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Trends in the Movement of Scientists between China and the United States and Implications for Future Collaborations

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I. Introduction

Scholarly scientific exchange between China and the United States has played an important role in the economic development of both nations. Since Deng Xiaoping first encouraged Chinese students and scientists to go abroad in 1978 more than seven hundred thousand Chinese citizens have heeded this call.[1] Many of these scholars spent their time abroad in the United States.[2]

During the 2004 to 2005 academic year, more than sixty-two thousand Chinese citizens were enrolled in U.S. educational institutions, primarily studying at the graduate level and more than seventeen thousand Chinese visiting scholars were conducting research or teaching at U.S. universities.[3] Judging from their predecessors, many of these nearly eighty thousand Chinese citizens will choose to remain in the United States after completing their studies. Some, however, will return to China. These decisions, made individually by Chinese scholars at the conclusion of their studies, are collectively of significant interest to policymakers in both the United States and China.

Chinese policymakers' interest in encouraging these scholars to return home derives from the goals of China's study abroad program. At the end of the Cultural Revolution, China found itself with a grave shortage of trained scientists and engineers. As Deng Xiaoping stated in 1977, "Compared with the developed countries, our country's science/technology and education has fallen behind by a full two decades."[4] The Cultural Revolution had taken its toll on the higher education system as well and China's universities were not up to the task of quickly producing a large number of highly-trained scientists. Thus, sending students abroad became a shortcut to train technical personnel and learn advanced science and technology.[5] The return of these scholars was a key step in the assimilation and adoption of advanced technology from abroad. Indeed, as the number of Chinese studying abroad increased dramatically, the small number choosing to return threatened the effectiveness of the program and became a salient policy issue. For this reason, China has, since the mid-1980s, taken a variety of steps to encourage its foreign-trained scholars to return.

Chinese scholars are valued in the United States because they, along with other foreign-born scientists and engineers, are a critical cog in the nation's economy. Fifteen percent of bachelor-level and thirty-five percent of doctorate-level scientists and engineers in the United States in 2003 were born outside the country.[6] China was the second largest provider of these foreign-born scientists in total and the single largest source of foreign-born doctorate-level scientists and engineers.[7] The United States has not, in recent years, trained enough U.S. nationals in technical fields to support its economy. Thus, its continued economic growth depends on foreign-born scientists, including, in large part, Chinese citizens.

Reports suggest that China's efforts to encourage its foreign-trained scholars to return have met with greater success, in recent years. To the extent this trend continues and, perhaps, accelerates, it could have implications for the ongoing development of science and technology in the United States and China as well as cooperative and collaborative research efforts between the two countries. This paper first examines the history of scholarly scientific exchanges between China and the United States, focusing on the growing number of Chinese studying abroad since the normalization of diplomatic relations in January 1979. It then examines available data on the movement of scientists between China and the United States to assess the extent to which quantitative data support the idea of recent changes in established patterns of scientific mobility between the two countries. The paper concludes by speculating on the potential impact of these trends, particularly if they continue, on collaboration between scientists in the United States and China.

II. A Historical Perspective

China and the United States have a long history of scholarly exchange. Individual exchanges date back to the 1850s when Yung Wing earned a bachelor's degree from Yale and became the first Chinese student to graduate from a U.S. university.[8] Formal exchanges started in the 1870s when Yung Wing, who had returned to China, organized the Chinese Educational Mission, which sent 120 young Chinese children to the United States to complete their secondary and college educations. This mission was cut short in 1881 amidst growing anti-Chinese sentiment in the United States and concerns among Chinese leaders that the students were adapting too much to life in America. Only two students completed bachelor's degrees, but, despite the interruption of their studies, many of these original exchange students went on to make significant contributions after their return to China.[9]

Following the return of this initial mission, only a handful of Chinese made their way to the United States for academic study in the remainder of the nineteenth century.[10] These were typically supported by western missionaries or Chinese provincial governors and had to overcome anti-immigrant and anti-Chinese attitudes prevalent in the United States at the time.

Ironically, the anti-foreigner sentiments in China that sparked the Boxer Rebellion led, albeit indirectly, to a significant increase in the number of Chinese studying abroad. This increase came about in 1908 when the United States decided to return a portion of the Boxer indemnity funds to China and the Chinese government agreed to use this money to support the education of Chinese students in the United States.[11] All told, some 1,800 Chinese citizens studied at U.S. universities between 1908 and 1929 using these funds.[12] Chinese study-abroad efforts continued into the 1930s but slowed during the Sino-Japan War, which commenced in 1937, and remained low throughout World War II.[13]

Following a brief upsurge near the end of World War II, educational exchanges between China and the Untied States came to halt following the 1949 Communist Revolution. For the next fifteen years, China's study abroad efforts focused on sending students to the Soviet Union and other socialist countries, primarily in Eastern Europe. No Chinese students went abroad during the Cultural Revolution between 1966 and 1969 and only a small number – primarily foreign language students – left between 1970 and 1977.[14]

III. The Modern Era

Against this backdrop of limited study abroad, the new policy encouraging Chinese scholars to train overseas adopted in 1978 represented a marked change. Indeed, the scale of the proposed (and, in retrospect, accomplished) expansion was extraordinary. In June 1978, Deng Xiaoping outlined the policy, stating:

> *I approve of increasing the number of students going abroad for studies, mainly to engage in the natural sciences…This will be an important means for getting quick results and improving our country's standards within five years. We must send them out by the thousands and tens of thousands, not send out merely eight or ten….We must quicken our pace by all possible means.*[15]

Implementing the policy posed numerous challenges. China had closed itself off from the rest of the world for many years and Chinese policymakers found, in the words of then-Vice Minister of Education Li Qi, that "we have few cultural exchanges with the West and know very little about the circumstances of their schools or even about how to send students abroad."[16] Another challenge was finding Chinese students with both sufficient foreign-language skills and the background knowledge required to take full advantage of higher and graduate education opportunities in the West. Because of the need for many Chinese students to complete additional training before studying abroad, the initial groups sent in the late 1970s and early 1980s consisted primarily of advanced studies personnel, often with many years of research experience.[17]

Despite these challenges, China rapidly renewed contacts with appropriate Western governments and expanded the number of students it sent abroad. A key agreement facilitating exchanges between China and the United States was the "Understanding on the Exchange of Students and Scholars." This understanding was signed in October 1978 by Zhou Peiyuan, President of the China Association for Science and Technology, during a visit to the United States. Zhou, who had received advanced degrees from the University of Chicago and the California Institute of Technology while training in the United States on a Boxer Indemnity Scholarship in the 1920s, wanted other Chinese to have the same educational opportunities he enjoyed.[18] Following the official reestablishment of diplomatic relations in January 1979, this agreement was subsumed within a larger agreement on cooperation in science and technology signed by Deng Xiaoping and Jimmy Carter.[19]

China's study abroad program geared up quickly. In 1979, the Chinese government sent 1,277 students abroad. This number increased to 1,862 in 1980 and 2,925 in 1981.[20] Chinese students and scholars studying abroad have traditionally been divided into three classifications, according to the funding source for their studies. These initial cohorts fell almost exclusively into the first category: state-sponsored scholars. Other students and scholars traveled abroad with funding from local Chinese governments or institutions; these individuals are said to be institution-sponsored. The third group consists of self-funded scholars. These individuals either fund their own educational experiences or, as is often the case in the United States, receive funding from foreign institutions to support their studies. Self-funded study abroad was rare in the initial years of the Chinese effort, but today accounts for the majority of Chinese who study abroad.

The policies governing Chinese study abroad efforts went though a number of iterations over the years.[21] In the early 1980s, the emphasis shifted from sending advanced scholars to degree candidates, first at the masters level and then, whenever possible, at the doctoral level. Selection policies were decentralized starting with the 1984-1985 academic year, giving individual institutions a greater role in selecting and funding overseas study. Importantly in December 1984, previous restrictions on self-funded study abroad were loosened. By providing study abroad opportunities to any Chinese citizen who could obtain funding and arrange for school enrollment, this step served to greatly increase the number of Chinese students studying internationally.[22]

As the number of Chinese studying abroad increased, concerns about the small number returning to China grew. These low return rates were influenced by many factors. The type of funding was one factor, as self-funded scholars were less likely to return than those funded by the Chinese government or other Chinese institutions.[23] But employment and political issues played roles as well. Chinese research organizations remained relatively impoverished and poorly managed for some time, limiting their appeal to students returning from the United States or other western nations.[24] Some returnees reported difficulties finding appropriate employment and these reports discouraged later scholars from returning. Two doctorate-holding organic chemists, for instance, who graduated from Rice University as part of a prestigious program jointly organized by the Chinese Ministry of Education and a Harvard chemistry professor, were given jobs teaching English rather than science.[25] Beyond employment concerns, political issues played a role as well. Although the 1980s were generally a time of reform in China, a series of anti-intellectual campaigns – specifically targeting Western influence or "bourgeois liberalism" as it was called – contributed to some overseas scholars' decisions to remain abroad.[26] Loopholes in U.S. visa policies, which allowed some students to extend their stays[27], as well as differences in the typical standard of living experienced by scientists in each country, may have played roles as well.

By the mid-1980s, Chinese policymakers' concerns about the extent of a possible "brain drain" led to a number of steps designed to encourage Chinese citizens studying abroad to return. These included a joint statement issued with the U.S. government reaffirming the obligation of state- and institution-sponsored Chinese scholars to return to China,[28] and letters published in Chinese newspapers describing the difficulties of life in the United States.[29] Any momentum these efforts generated was lost abruptly, however, following the Tiananmen Square incident in June 1989. This event discouraged many Chinese scholars abroad from returning and led governments in a variety of nations, including the United States, Canada and Australia, to grant permanent resident status to Chinese scholars rather than force them to return. In all, approximately 50,000 Chinese citizens were granted permanent resident status in the United States, as a result of Tiananmen Square related policy changes.[30]

The Chinese government added new restrictions to overseas study in 1989, but these did little to stem the flow of students and scholars out of the country.[31] Indeed for students sympathetic to the June 1989 protests, studying abroad, perhaps with no intention of returning, seemed the only desirable option.[32] Perhaps, with these students and other overseas scholars upset by the Tiananmen Square incident in mind, the Chinese government introduced new policies on overseas study in 1992. This policy was described in a circular issued by the General Office of the State Council, which read, "People who study abroad are the country's precious treasure….All personnel who are studying abroad, regardless of their past political attitude are welcome to come back."[33] The same year Li Tieyeng, chair of the State Education Commission introduced a slogan ("support overseas study, encourage people to return, and give people the freedom to come and go") to describe the new policies.[34]

In the following years, these changes were complemented by a host of other policies designed to encourage overseas Chinese to return.[35] These changes included new flexibility in the types and locations of jobs returnees could take as well as increases in higher education budgets to enhance the appeal of Chinese universities to overseas scholars. They also included a program providing funding for those who wished to remain overseas to return for short visits to give lectures and engage in research collaborations. Between 1992 and May 2003, more than eight thousand people returned to "serve the country" on these short visits.[36] By introducing these scholars to the modern research environment in China, this program may encourage them to return at a later date.

