition, can identify entrepreneurs that have the research skills and product vision to jumpstart a fledgling industry. Similarly, programs like the Thousand Talents Program have the potential to infuse Chinese industry with expertise in innovation and research. Educational reforms that expand opportunities for critical thinking, grant more intellectual freedom, or reduce the research demands on faculty, may further contribute to fostering an innovative environment in the long term.

Yet such hopeful approaches remain in their infancy, and face the many obstacles and challenges we have discussed in this paper. The Chinese devolution of policy to the provincial level allows for considerable latitude, which can allow for policy experimentation such as that found at Nanopolis. However, the variability inherent in the political process, particularly the lack of guaranteed policy continuity, create the kind of uncertainty that discourages innovative approaches. Moreover, the ever changing set of policy directives emanating from Beijing – including dictates aimed at stemming corruption and ferreting out "Western" influences perceived as corrupting socialist values – are increasing uncertainty and may stifle the limited advances previously made. Will efforts to ferret out the corrupting influence of *guanxi* connections contribute to the rule of law, which could advance Chinese innovation and entrepreneurship – or will it remove a key lubricant of Chinese business practices that has been central to China's economic advances thus far?

Such deeply rooted constraints have and will continue to limit the creative potential of Chinese scientists; overcoming them will be difficult. Initiatives that appear encouraging, like the Nanopolis and bioBay incubation programs, affect a small subset of companies. Even in these cases, it is not clear that such initiatives will develop a significantly different business culture within companies that are supported by these incubators. Nanopolis, for instance, is a highly selective, short-term program. Even successful startups within the program will have to interface with the outside business community, where other norms prevail. Furthermore, once they graduate from the program, these startups will face the same financial pressures as other firms, which might shift them away from a focus on long-term, sustainable commercialization.

Similar issues could hamstring efforts at university reforms. Even reform-minded programs, like those which give students greater flexibility in developing their academic curricula, depend on students who are able to break free of the current exam-oriented culture. Additionally, the short-term emphasis on the numbers of papers published by Chinese professors risks discouraging complex, long-term research, a mindset that can be transmitted to students. While the inclusion of Western-trained faculty may inject a more innovation-oriented mindset, the advantages many of them

[21] While we do not have systematic data on the average age of state- or private-VC firms in China, we believe our sample to be typical, given the youth of the VC industry as a whole. In one study, for example, the median age of Chinese VC firms was found to be only 5 years [97].

[22] A play on a Chinese saying that described the situation where the emperor could not intervene into local matters ("Heaven is high and the emperor is far away"). See also [3,65,78].

are granted through repatriation programs can lead to resentment from other faculty, and a backlash against this mindset.

China also faces challenges with its publicly funded venture capital programs. Originally created to fill a vacuum in long-term, sustainable investment, they now face competition from private venture capital funds that can offer higher financial incentives to promising young business professionals. As a result, younger, less experienced venture capital professionals receive training and experience by initially working for the government-backed venture capital funds have a primary goal of increasing China's innovation capabilities and international competitiveness; after gaining experience, they face significant temptations to leave the public sector for a private venture capital fund. Such a talent exodus may constrict the Chinese government's efforts to use public venture capital activities to pursue sustainable, long-term indigenous innovation.

Part of policy experimentation includes some level of uncertainty. However, problems can emerge when pilot programs work toward contradictory goals — such as calling for indigenous innovation while rewarding short-term commercial returns rather than long-term innovation. One result is uncertainty in China's emerging private sector regarding the government's intentions, which undermines China's long-term aspirations to wean itself from dependence on foreign technology and innovation breakthroughs.

While many of the programs outlined here have made tremendous strides, there has yet to emerge a unified policy set that will pave the road toward a true culture of indigenous innovation. China will find itself faced with a grand challenge as it tries to integrate the lessons from this experimentation with national level policies, where political wrangling, the needs of regions neglected by China's technological boom, and reflexive conservation of the status quo will challenge significant reform.

Only time will tell if Xi's "Chinese dream" of "the great revival of the Chinese nation" will be realized. To the extent that the dream depends on becoming a global science and technology powerhouse through indigenous product innovation - moving beyond the second-tier process innovations that have served its developmental model well so far - our research suggests that China's innovation system must first overcome many significant challenges.

Appendix A. Interviews cited

Respondents	Gender	Returnee/domestic scholar	Highest degree	Occupation	Location (city)	Interview date
A	Male	NA	PhD	University research official	Hangzhou	August 1, 2007
B	Male	Returnee: Visiting scientist in US over several periods	PhD	Professor of physics	Shanghai	July 27, 2007
C	Male	Returnee: worked in Japan and Europe	PhD	Professor in materials sciences	Hangzhou	August 2, 2007
D	Male	NA	NA	Official at a governmental nanotechnology center	Shanghai	April 16, 2012
E	Male	NA	PhD	Official at a governmental nanotechnology center	Shanghai	April 16, 2012
F	Male	NA	PhD	Official at a governmental nanotechnology center	Shanghai	April 16, 2012
G	Male	Returnee: studied in Europe for 5 years prior to returning to China	PhD	Associate professor in materials and biomedicine	Shanghai	April 18, 2012
H	Male	Domestic: Received BA, MS, and PhD from universities in China	PhD	Professor in innovation and geography	Shanghai	April 19, 2012
I	Male	NA	NA	General manager of a nanotech company	Shanghai	April 20, 2012
J	Male	Domestic	MA	Venture capitalist	Suzhou	April 20, 2012
K	Male	Returnee: Worked in the U.S. close to twenty years prior to returning to China	PhD	President and CEO of a small company in SIP	Suzhou	April 22, 2012
L	Male	Domestic	PhD	Scientist in a small company at SIP	Suzhou	April 23, 2012
M	Female	NA	NA	Official with NanoPolis at SIP	Suzhou	April 23, 2012
N	Male	Returnee: Received both BSc and MA from universities in Europe	MA	Official with NanoPolis at SIP	Suzhou	April 23, 2012
O	Male	Returnee: Educated in China but worked in the U.S. for approximately 10 years prior to returning to China		Professor in materials science	Suzhou	April 24, 2012

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