Both the Chinese government and the Chinese Academy of Sciences have offered incentives to encourage overseas scholars to return. These include increased salaries, additional research funding, tax breaks, and assistance finding housing. Among these incentives are the Cheung Kong Scholars Programme, which brought 537 scholars from overseas to China between 1998 and 2004,[37] the Distinguished Young Scholar Programme, which does not focus specifically on overseas scientists, but has frequently rewarded those with such experience,[38] and the Hundred Talents Programme. These incentives were complemented by the continuing growth of China's economy, which offered an incentive of its own for overseas scientists interested in returning to start commercial ventures.

IV. Recent Quantitative Data

Recent scholarship suggests these various programs and incentives, combined with other factors, such as China's improving economy and acceptance into the WTO, are starting to turn the tide and encourage Chinese scholars studying abroad to return home. Cheng Li, for instance, describes a "tidal wave of returnees" in recent work.[39] He crafted a database of 2,044 people who had previously studied abroad but now taught at China's top twenty-five universities and found that these returnees were predominately male (86 percent), scientists or engineers (73 percent) who had served as visiting scholars (61 percent) for one to two years (62 percent) abroad.[40] David Zweig has reported that the number of returnees increased dramatically starting in the late 1990s, but that returnees remain small as a percent of people going overseas because of continuing increases in the number of Chinese studying abroad.[41] Through a number of surveys, including interviews with a set of scientists at the Chinese Academy of Sciences, he concluded that returnees were typically of higher quality than scientists who had not gone abroad, but noted this conclusion was clouded by selection bias, since more talented students have greater opportunities to study abroad in the first place.[42]

Several data sources offer insight into the movement of Chinese scholars. Figures 1 and 2 provide a view of China's overall study abroad efforts since 1978. The annual data in figure 1 highlight a recent increase in the absolute number of overseas scholars returning to China. This trend has accelerated since 2000 and a record 27,200 Chinese nationals returned from abroad in 2005.[43] These returnees were dwarfed by the 118,500 Chinese who studied abroad the same year, however. The number of Chinese citizens studying abroad has leveled off since peaking in 2002, while the number of returnees continues to rise. If these trends continue, the difference between the number of scholars studying overseas and the number returning may decline.

The difference between the number of overseas students and scholars and the number of returnees in the cumulative data in figure 2 illustrates the extent of the "brain drain" from China to other countries. Between 1978 and 2003, 700,200 people left China to study abroad and 172,800 (25 percent) of these returned to China. Those who had not yet returned were divided into two groups: 356,600 (51 percent) still completing their studies or research and 170,800 (24 percent) who had completed their studies but not returned to China.[44]

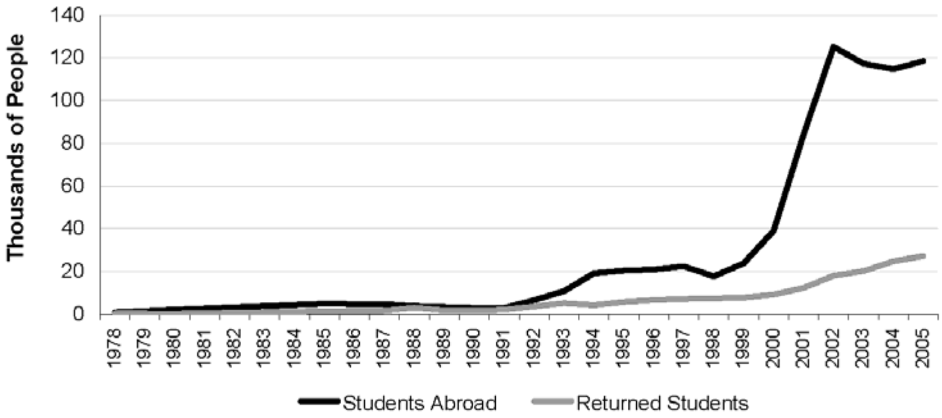

Figure 1 – Number of Chinese students studying abroad and returning to China, by year. Source: National Bureau of Statistics of China, *China Statistical Yearbook*, 693

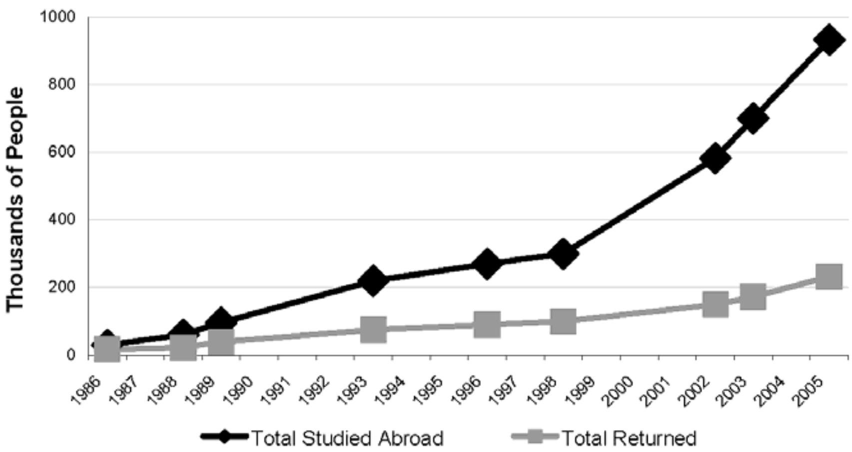

Figure 2 – Cumulative number of Chinese students and scholars studying abroad and returning since 1978. Lines represent interpolations between nearest data points. Source: 1986 – 2003: Li "Coming Home to Teach," 81, 2005: Xinhuanet "More Chinese choose to come back after studying abroad" June 6, 2006.

Figure 3 illustrates the rapid increase in the number of Chinese students and visiting scholars in the United States since 1978. There are now more than 60,000 Chinese students and 17,000 visiting scholars studying in the United States each year and Chinese students account for 11 percent of all foreign students studying at U.S. educational institutions. The number of Chinese students studying in the United States has remained relatively flat the last few years, in line with the overall number of Chinese students studying abroad.

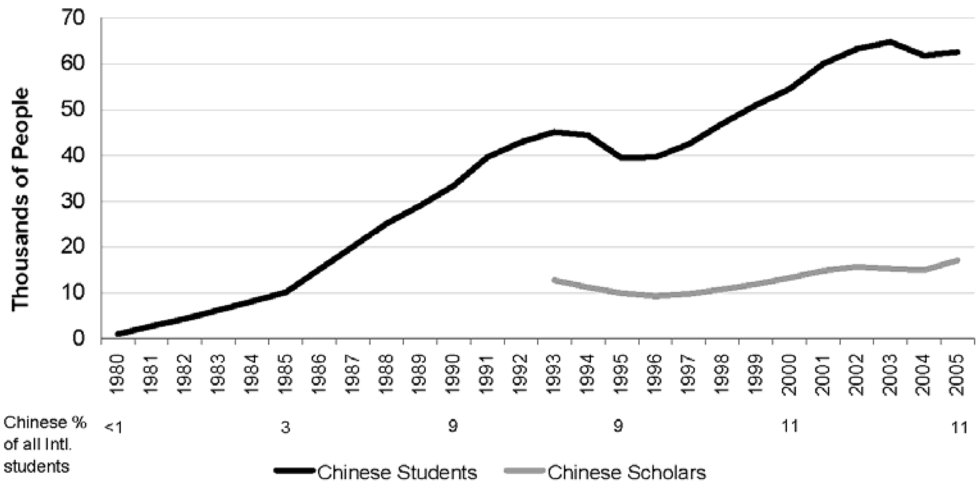

Figure 3 – Chinese students and visiting scholars in the United States
Source: Institute of International Education, Open Doors Reports

Perhaps owing to the focus of China's study abroad program on the natural sciences, the growth in the number of Chinese citizens receiving science and engineering doctorate degrees in the United States has been particularly impressive (see table 1). In 1986, 199 Chinese citizens received science and engineering doctorate degrees in the United States. Ten years later, this number had grown fifteen fold. In 1996, more than three thousand science and engineering doctorate degrees were awarded to Chinese citizens and these degrees accounted for 11 percent of all science and engineering doctorates awarded in the United States that year. Chinese scientists have earned roughly the same share of science and engineering doctorates in the years since.

Figures 4 and 5 examine trends in the post-graduation plans of Chinese citizens receiving science and engineering doctorates in the United States. Between 1994 and 2004, a high percentage of Chinese doctorate recipients consistently indicated that they planned to remain in the United States following graduation. Since reaching a high of 97 percent in 2004, this metric has declined slightly. A related metric, called the stay rate, is the percentage of foreign-doctorate recipients remaining in the country a given number of years after graduation. As expected from their post-graduation plans, the five-year stay rate for Chinese doctorate recipients has been consistently high. The rate has declined slightly in recent years, however. Ninety-six percent of Chinese doctorate recipients in 1996 were still in the United States in 2001. In contrast, 90 percent of Chinese doctorate recipients from 1998 were still in the country five years later in 2003. Both of these metrics indicate that, compared to doctorate recipients from other nations, Chinese citizens are more likely to remain in the United States following completion of their degrees. However, the recent downward trends suggest that China's efforts to encourage overseas scholars to return may indeed be starting to pay dividends.

	1986	1988	1990	1992	1994
Chinese doctorate recipients	199	480	1,150	2,045	2,531
All Non-U.S. doctorate recipients	5,154	6,066	7,768	9,475	10,542
All S&E doctorate recipients	19,437	20,932	22,868	24,675	26,205
Chinese share of non-U.S. doctorates	4%	8%	15%	22%	24%
Chinese share of all S&E doctorates	1%	2%	5%	8%	10%
	1996	**1998**	**2000**	**2002**	**2004**
Chinese doctorate recipients	3,022	2,510	2,378	2,401	2,869
All Non-U.S. doctorate recipients	10,845	9,795	9,069	8,857	10,121
All S&E doctorate recipients	27,241	27,278	25,966	24,588	26,275
Chinese share of non-U.S. doctorates	28%	26%	26%	27%	28%
Chinese share of all S&E doctorates	11%	9%	9%	10%	11%

Table 1 – Chinese share of U.S. science and engineering doctoral degrees
Source: National Science Foundation/Division of Science Resources Statistics, Survey of Earned Doctorates; S&E Doctorate Awards 2004, 1997, 1994

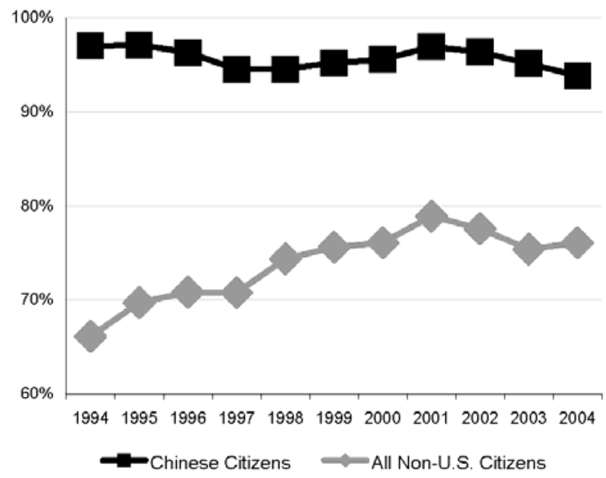

Figure 4 – Percent of Chinese citizen and all non-U.S. citizen science and engineering doctorate recipients with plans to stay in the U.S. after graduation
Source: Survey of Earned Doctorates, special tabulation by the National Science Foundation, August 2006

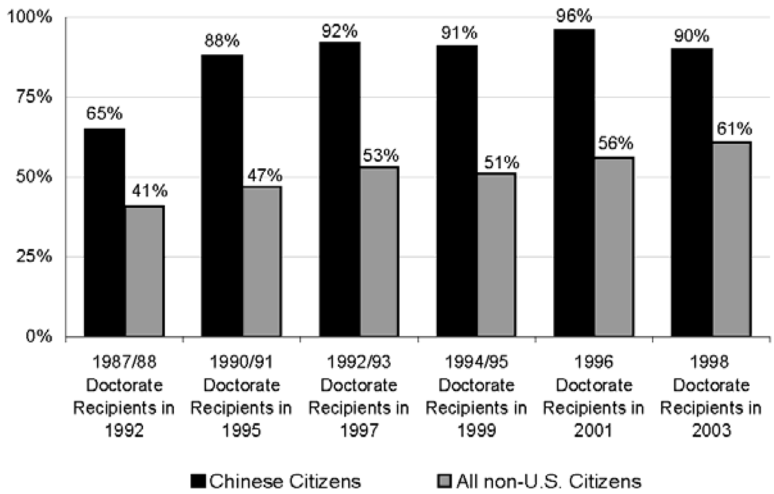

Figure 5 – Percent of Chinese citizen and all non-U.S. citizen science and engineering doctorate recipients still in the United States four to five years after graduation
Source: Finn, Michael G. "Stay Rates of Foreign Doctorate Recipients from U.S. Universities, 2003"

V. Scientific Collaboration and Cooperation

If, as recent trends suggest may be a possibility, Chinese scholars studying in the United States increasingly decide to return to China in the coming years, the scientific research communities in both countries should expect significant changes. China would stand primarily to benefit from an influx of returning experts, but must overcome key challenges to successfully integrate returnees. The United States would need to adjust to a reduction in the number of highly-trained foreigners available to take positions in U.S. companies but may benefit, in the longer term, from new opportunities for collaboration with China.

China's rapidly growing economy and its success in many high-tech fields testify to the nation's successful modernization efforts in recent decades. That this modernization has been accomplished in so short a time and with so many highly-trained people remaining abroad is impressive. An increasing number of returnees should help Chinese science and technology to continue developing. However, the integration of returning scholars into existing research environments requires careful attention. If large numbers of returning scholars cannot find positions appropriate to their training levels, as was the case for some earlier cohorts of returnees, the flow of scientists from abroad may slow or stop. On the other hand, if returnees are favored and given their choice of positions, conflicts may arise between scientists trained solely at Chinese institutions and those trained abroad. Anecdotally, conflicts resulting from preferential treatment granted to returnees have been reported[45] and these could potentially increase if the flow of returnees continues to grow.

International collaboration, as measured by co-authorship, has been growing in recent years and collaboration between scientists in China and the United States is no exception. Between 1996 and 2003 the share of U.S. internationally co-authored papers including Chinese authors increased from 2.6 percent to 4.7 percent.[46] This increase may well reflect the impact of the large numbers of Chinese scientists studying abroad in the Untied States as well as those returning home during this time period.

Among the many factors that can contribute to the start of a new research collaboration is the teacher-student relationship.[47] Chinese scientists who study abroad and then return to China are well positioned to collaborate with the principal investigators who oversaw their work in the United States. This idea is supported by the relatively strong correlation between the number of science and engineering doctorates awarded to foreign-born students in the Untied States and the number of publications jointly authored by their country of origin and the United States.[48] This relationship and the increasing flow of scientists back to China should lead to increases in the absolute number of papers jointly authored by U.S. and Chinese scientists.

An increase in the number of U.S.-trained Chinese returning to China may open the door to more complex interdependent forms of collaboration, particularly if Chinese scientists who have lived and worked in the United States for many years decide to return. The familiarity these more-senior scientists have with senior U.S. scientists and, in some cases, business executives, would facilitate tighter academic collaborations and research-industry linkages. They may also facilitate the creation of additional joint research programs, such as the long-standing Hopkins-Nanjing Center or the more recent Fudan-Yale Biomedical Research Center.

The Fudan-Yale collaboration is a particularly interesting example. It features two interdependent genetics labs, one in Shanghai and one in New Haven, both led by Tian Xu, a Chinese-born U.S.-trained scientist who holds academic posts at both schools. The labs work on related, but distinct, projects and students move regularly between the two facilities.[49] The dual laboratories allow projects to be tackled in the most appropriate location. For instance, the Fudan laboratory is taking the lead on a massive program to create thousands of knockout mice, animals genetically modified to lack specific genes. Xu estimates that the project's total cost in China will be only one fifth to one fourth what it would cost in the United States.[50]

U.S-China collaborations offer a host of other benefits, beyond China's attractive cost structure. These include an environment more conducive to animal research than that found in many western countries. This is particularly true for research on our closest animal relatives, primates. While primate research is expensive and controversial in the United States, it remains a crucial biomedical research tool. Conditions in China, where monkeys are both plentiful and affordable and animal research generates little controversy, seem to set the groundwork for potential collaborations, particularly as more U.S.-trained Chinese scientists return and start working at Chinese primate research centers.

Although an increase in the number of returnees to China should facilitate collaboration across almost all scientific fields, opportunities may be particularly rich in fields the Chinese government has made the focus of national research efforts. These fields include human embryonic stem cell research, where numerous Chinese groups have reported significant progress, including experiments using the controversial but promising somatic cell nuclear transfer technique.[51] Notably, international assessments have placed Chinese scientists "at or near the forefront of international stem cell research."[52] Nanotechnology, another field where focused Chinese efforts appear to have yielded significant dividends,[53] may provide similar opportunities for collaboration. As the number of fields where Chinese scientists are at the forefront of international research efforts increase, new opportunities may arise for U.S. scientists to train, particularly at the post-doctoral level, in China.

Of course, collaborative efforts in controversial fields such as human embryonic stem cell research or primate research pose additional challenges. Scientists from both countries must be careful to ensure collaborations are substantive and do not simply represent the outsourcing of ethically-contentious research. Adherence by researchers in both the United States and China to the same set of international standards, such as those proposed by the International Society for Stem Cell Research to oversee human embryonic stem cell research, could help alleviate these sorts of concerns.

In the years since Deng Xiaoping's decision to send students abroad, Chinese science has advanced immeasurably. These improvements occurred despite large numbers of China's most highly-trained scientists choosing to remain abroad. If the number of U.S.-trained Chinese scholars returning to mainland China significantly increases in the coming years, as some analysts suggest is already occurring and recent data suggest may be a possibility, it will initially pose challenges for both nations. In the long run, however, such changes should offer enhanced opportunities for bilateral scientific collaboration and benefit both nations.

Notes

[1] Cheng Li, "Coming Home to Teach: Status and Mobility of Returnees in China's Higher Education," in *Bridging Minds across the Pacific : U.S.-China Educational Exchanges, 1978-2003*, ed. Cheng Li (Lanham, Md.: Lexington Books, 2005), 81.

[2] Since 1978, the vast majority of Chinese citizens studying abroad have been either graduate students or visiting scholars. Visiting scholars are typically called post-doctoral researchers in the United States. For simplicity, both groups will be referred to as "scholars" in this paper, unless discussing a specific data source or policy that applies only to one of these two groups.

[3] Hey-Kyung Koh Chin, ed., *Open Doors 2005: Report on International Educational Exchange* (New York: Institute of International Education, 2005).

[4] Quoted in Ted Wang, trans, "Retrospect and Analysis of China's Policies with Regard to Students Sent by the State to Other Countries since 1978," *Chinese Education and Society* 38, no. 3 (2005): 13.

[5] Ibid.

[6] National Science Board, "Science and Engineering Indicators – 2006," (Arlington, VA: National Science Foundation, 2006), table 3-20.

[7] Ibid., figure 3-39.

[8] Wing's story is told in Thomas E. La Fargue, *China's First Hundred* (Pullman,: State college of Washington, 1942), 17-35.
[9] The history of the Chinese Educational Mission is reviewed in Stacey Bieler, *"Patriots" Or "Traitors"? : A History of American-Educated Chinese Students* (Armonk, NY: M.E. Sharpe, 2004), 1-17, China Institute in America. Committee on Survey of Chinese Students in American Colleges and Universities., *A Survey of Chinese Students in American Universities and Colleges in the Past One Hundred Years.* (New York,: 1954), Li, "Coming Home to Teach," 73. and recounted in detail in La Fargue, *China's First Hundred*.
[10] See China Institute in America. Committee on Survey of Chinese Students in American Colleges and Universities., *Survey of Chinese Students*.for a year by year estimate and Y. C. Wang, *Chinese Intellectuals and the West, 1872-1949* (Chapel Hill,: University of North Carolina Press, 1966), 41-73.
[11] Michael H. Hunt, "The American Remission of the Boxer Indemnity: A Reappraisal," *The Journal of Asian Studies* 31, no. 3 (1972).
[12] Li, "Coming Home to Teach," 73.
[13] Linqing Yao, "The Chinese Overseas Students: An Overview of the Flows Change" (paper presented at the 12th Biennial Conference of the Australian Population Association, Canberra, Australia, 2004), 4.
[14] Li, "Coming Home to Teach," 75.
[15] Wang, "Retrospect and Analysis," 13.
[16] Ibid.: 20.
[17] Ibid.: 18.
[18] Mary Brown Bullock, "Mission Accomplished: The Influence of the Cscprc on Educational Relations with China," in *Bridging Minds across the Pacific : U.S.-China Educational Exchanges, 1978-2003*, ed. Cheng Li (Lanham, Md.: Lexington Books, 2005), 55.
[19] Richard P. Suttmeier, "Scientific Cooperation and Conflict Management in U.S.-China Relations from 1978 to the Present.," *Annals of the New York Academy of Sciences* 866 (1998): 142-3.
[20] Wang, "Retrospect and Analysis," 25.
[21] Reviewed in David Zweig, Changgui Chen, and with the assistance of Stanley Rosen, *China's Brain Drain to the United States: Views of Overseas Chinese Students and Scholars in the 1990s* (Berkeley: Institute of East Asian Studies, University of California, Berkeley, Center for Chinese Studies, 1995), 19-23.
[22] Wang, "Retrospect and Analysis," 34.
[23] Li, "Coming Home to Teach," 79.
[24] Suttmeier, "Scientific Cooperation," 148.
[25] Jim Mann, "China's Lost Generation: After Tian an Men, the Best and Brightest Say They Can't Go Home Again," *Los Angeles Times Magazine*, March 25 1990, 14-5.
[26] Bieler, *"Patriots" Or "Traitors"?* , 353-4.
[27] Zweig, Chen, and Rosen, *China's Brain Drain*, 21.
[28] Robert Jacobsen, "China and U.S. Express Concerns over Return of Exchange Students," *Chronicle of Higher Education*, June 17 1987, 32, Li, "Coming Home to Teach," 78.
[29] Mann, "China's Lost Generation," 16.
[30] David Zweig, "To Return or Not to Return? Politics Vs. Economics in China's Brain Drain," *Studies in Comparative International Development* 32, no. 1 (1997): 93.
[31] Zweig, Chen, and Rosen, *China's Brain Drain*, 22.
[32] Bieler, *"Patriots" Or "Traitors"?* , 357.
[33] Fullang L. Xin, "The Basic Line of Thinking in Shanghai's Efforts to Attract Overseas Chinese Intellect," *Chinese Education and Society* 34, no. 3 (2001).
[34] David Zweig, "Learning to Compete: China's Efforts to Encourage A "Reverse Brain Drain"," in *Competing for Global Talent*, ed. Christiane Kuptsch and Eng Fong Pang (Geneva: International Institute for Labour Studies, 2006), 190.
[35] Reviewed in Ibid.
[36] Ibid., 197.
[37] Ibid., 200.
[38] Cong Cao and Richard P. Suttmeier, "China's New Scientific Elite: Distinguished Young Scientists, the Research Environment and Hopes for Chinese Science," *China Quarterly*, no. 168 (2001): 962-3.
[39] Li, "Coming Home to Teach," 76.

[40] Ibid., 83-98.
[41] Zweig, "Learning to Compete," 188.
[42] Ibid., 203-5.
[43] Xinhuanet "More Chinese choose to come back after studying abroad" June 6, 2006
[44] Chinese Ministry of Education, http://www.moe.edu.cn/english/international_2.htm, Also reported in Xinhuanet "Record 20,100 students back home from abroad" February 16, 2004
[45] Zweig, "Learning to Compete," 210-1.
[46] National Science Board, "Science and Engineering 2006," appendix tables 5-48, 5-49.
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Intellectual Property Rights Issues in China and the United States

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I. Introduction

Intellectual property rights (IPR) protection has been the topic of many science and technology policy debates from the halls of the US Congress to the World Trade Organization, and other international forums, and the debates go on. What should be protected? To whom should such protections be granted? Who should enforce intellectual property rights protection? How ought differences in national policies be resolved? What is the appropriate balance between intellectual property rights protection and dissemination of knowledge in the public domain? The first question to address is, perhaps, why are intellectual property rights and their protection important?

Economic studies have suggested that innovation and technical progress are important components of economic growth. Robert Solow's seminal 1957 paper showed that about 80 percent of the economic growth occurring in the United States between 1909 and 1949 was due to a component other than the capital/labor ratio. In this work, he suggests that this component is technological change.[1] Other studies have led to the conclusion that technological change or progress contributes to growth in the economy. [2]

This relates to intellectual property and intellectual property rights protection because it is also a generally agreed among economists and legal scholars that intellectual property rights are a way of encouraging innovation. IPR allow the entity that has invested the time and effort into the research which led to the innovation to recoup the costs by conferring a legal monopoly. And, the length of that monopoly period varies depending on the type of IPR and upon the granting nation.

Intellectual property rights can be protected through a number of mechanisms including trade secrets, trademarks, copyright, and patents. Patents are particularly interesting because generally they are conferred for a limited time and are issued to protect either a product or a process that is often associated with a new industry or business sector or company. In most countries, one must file for a patent in order to have the protection it offers. When an individual has a patent for a particular technology, she has an exclusive right to that technology meaning that no other person or entity can make use of that technology without the go-ahead from the patent holder. The patent itself does not ensure the patent holder with exclusive rights; rather it enables the patent holder to bring suit against anyone who infringes the patent by using the patented technology without permission.[3]

In this essay, I will discuss the patent system in both the United States and in China, with some attention to patenting of life sciences technologies. A comparison such as this is interesting on several counts including that in one instance the patent system has been in place legislatively since the late 1700's (the United States)[4] while in the other instance, legislative action establishing the system did not occur until the mid-1980s (China).[5] An obvious question to ask is what can China learn from the United States? I would also contend that the reverse question ought also be asked: what can the United States learn from China? As China looks to the United States, European nations, and other countries with more extensively developed economies and more mature IPR regimes, it will no doubt attempt to select and incorporate the "best" components of each. In turn, the United States might learn from Chinese IPR practices by attempting to see through that unique perspective what principles and practices might be useful modifications to its own IPR system.

In addition, as I noted in my opening paragraph, intellectual property rights and their protection are the topic of numerous science and technology discussions. In an era of increasing globalization – both in terms of economics and trade and of international scientific collaborations, how we reach workable resolutions to national differences in treating intellectual property is essential as the world business community strives toward seamless and more efficient international interactions.

I first want to discuss briefly the patent systems for both the United States and China. I will then point to topics that I believe to be current and or emerging issues in this policy area.

II. Patents in the United States

The notion of protecting intellectual property is actually imbedded in the US Constitution, which provides for the protection of creative works and invention. This is incidentally the only reference to the federal government's role in national science policy.[6]

> *The Congress shall have Power ... To promote the Progress of Science and useful Arts, by securing for limited Times to Authors and Inventors the exclusive Right to their respective Writings and Discoveries;*
>
> ~ Article 1, Section 8

The United States was by no means the first nation to adopt a patent law – the first such law was established by the Republic of Venice in 1474.[7] Prior to this the English Crown had been granting persons with a right to a monopoly to produce goods or services. The English system evolved, and it is what served as the foundation for the American system.[8] At the time of the passage of the first US patent law in 1790, the life of a patent was 14 years. Since its enactment, the patent law has been amended a number of times, including for increased protection longevity. For instance, the Patent Act of 1836 kept the length at 14 years but allowed for a seven-year extension to be granted. The patent law was changed again in 1860, extending the life of a patent to 17 years. The basic structure of the current US patent law was put in place with the Patent Act of 1952.[9] Since 1995, the length of a US patent is 20 years. This change in US policy was in accordance with the end results of the Uruguay Round of trade negotiations, which led to revisions of the General Agreement on Tariffs and Trade (GATT) and to the creation of the World Trade Organization (WTO).[10]

US patents can be issued for a product or a process. Three different kinds of patents can be issued by the United States Patent and Trademark Office: utility patents, design patents, and plant patents. The product or process to be patented must be novel and non-obvious and must be useful (novelty, non-obviousness, and utility).[11]

There are a number of legislative acts in place that affect intellectual property, and a number of these affect the nation's science and technology enterprise. Two that are particularly relevant to science and technology policy are the Patent and Trademark Law Amendments Act of 1980 (Bayh-Dole Act)[12] and the Drug Price Competition and Patent Term Restoration Act of 1984 (Hatch-Waxman Act).[13] The former allows universities and other non-profit research institutions to own intellectual property resulting from federally funded research. This has opened the way for these institutions to engage actively in licensing technologies to the commercial sector. The latter has made it easier for generic drug manufacturers to bring their products to market. Unfortunately, several provision of the Hatch-Waxman Act, intended to be of benefit to pharmaceutical and biotech companies of brand name therapeutics, have come under scrutiny due to concerns of abuse by the brand-name manufacturers.[14]

III. Patents in China

What is thought of as the 'modern' Chinese Patent Law was passed in 1985. In the early part of the 20th century with the establishment of a national governance structure, the Chinese government adopted the practice of providing patent protection to inventions of Chinese nationals.[15] Eleven years later, Chinese patent protection was extended to include Americans holding US patents.[16] It was not until 1932 that a patent law was actually passed and put into place. This law permitted granting of patents only to Chinese nationals; it did not recognize patents of foreign inventors, even if the non-national inventors held a patent from the United States or some other foreign government.[17] The adoption of intellectual property laws, including patent laws, based on the model used in the Soviet Union took hold with the creation of the People's Republic of China in 1949.[18] It was during the 1970's and 1980's that Chinese leaders acknowledged the importance of fundamental property laws to a successful market economy or mixed market-socialist economy. Efforts were made to analyze patent systems around the world and draft and pass legislation establishing a modern day patent regime.[19]

Today, what is patented in China must meet the requirements of utility, novelty, and inventiveness (this is comparable to the non-obvious requirement in US patent law).[20] Things that were patentable under the 1985 Patent Law included processes and some products; it excluded chemicals, pharmaceuticals, and most agricultural products.[21] In the

1993 amendments to the law, these products became patentable.[22] In addition, the 1985 law recognized invention patents (analogous to the United States' utility patents) and utility models, a form of petty-patents recognized by a number of other countries but not the United States.[23]

It is interesting to note that in ancient China as in other cultures, the notion of an individual owning and having rights over any intellectual creation was not supported. Confucianism influenced the way of thinking in ancient times putting emphasis on personal development rather than personal gain. Individual creativity was important in as so much that it contributed to society as whole. That creative and inventive achievements could be owned by an individual and protected by property rights was not just foreign to the Chinese way of thinking, but it was "essentially beyond the scope of their mental picture of the world".[24]

IV. Policy issues

As China proceeds in developing its patent system, there are a number of policy issues to be considered.

One issue of concern that was expressed at the China-US Forum on Science and Technology Policy, October 2006 was that of *indigenous innovation*.[25] This is a term used by Chinese officials to describe a goal they are striving to achieve. Loosely, this term seems to refer to the notion that the China's people should become contributors and users of technologies that are developed by Chinese scientists and engineers. Some US officials and others are slightly uneasy with the use of the phrase and the prominence that the Chinese have placed on reaching the goal. This is partially due to the fact the exact meaning is literally "lost in translation". Other concerns of course are related to the United States' desire to remain the global leader in science, technology, and innovation.

With its recent admission to the World Trade Organization, China has had to be concerned with its successful implementation of WTO treaties, including the Trade Related Aspects of Intellectual Property Rights (TRIPS) Agreement.[26] One of the goals of the TRIPS agreement was to address the issue of piracy of intellectual property. Developed countries have had concerns over the illegal copying and selling of products and processes in the international market place, i.e. a company from the developing world manufactures and sells a product that a multinational company still has on patent. This has been a huge concern for multinational pharmaceutical and biotechnology companies. The AIDS epidemic and the high cost of AIDS/HIV drugs and lack of availability of these in developing nations where AIDS/HIV prevalent is one instance in which such a scenario has played out. A mechanism the TRIPS agreement uses to resolve issues like that with AIDS/HIV drugs is compulsory licensing, which essentially means a patent holder is forced to grant use and or manufacture of the patented technology to an outside party even before the patent expires.

On the flip side is the issue of biopiracy, "the development and patenting of material derived from resources and knowledge" taken from less developed nations "for the benefit of corporations" located in developed countries.[27] Biopiracy, or rather preventing biopiracy while still facilitating efforts to preserve biodiversity is another important policy issue for China. This is also called bioprospecting and largely encompasses the patenting of living organisms, including plants, and germ plasm.

Developing nations have proposed an amendment to the TRIPS Agreement that would require patent applicants to disclose the origin of biological materials and traditional knowledge included in the patent and to demonstrate they had received Prior Informed Consent from the government of the nation of origin. Along with this, patent applicants would be required to arrange for an access and benefit sharing plan of the materials and patented item with the people of the nation of origin.[28] The point of the amendment according to the developing nations is to prevent biopiracy. Many developed nations, including the United States, do to not agree with the terms of the amendment and claim that it would not have the effect of limiting biopiracy.[29] China was not one of the original countries officially communicating this proposal to the WTO, but the Chinese government should have an interest in how this plays out given its role in the global economy and its wealth of natural resources and traditional practices.

One factor enabling China to be a player in the global economy is its ability to attract foreign investment. And one crucial factor for multinational companies in deciding whether to invest in a particular company is the strength of the government's intellectual property rights protection. [30] Empirical evidence supports this: studies on the relationship between US foreign direct investment and patent strength demonstrate that companies limit their investments in nations with weak patent regimes.[31] Survey studies also provide evidence that companies are reluctant to build research and development (R&D) facilities in countries with weak patent systems.[32]

While there is no doubt the Chinese government has taken measures to develop and put in place a patent system, concern has been expressed about the enforcement of these laws. [33] A review conducted in early 2005 by the Office of the US Trade Representative found that infringement levels for nearly every form of intellectual property was at 90 percent or above. That same review found that foreign pharmaceutical companies (non-Chinese) lost 10-15 percent of their annual reviews in China as a result of increased drug and therapeutic counterfeiting.[34] In fact, some view the weak environment for intellectual property protection in China as being one thing preventing its market from being "overwhelmingly" endorsed by multinational companies.[35] Others, however, believe that the changes China has made to its intellectual property system in the last several years has made it one of the toughest systems in the world with prosecution of infringers by the Chinese government on the rise.[36] To take into account here is that enforcement of patent protection differs across regions within the country. In any case, China does have an interest in continuing to develop its system of patent protection and enforcement because of its importance to the growth of China's domestic firms as they become more technology driven and R&D focused.

Also to be considered is that for poor, developing countries it is not necessarily the case that strong intellectual property protection is to its benefit.[37] For China, however, because of its growing R&D infrastructure and place in the global economy, the situation might be different. There are those, though, who argue that strong, broad patent protection is not necessarily a good thing regardless of the country. This point is argued particularly for university-based research and often in the life sciences.[38]

In 1980 the US Congress passed the Bayh-Dole Act, and this Act is often attributed with the success of the US R&D enterprise over the past two and half decades. Because of this, other countries either have put into place or are seriously considering adopting legislation similar to the Bayh-Dole Act because of the apparent link between it, technology transfer between universities and industry, and economic growth. It has been argued, though, that growth in university-industry relations was underway before the passage of the Bayh-Dole Act and that growth in the biotechnology and information technology sectors would have occurred regardless of the Bayh-Dole Act.[39]

The Bayh-Dole Act is the likely source of the increase in patenting of what are commonly referred to as research tools. Research tools are the technologies that are upstream in the product development process. They can be materials or processes that might be used by many other scientists in their quest for developing a particular therapeutic compound or test. Research tools might be materials or processes that are useful to basic researchers in their daily research endeavors. When a research tool is patented – protected by intellectual property rights, its use by other scientists is greatly limited and some would argue that this in turn puts restrictions and hindrances on progress in science.[40] Research tool patents can concentrate the right to use the technology in the hands of a few (some would argue that the Wisconsin Alumni Research Foundation (WARF) patents on the process of human embryonic stem cell derivation and products is an example of this) or they can create a situation in which in order for a researcher to proceed, she must license various research tools from various patent holders (some would argue that this situation is created by the patenting of DNA sequence).[41]

I mentioned at the beginning of this essay that there are things China, a country with a relatively young modern patent system, can learn from the United States, a country with a more established patent system. One area in particular in which I think Chinese policymakers should look to the United States experience is with the Bayh-Dole Act and the patenting of research tools. In this case, I think China might not want to follow the exact same path that the United States has taken. Whether there is any real long term social benefit from the Bayh-Dole Act and from the increased technology transfer and licensing activities of universities is not quite clear. Nor is it clear that social benefits result from the patenting of research tools in the life sciences.

Another point of criticism regarding Bayh-Dole is that it has led to increased conflicts of interest for universities and university research and that is has even decreased the integrity of science. While people laud the Bayh-Dole Act for facilitating interactions among industrial and university scientists;[42] others say these increased interactions have come at a cost, in particular where unfavorable findings from drug studies have been suppressed.[43] In addition, there is a notion that universities are becoming too engrossed in technology transfer simply as another means of generating revenues, so much so that they are being aggressive at the negotiating table with potential industrial licensees.[44]

The Hatch-Waxman Act offers another point from which China might learn from the US experience. The original legislation does facilitate bringing generic versions of brand name drugs to market more quickly, but it also has provided loopholes that brand name pharmaceutical companies have used to extend the exclusivity of a brand-name drug. Examples include patenting additional features of a drug when it is about to go "off patent", brokering deals with generic drug manufacturers that essentially result in delaying the production and marketing of a generic version, and manufacturing or authorizing the manufacture of a generic version (such that the brand name pharmaceutical company a) has a say in the pricing and b) receives some revenue from sales).[45]

While the intent of the Hatch-Waxman Act was to facilitate bringing generic, more affordable drugs to market sooner, it is relevant to keep in mind the importance of patents to the pharmaceutical industry. Because of the intricate link of affordable therapeutics to affordable healthcare and overall national well-being, if China ever were to reach a point of considering something like the Hatch-Waxman Act, it might do better to find incentives for drug makers to directly provide drugs at lower costs. Since patents are important to the pharmaceutical industry – more so than in other industry, it seems that governments would do well consider mechanisms that allow pharmaceutical companies to have strong R&D programs while re-covering investments without the incredible consumer prices, e.g. subsidies and substantial tax credits.

I think if the Chinese government proceeds cautiously taking the empirical evidence into account, it has the opportunity to establish a system that can achieve the goals of stimulating innovation, inventiveness, and investment in R&D without hindering basic scientific research. In fact, the United States might find some of the practices implemented by China reasonable modifications to make to its own system.

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Nanotechnology Policy: An Analysis of Transnational Governance Issues Facing the United States and China

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I. Introduction

Nanotechnology, the emerging field of manipulating matter at the nanoscale, is expected to become a key, transformative technology of the 21st century. Researchers are exploring ways to see and build at this small scale by re-engineering familiar substances like carbon, silver, and gold to create new materials with novel properties and functions. Not surprisingly, nanotechnology applications in areas as diverse as healthcare, energy storage, agriculture, water purification, and security are envisioned, and these anticipated developments have encouraged significant investments in nanotechnology research and development (R&D) worldwide, with the United States National Science Foundation (NSF) estimating that by 2015 nanotechnology will have a $1 trillion impact on the global economy.[1]

Nanotechnology has also emerged as a central science and technology policy topic in both the United States and China, and, accordingly, it is expected to pose a number of significant transnational governance challenges and opportunities for a wide range of stakeholders—including government, industry, and the public—in the near future. These broad ranging issues will have to be addressed in a collaborative and proactive manner in order to make certain that nanotechnology is developed in a safe, sustainable, and responsible manner. By analyzing a number of these transnational governance matters, this article will sketch out some of the multiple and complex factors and needs involved in establishing appropriate management strategies for nanotechnology in particular and for new and emerging technologies in general. In particular, five points will be addressed, including:

- Prioritization of nanotechnology research and development;
- Need for internationally coordinated risk research strategies;
- Need for effective oversight mechanisms;
- Rapid commercialization of consumer products; and
- Low levels of public awareness and trust in government.

Overall, this assessment will illuminate that a host of new occasions for collaboration and topics for deliberation will emerge as developments in nanotechnology move from the fringes to the center of society. Policymakers in both the United States and China must begin to focus on questions as diverse as how does nanotechnology factor into their nation's long-term future, who does the public trust to handle and manage the potential risks posed by nanotechnology, how should information related to nanotechnology be communicated and made available to the public, what mechanisms work best to regulate nanotechnology-based products, and how can potential chronic risks and consequences be systematically analyzed and addressed by government agencies. Clearly, in order to adequately tackle these interrelated subjects, an open dialogue is needed that can produce imaginative approaches to the governance of nanotechnology.

II. Prioritization of Nanotechnology Research and Development

As noted earlier, both the United States and China have been at the forefront of this trend in adopting nanotechnology as a main component of their strategic policy plans for future developments in science and technology. This was most recently enunciated in the February 2006 report from the United States Office of Science and Technology Policy, *American Competitiveness Initiative: Leading the World in Innovation*, which articulates that in order to succeed on the global stage, the United States must develop a necessary suite of technology platforms that includes "world-class capability and capacity in nanofabrication and nanomanufacturing that will help transform current laboratory science into a broad range of new industrial applications for virtually every sector of commerce."[2] China has taken a similar approach in its recently released *National Medium- and Long-term Science and Technology Development Plan (2006-2020)*, where nanotechnology is identified as a "priority mission area"[3] and as a key frontier technology over the next 15 years. For China, the overall aim is to use nanotechnology R&D as way toward reaching its eventual goal of setting "the proportion of research and development expenditures at 2.5 percent of the gross domestic product."[4]

More specifically, nanotechnology research priorities in both countries seem to be progressing along similar lines of inquiry, with two of their similar aims being (1) the societal benefit of nanotechnology and (2) better understanding the intersections and inter-relationships between nanotechnology and other strands of technology. With respect to these points, the *Guide to Programs* from the National Natural Science Foundation of China (NSFC) highlights "basic research on nano science and technology" as one of two new Major Research Plans for 2006, the broader aim of which is to "solve nano science issues that are of great importance in the progress of science and technology of China" and use nanotechnology commercialization toward "the development of the national economy."[5] NSFC also highlights a range of interdisciplinary scientific goals, from studying "nano materials design and preparation" to "new theory and new methods for nano system construction," with particular and preferential emphasis on funding areas in "nano electronics and nano electronics devices" and "nanobiology."[6]

In the United States, *The National Nanotechnology Initiative Strategic Plan* offers a vision in which nanotechnology becomes socially relevant by facilitating the "transfer of new technologies into products for economic growth, jobs, and other public benefit" and simultaneously developing "educational resources, a skilled workforce, and the supporting infrastructure and tools to advance nanotechnology."[7] Moreover, the National Nanotechnology Initiative's (NNI) *Supplement to the President's FY 2006 Budget* makes a point to emphasize "interdisciplinary research at the intersections of nanotechnology, biotechnology, and information technology," noting that a variety of federal agencies "will seek new opportunities for synergistic research" at the interfaces of these technologies.[8]

Both countries are also ensuring that substantial funding and financial investments are directed toward nanotechnology.[9] In the United States, the 2007 budget request allocates over $1.2 billion under the NNI, bringing total federal government spending in nanotechnology to over $6.5 billion since the NNI's inception in 2001.[10] While it is difficult to accurately compare funding levels between the United States and China, Lux Research estimates that the Chinese government spent $250 million on nanotechnology in 2005—a figure that, when adjusted for purchasing-power parity, places China's nanotechnology investment second only to the United States.[11] Similarly, local, state, and regional governments in the United States and China are investing in nanotechnology, with United States hotspots including California,[12] Texas, Virginia, Massachusetts, and New York, and with Chinese hotspots including Beijing, Hong Kong, and Shanghai, the latter of which established the Shanghai Nanotechnology Promotion Center in 2001.[13]

Such investments by both the United States and China have begun to translate into world-class research results in terms of published papers, paper citations, and patents. In particular, while United States leadership in the field has been consistent throughout previous decades, China's transformation into an emerging nanotechnology power is more recent. In their article on the subject, Liu and Zhang[14] highlight various supporting points for this claim, noting that a 2001 Asia-Pacific Economic Cooperation (APEC) report indicated that China followed only the United States and Japan in terms of the number of nanotechnology papers published in that year. They also note that studies undertaken by the Scientific Citation Index indicate that during the 1992-2002 timeframe, the top four institutions with the most citations of published nanotechnology papers include the University of California-Berkeley, IBM, the Massachusetts Institute of Technology (MIT0, all in the United States, and the Chinese Academy of Sciences. Finally, they cite an estimate that from 2000 to 2002, China ranked third behind only the United States and Japan in terms of the number of nanotechnology patents held. More recent studies analyzing publication outputs from 1999 to 2004 have shown similar results, with China maintaining its third place position with roughly 7,000 papers.[15] Taken together, these data points indicate, as Andrew Batson of *The Wall Street Journal* notes, that "China is rapidly catching up to the United States in nanotechnology" and that this "success could hold lessons for U.S. policy makers seeking to maintain a competitive edge in scientific research."[16]

III. Need for Internationally Coordinated Risk Research Strategies

However, even given the currently high level of funding and planning for nanotechnology, there are no currently internationally coordinated risk research strategies designed to investigate and manage the potential environmental, health, and safety (EH&S) risks posed by nanotechnology. In the absence of such risk management strategies, it will be difficult for the science community to determine the potential downsides of the technology and reach conclusions about where the greatest risks may lie. Over the past 15 years, scientific data on the EH&S impacts of nanostructured materials have been growing slowly. However, research results on the implications of engineered nanomaterials have been readily available only for the past five years.[17,18] Though much more work needs to be done in this area, a number of research studies have begun to raise more questions than answers about potential hazards—hazards that could impact populations in developed countries, like the United States, and in more developing countries, like China.

In short, published research has demonstrated that because of their unique size, shape, and chemistry, some engineered nanomaterials can behave differently in the body and in the environment than more conventional materials. Moreover, these nanomaterials may present health risks that are not captured within established risk assessment paradigms. For example, in testimony before the United States Senate Committee on Commerce, Science, and Transportation, J. Clarence Davies, Senior Advisor to the Project on Emerging Nanotechnologies, highlighted concerns raised by some of these early-stage risk research results, including:

- Nanometer-scale particles behave differently from larger sized particles in the lungs, possibly moving to other organs in the body;
- The surface of some nanostructured particles is associated with toxicity, rather than the more usually measured mass concentration; and
- Conventional toxicity tests do not seem to work well with some nanomaterials, such as carbon nanotubes.[19]

In order to learn more about the novel effects of nanomaterials on human health and the environment, it is clear that more research will be needed. To this end, both the U.S. and Chinese governments have begun to heed the call for more risk-related research. The United States government estimates that is spent $38.5 million on EH&S research in 2005, and there are signs that it is looking to increase this level of investment in the future. More specifically, the Environmental Protection Agency (EPA) plans to nearly double its implications research budget in fiscal year 2007 and has put together a *Nanotechnology White Paper* that identifies a set of key questions that the agency should address as nanotechnology R&D progresses.[20]

Though China has trailed the United States in terms of focusing its resources on investigating EH&S issues, it began to study the potential toxicological effects of nanotechnology by establishing a Nanosafety Lab under the auspices of the National Center for Nanosciences & Nanotechnology (NCNN), located in Beijing. It is estimated that the Chinese government will spend nearly $5 million on such EH&S research from 2004-2010, an amount of money that, once again, may rather substantial in terms of purchasing-parity power.[21] Moreover, as demonstrated by hosting the International Symposium on Nanotechnology in Environmental Protection and Pollution in Hong Kong in June 2006[22], it is becoming evident that China is looking to play an increasingly substantial role in advancing nanotechnology EH&S research in the future.

Nevertheless, focusing solely on such investments does not address the issue of whether government agencies in the United States or China possess sufficient human and strategic resource capacities to adequately address EH&S concerns raised by academic researchers and various non-governmental organizations (NGOs). For instance, the Project on Emerging Nanotechnologies (at the Woodrow Wilson Center in Washington, DC) has assembled the only publicly available inventory of ongoing EH&S research projects, indicating that there may be significant gaps—such as a lack of research on the effects of nanomaterials in the gastrointestinal track and few resources devoted to life-cycle analysis and end-of-life issues—that have yet to be systematically addressed in the present risk research portfolio. Moreover, Andrew Maynard, in his report *Nanotechnology: A Research Strategy for Addressing Risk*, has argued that a new, internationally coordinated, comprehensive framework for methodically exploring nanotechnology's possible risks is needed both to address such research gaps and to ensure that the limited financial resources devoted to these issues are leveraged in a strategically planned portfolio of short, medium, and long-term projects.[23]

IV. Need for Effective Oversight Mechanisms

In the United States, there is currently a concern amongst a wide range of NGOs—including Environmental Defense, Natural Resources Defense Council, Friends of the Earth, International Center for Technology Assessment, and ETC Group—that, so far, the United States government's overall regulatory approach to nanotechnology been ad hoc and incremental, with little attention focused on how nanomaterials are *already* being used in consumer and industrial products. As will be discussed in greater depth in following sections, one difficulty is that there are many kinds of nanotechnology-based consumer products, such as cosmetics and dietary supplements, that are entering the market in areas where there is less government oversight. This point is emphasized in a recent Project on Emerging Nanotechnologies submission to the Food and Drug Administration (FDA), where it is argued that the government's approach to nanotechnology oversight has been limited by a number of factors, including:

- Insufficient consideration of how nanotechnology systematically impacts a range of agencies, including EPA, FDA, the United States Department of Agriculture (USDA), and the Consumer Product Safety Commission (CPSC);
- A focus on single statutes, such as EPA's Toxic Substances Control Act (TSCA), rather than on an integrated, multi-statute approach; and
- A focus on regulating products more than on the facilities where production occurs and processes are used.[24]

Concerns about regulatory jurisdiction and responsibility are particularly pressing because as new nanotechnology based products are commercialized, it is evident that similar kinds of nanomaterials will be employed in a variety of ways, requiring substantial coordination of oversight on the part of government agencies tasked with ensuring the health and safety of the public and the environment. Similar problems related to regulatory overlap and confusion could occur in China as well, especially if the government is focused primarily on funding and supporting R&D related to nanotechnology's applications and places less importance on managing the possible implications of nanotechnology. Only a concerted effort between different parts of the regulatory system—at local, state, national, and international levels—within both countries will be able to overcome these governance challenges and ensure that consistent regulatory regimes and safety standards are developed worldwide. One possible solution, as Davies argues in his report *Managing the Effects of Nanotechnology*, is that a new law or set of laws may be required to address the current oversight system's deficiencies.[25]

However, the difficulties associated with managing nanotechnology's potential risks are not restricted to a simple lack of regulation. For instance, many countries may be forced to rely on potentially outdated legislative and regulatory regimes that are not equipped to address nanotechnology's potentially revolutionary impacts. Additionally, in more developing countries like China, government agencies may still be grappling with the policy implications of past and on-going technological revolutions, particularly those associated in biotechnology, genomics, and information technology. In short, because the bureaucracies of these nations may already be stretched thin to deal with a range of science and technology challenges, they could be hard-pressed to oversee the responsible development of nanotechnologies in a proactive manner.

Recently, there have been attempts to address this lack of effective oversight mechanisms through advancing nationally and internationally coordinated efforts in this area. On a national level, a voluntary information reporting program for engineered nanomaterials has been developed by the Department for Environment, Food, and Rural Affairs (Defra) in the United Kingdom[26] and a voluntary stewardship program is being planned by the EPA in the United States for the middle of 2007.[27] Additionally, in China, Chunli Bai, Executive Vice President of the Chinese Academy of Sciences, notes that China has established a "national technical committee on nanotechnology standardization," charged with "strengthening the inspection of research facilities in public institutions and with meeting the needs of manufacturers in China."[28]

On an international level, the Organization for Economic Co-operation and Development (OECD) recently established a Working Party on Manufactured Nanomaterials to discuss issues surrounding the environmental, health, and safety implications of nanotechnology, particularly in the area of chemicals and toxic substances.[29] More specifically, both the Meridian Institute's Global Dialogue on Nanotechnology and the Poor (GDNP)[30] and the United Nations Industrial Development Organization (UNIDO) North-South Dialogue are explicit attempts to include developing countries in the global discussion of managing nanotechnology's risks and benefits.[31] The International Risk Government Council (IRGC) is also in the process of developing an oversight and risk management framework for nanotechnology through an elaborate consultation process that includes input from a range of stakeholders in multiple countries.[32] Finally, attempts to collect and detail “best practices” for worker protection and standardize nanotechnology nomenclature and definitions are occurring on an international basis, with efforts underway through the International Council on Nanotechnology (ICON)[33], the International Standards Organization (ISO)[34] and ASTM International.[35]

While representatives from the United States and China are actively participating in a number of these oversight endeavors, it is of great importance that the national governments of these countries remain committed to structuring their own, internal regulatory system in harmony with such international efforts. Doing so will allow for the establishment of a globally level playing field for private firms involved in commercializing nanotechnology research and products and, in turn, ensure that they do not encourage irresponsible corporate actors, thereby damaging the industry as a whole.

V. Rapid Commercialization of Consumer Products

Concerns about the shortage of toxicity data and lack of effective oversight mechanisms are all the more pressing given the rapid commercialization of nanotechnology in consumer and industrial products. In March 2006, the Project on Emerging Nanotechnologies released an online inventory that now contains over 300 manufacturer-identified, nanotechnology-based consumer products that are available on the market from over 15 countries, including the United States, China, and many European and Asian nations.[36] This number far exceeds the previous United States government accepted estimate of approximately 80 consumer products on the market, and, according to EmTech Research, there are an additional 600 nano-based electronics components, raw materials, drug delivery technologies, and research, process, and software tools, the latter of which is used to manipulate nanomaterials and fabricate at the nanoscale.[37] However, since the searches conducted by the Project on Emerging Nanotechnologies were largely limited to English-language sources, it is expected that there may be many more nanotechnology consumer products on the market throughout Asia—particularly in China—that have yet to be accounted for, thereby further amplifying the extent of nanotechnology’s commercialization.

The fact that this first wave of consumer products is already available on store shelves may be surprising, especially since only a few years ago, there were a mere handful of nanotechnology companies and virtually no nanotechnology-based products being made and marketed to consumers. However, it has been estimated that over the past few years, 1,200 nanotechnology-related start-up companies have emerged, many of which are based in the United States.[38] In China, Liu and Zhang have estimated that “the number of registered companies with a nanotechnology focus reached 800 by [the] end of 2003, resulting in a total of 10 billion RMB ($1.2 billion) in registered capital.”[39] Along these lines, Lux Research has estimated that more than $32 billion in products incorporating nanotechnology were sold worldwide in 2005, a number that is only expected to grow as more research is funded, more patent applications are filed, and more companies are formed.[40]

A search of the Nanotechnology Consumer Products Inventory can provide numerous examples of products already on the market, ranging from cosmetics and personal care items to dietary supplements and cooking supplies and from automotive and home improvement products to advanced coatings for glass surfaces and stain-resistant clothing. In many cases, these products are available for purchase in local stores or over the Internet. However, in the event of a mishap or accident, it is not clear whether product safety laws in the United States, China, or elsewhere are sufficiently robust to protect the public's health or safety. While such a situation may sound far-fetched, there has already been the case of Magic Nano, a bath and tile treatment product sold in Germany that was recalled after causing significant health problems, with over 100 people affected with respiratory problems and six hospitalized with pulmonary edema.[41] Although the Federal Institute for Risk Assessment (BfR) in Berlin concluded that the product did not actually contain nanomaterials and that nanotechnology was not the cause of the reported health problems,[42] the Magic Nano incident illuminated other concerns—such as a lack of transparency in terms of timely disclosure of information and misuse of a third-party verification seal purporting to ensure that the product was independently tested—that could affect regulatory agencies in the United States or China if a similar situation were to occur in either country.

It is also anticipated that there are many more nanotechnology consumer products on the market that are either not labeled or described as containing nanomaterials or that make claims about nanotechnology that may not be accurate. While there are currently no stipulated requirements to either label a product that contains nanomaterials or independently verify claims associated with nanotechnology, such products are beginning to garner increased attention and scrutiny from consumer and environmental groups around the world, including:

- In the United States and Australia, environmental groups have called for an interim recall of sunscreens that contain nanosize zinc oxide and titanium dioxide until more adequate safety tests are undertaken;[43]
- In Korea, a consumer group has tested a washing machine claiming to use silver nanomaterials as anti-bacterial agents and has concluded that there was little to no improvement in performance over similar products that did not contain nanotechnology;[44] and
- In Germany, a media outlet has investigated claims made by a dietary supplement manufacturer that purports to use nanotechnology to make vitamins more easily available to the body.[45]

Such instances illustrate a growing policy challenge: the mislabeling or over-promising associated with nanotechnology consumer products may have the potential to negatively impact the public's perception of the field in general, well before potentially more significant and transformative applications, in applications such as healthcare and energy, can be developed. Bai indicates that this tension between nanotechnology hype and reality is beginning to emerge in China. He notes that while there are rising numbers of legitimate and beneficial applications of nanotechnology being made available through commercialization—such as the use of photocatalytic nanoparticles in a self-cleaning glass coating on the new National Opera House in Beijing—some firms are taking advantage of nanotechnology's growing popularity as a buzzword and are "finding that they can raise their profits simply by adding the label 'nano' to their products."[46] It is imperative that such misunderstandings are avoided in the United States and China so that a consumer backlash does not occur and that the nascent nanotechnology industry has an opportunity to develop more fully over the long term.

VI. Low Levels of Public Awareness and Trust in Government

Given the increasing availability of nanotechnology consumer products worldwide, it might be expected that the public would be rather familiar with the term nanotechnology and understand what it means. However, in the midst of this accelerating commercialization, publics throughout the world remain largely in the dark about nanotechnology. A major study, funded by the NSF and conducted in 2004 by Michael Cobb and Jane Macoubrie at North Carolina State University (NCSU), found that 80 percent to 85 percent of the American public has heard "little" or "nothing" about nanotechnology.[47] Similarly, a nationally representative, August 2006 poll of over 1,000 adults, commissioned by the Project on Emerging Nanotechnologies and conducted by Peter D. Hart Research Associates, found similar results, with about 70 percent of the public reporting that they have heard little to nothing at all about nanotechnology.[48] These findings are consistent with similar polls that have been commissioned in Europe and Canada, and it is possible that these trends associated with low levels of public of understanding of nanotechnology would also occur in China as well.[49,50] Bai alludes to this potential lack of awareness about nanotechnology by the Chinese public by noting that, "the scientific community need[s] to better inform and educate the public about the transformations this new era is likely to bring."[51] Without such public engagement efforts, citizens and consumers may form negative public perceptions that could hinder nanotechnology's development far into the future.

What is even more striking about the public perception studies mentioned above is that, in addition to a lack of basic awareness about nanotechnology, publics in many countries have little to no trust in their government's ability to manage the potential risks posed by nanotechnology. Such findings were illustrated in Jane Macourbrie's 2005 study, *Informed Public Perceptions of Nanotechnology and Trust in Government*, which found that even when participants were provided with information about the roles and responsibilities of government regulatory agencies, such as EPA, FDA, USDA, and CPSC, no more than 50 percent of respondents believed that they could trust these agencies to regulate nanotechnology-based products accurately and successfully.[52] Along these lines, the Hart Research data also indicates that while public approval ratings for various agencies has declined in recent years, there tends to be more confidence in these bodies than in business or industry to management technological risk. It is evident that if concerns about government's and industry's ability to manage nanotechnology's risks are *not* addressed, these negative public perceptions may continue to grow and, once again, potentially hamper nanotechnology's development due to consumer backlash or over-regulation.

To address this current situation—in which a largely uninformed or under-informed public has little to no trust in the government's ability to manage nanotechnology's risks—Macoubrie has found that respondents have centered on a desire for "increased safety tests *before* products go to market" and "supplying more information to support informed consumer choices."[53] Additionally, by focusing on the issue of monitoring the safety and effectiveness of cosmetics and over-the-counter drugs—two product categories that have seen relatively high amounts of nanotechnology commercialization in recent years—Hart Research found that the public feels that federal government agencies, along with universities and independent researchers, should work together and be involved in such oversight. Such proactive and integrated policy steps would not only help build awareness, trust, and citizen engagement around nanotechnology, but they would signal to citizens and consumers that their concerns are being heard and addressed. As of now, there is still time to inform public perceptions about nanotechnology and to make clear that nanotechnology is being developed in a way that citizens—as well as the insurance industry, corporate investors, NGOs, and regulatory officials—can trust. However, with the production of nanomaterials ramping up in the United States and China, and with more and more nanotechnology-based products pouring into the marketplace, this window is closing fast. Without such assurances, publics around the world will increasingly have to make sense of competing claims, complex science, and emerging risk research with little or no preparation or support.

Conversely, worries are already being voiced that public input will be used simply as a "tokenistic add-on" rather than as a valuable policy-making tool.[54] To avoid this undesired outcome in both the United States and China, coordinated nanotechnology education and engagement programs will be needed, supported by both government and industry. These efforts will have to be structured to reach a wide range of consumers, many of which may have little to no scientific or technical training. Establishing such a widespread public engagement campaign will require the use of both traditional media outlets—such as print, radio, television, and film—alongside more non-traditional media outlets—such as the Internet, weblogs, games, and podcasts—to capture the attention of a diverse range of individuals in various age, gender, and socioeconomic categories. As researchers from the United Kingdom argue, a new approach to public engagement is required, one that can "build in more rich, more complex and nuanced, and more mature models of publics into 'upstream' modes of practice."[55]

VII. Conclusion

It would be unfortunate if government agencies, in the United States, China, and elsewhere, squandered this unique opportunity to help direct nanotechnology along a responsible path, improve public confidence in the private and public sectors, and increase the capacity of public institutions to deal with the risks and challenges posed by cutting-edge innovation. The thrust of the arguments presented above is clear: nanotechnology is here and that we, as a global society, are not yet fully prepared to deal with it. The encouraging point is that a collective response—with the United States and China as central players—to the aforementioned challenges can still be formulated.

Much remains to be done, however, and it cannot be assumed that addressing such transnational nanotechnology governance questions will be easy. In fact, the opposite is true, since nanotechnology's development is expected to test the notion that innovation progresses in a linear and continuous fashion. Due to the rapid pace of R&D, discoveries in nanotechnology could come in great, discontinuous leaps and, in turn, revolutionize society's knowledge and understanding of the physical world in rather short amounts of time. In turn, these technological leaps could come to strain the ability of public institutions and public infrastructure—especially in China, which will likely face an additional host of resource, population, and energy challenges in the coming decades—to respond in an effective and timely manner.

For this reason, authors such as Michael R. Taylor, in his report *Regulating the Products of Nanotechnology: Does FDA Have the Tools It Needs?*, argue that the eventual success or failure at overseeing nanotechnology will be based on the devotion of various kinds of resources—human, strategic, regulatory, and financial—to the issue. While Taylor makes this argument in the context of one agency (the FDA) in one country (the United States), the point and ensuing recommendations are applicable both for other agencies and for other countries. Such resources will become even more crucial and important as broader, cross-cutting policy issues—such as trade, intellectual property protection, and the open sharing of scientific and technical information—begin to emerge with respect to nanotechnology. While specific analyses of nanotechnology's interface with these larger areas of concern is beginning to occur,[56] it is clear that the expected innovative jumps increasingly associated with nanotechnology's future could make today's issues related to product risk management and internationally coordinated oversight strategies appear trivial by comparison. Such would be the case in the wake of a high-profile mishap or perceived accident, as occurred with respect to other areas of technological development, such as chemicals (Bhopal) and nuclear power (Three Mile Island).

In the meantime, in order to make certain that nanotechnology does not "fall through the cracks" of the oversight system, a dual risk management approach must be adopted, one that supports research into nanotechnology's greatest near-term risks and benefits while, simultaneously, looks prospectively to any transformations or shifts in the technology's development that that may occur in the future. Though nanotechnology R&D is currently an effort based largely upon chemistry and materials science, the high priority placed on it in both the United States and China will quickly lead nanotechnology to interact with other fields of study—such as biotechnology, information technology, and cognitive science—that could further quicken the pace of both basic research and product development. This convergence of technologies could cause an even greater set of governance challenges than nanotechnology alone, further impacting institutions tasked with the responsibility of managing new technological advances. Since developments in nanotechnology are at the forefront of these potentially radical innovations, the United States and China have the chance to think and operate proactively, and work collectively, toward getting the governance system "right" from the start.

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Quantitative Evaluation of China's Biomedical Research Strengths Using an Empirical Analysis of Life Science Publication Data

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The fifteen-year science and technology (S&T) plan of the People's Republic of China specifies the nation's research priorities in the biomedical sciences. Here I present an empirical study that quantifies the degree to which this plan leverages China's existing strengths or, conversely, targets underdeveloped research areas in biomedical S&T. By analyzing the subject content of nearly 45,000 life science research papers produced in China since 2000, I identified a set of research areas that are statistically overrepresented as a fraction of China's biomedical research output. These include historically strong areas such as traditional medicine and population genetics, and relatively new areas such as computational biology. Neither of the two research priorities laid out by the new fifteen-year plan (protein research; development and reproductive biology) are current strengths of biomedical research in China. However, China has strengths in some particular niches, including stem cell biology and protein structure, from which the broader research areas can be developed.

I. Introduction

It is often said that biology is science and technology's next great frontier. This view is reflected in science and technology (S&T) agendas of both the People's Republic of China (PRC) and the United States. For example, between 1998 and 2003, the U.S. Congress ordered a five-year doubling of the nation's biomedical research budget; and the P.R.C.'s National S&T Plan for 2006-2020 places central importance on biomedical research. Given these developments, there is significant potential for scientific collaboration in the biomedical sciences between the United States and the P.R.C.; however the realization of this potential will depend on China's ability to raise its biomedical research to the world-class standard currently set by U.S. investigators. The objective of this study is to provide a new set of quantifiable metrics to evaluate China's biomedical S&T research productivity. Metrics such as these will help evaluate the effectiveness of China's S&T policies towards advancing indigenous biomedical research. In addition, these metrics may help identify productive biomedical research niches within China that have a high potential for collaboration between American and Chinese investigators.

II. Background

The United States is the undisputed world leader in biomedical research. The National Institutes of Health (NIH), part of the U.S. Department of Health and Human Services (HHS), is the world's largest biomedical-funding agency. The NIH spent $28.9 billion on health-related research and development (R&D) in 2005, representing 27 percent of all U.S. federal R&D expenditures [1]. More than half of this money ($15.2 billion) is spent on basic biomedical research, and therefore it is not surprising that 60 percent of all U.S. scientific publications are in the life and medical sciences.

In contrast, China lags behind other top research-producing countries in the life and medical sciences as determined by the percent of papers from China that are published in this research field (Figure 1). Perhaps in partial response to such indicators, the National Plan for Medium- and Long-term Science and Technology Development (2006-2020) issued by the State Council of the People's Republic of China in February 2006 specifies two of the four national basic scientific research programs in the biological sciences: protein science, and development and reproductive biology [2, 3]. The High Technology Research and Development (R&D) Program (also known as the 863 Program), which was issued by the Chinese government twenty years ago in 1986, also focused on biological, agricultural, and pharmaceutical technology development as one of four key growth areas.

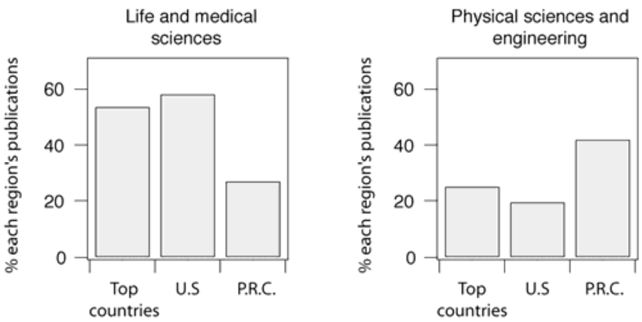

Figure 1: Portfolio of S&E articles by field (2003). Data from National Science Board, Science and Engineering Indicators 2006, Appendix 5-45.

Despite this long-term commitment to health-related research, China does not have a central institution overseeing the country's investment in biomedical research like the NIH. The Ministry of Science and Technology (MOST) provides the majority of the funding for biomedical research, with an additional portion of the funding for basic research coming from the National Science Foundation of China (NSFC). Following China's slow response to the outbreak of severe acute respiratory syndrome (SARS) in 2002, Zhu Chen, vice-president of the Chinese Academy of Sciences, proposed the creation of an NIH-like agency in China [4]. Although this is not currently being pursued, demand for biomedical research funding continues to grow. According to officials at the NSFC, the average acceptance rate for a grant proposal in the life sciences is 14 percent, well below the overall acceptance rate of 20 percent, indicating that current funding levels are not sufficient to meet the needs of scientific investigators[1].

The future success of scientific collaborations between the United States and the P.R.C. will depend largely on how well China's biomedical science policies support and further the quality and productivity already present in China's biomedical research environment. In this study, I analyze the subject matter and author affiliations of articles published by Chinese authors in the biomedical literature, and use these data as a proxy for scientific productivity within the P.R.C. I discuss the results of this analysis in the context of past and current government policies to understand the degree to which the new fifteen-year plan leverages China's existing strengths or, conversely, targets underdeveloped research areas in biomedical S&T. I conclude with a discussion of these results in the context of the conclusions of the October 2006 China–U.S. Forum on Science and Technology Policy.

III. Methods

There is significant precedent in the literature for using research publication data to evaluate the quantity and quality of a country's scientific research output [5-8]. For example, David King recently analyzed published research papers and their citations indexed by Thomson ISI database[2] to evaluate scientific strengths, research efficiency, and scientific impact of 31 nations [7]. The PubMed reference database, a service of the U.S. National Library of Medicine, is widely used for secondary research by the biomedical and life science communities. PubMed is an index of over 16 million articles from more than 4800 international life science journals in biomedical-related fields dating back to the 1950s[3], providing a reasonable proxy for international impact in biomedical research. As shown in Figure 2, China has increased its share of PubMed citations 100-fold in the past 15 years, from approximately 0.4 percent in 1990 to over 4.0 percent in 2005.

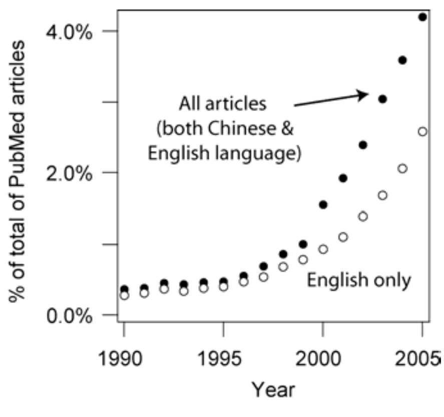

Figure 2: Summary of articles indexed in PubMed for the total and China-specific biomedical community.

[1] Meeting with officials at the National Science Foundation of China, October 18, 2006.
[2] Previously called Institute for Scientific Information (http://www.isinet.com)
[3] See http://www.ncbi.nlm.nih.gov/entrez/

Notably, when citations are limited to publications in English only, the fold increase reduces by half[4]. Between 2000 and 2005, nearly 100,000 publications from Chinese institutions were indexed by PubMed, providing a reasonably large sample with which to perform a bibliometric analysis.

PubMed is an especially powerful database because it is annotated with searchable tags for information such as authorship, affiliation, journal and publication language [9]. In addition, the articles are annotated with medical subject headings (MeSH), a set of descriptive terms, created and controlled by the National Library of Medicine, which permits searching key subject areas at various levels of specificity. MeSH descriptors are organized in a hierarchical structure. For example, the more specific heading "HIV infections" is found under the broader heading "Virus diseases". To further ease retrieval of the most relevant references, PubMed includes a "MeSH Major Topic" term, extracted from the title or the abstract of the article[5]. This extensive annotation permits rapid and automated text searching of millions of indexed articles.

The following analysis uses data collected from PubMed to identify current biomedical research strengths in China and institutional centers of productivity. To evaluate biomedical research strengths, I quantified the percentage of total Chinese publications in all research areas (as defined by MeSH Major Topics) and compared this to publication percentages by research topic for the PubMed database as a whole (worldwide sample). The analysis included all papers in PubMed produced by Chinese institutions between the years 2000 and 2005 that were annotated with MeSH Major Topic term(s) (approximately 45,000 articles)[6]. The worldwide sample included 10 percent of all PubMed references chosen randomly from the same time period (approximately 100,000 articles). *Note that not all PubMed articles are annotated by MeSH terms, and therefore these results are only a representative sample of total research output.* This empirical dataset provides a unique lens through which to evaluate the biomedical research environment in China.

IV. Results

Seven of the top ten most frequent MeSH major topic terms significantly overrepresented in Chinese citations have been previously reported as areas of biomedical expertise in China (Table 1). The most overrepresented areas of research in China are in the related fields of Chinese traditional medicine ($p < 10^{-200}$)[7], medicinal plants ($p < 10^{-124}$) and phytotherapy ($p < 10^{-100}$)[8]. Microsurgery, of which surgical flaps is an important

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[4] Suggests that a portion of the overall fold increase is due to an increase in the number of Chinese language journals indexed by PubMed

[5] For a disease, the focus excludes about 40 percent of the references, 70 percent for a technique

[6] The author thanks Dr. Kyle Jensen for writing the text-mining software to enable this analysis. Software and additional method details available upon request.

[7] All p-values are calculated assuming a binomial distribution

[8] As a point of reference, top research areas of the general medical and biological community for which China did not have a significant focus include magnetic resonance imaging, signal transduction, and animal models of disease.

technology, was recognized as early as the 1980s as a strength of Chinese doctors [10]. China is also known to have made rapid progress in the biomedical technology of gene therapy, ninth on the list of focus areas. In 2003, the State Food and Drug Administration of China (SFDA) approved the world's first commercial gene therapy, an adenoviral vector therapy for head and neck squamous cell carcinoma [11]. In summary, these data appear to provide a reasonable quantitative metric of biomedical research focus in China that is consistent with reports based on anecdotal or limited data.

Table 1: Focus areas of biomedical research in China

Major Focus Area (MeSH term)[9]	**Total Score**[10]	**Fold enrichment over worldwide background**	**English/ Chinese**
Polymorphism, Genetic	112	3.0	0.9
Apoptosis	101	2.7	0.9
Mutation	84	1.7	0.7
Phytotherapy	72	3.7	1.3
Surgical Flaps	62	3.7	0.2
Plants, Medicinal	55	5.3	0.3
Algorithms	48	1.9	3.3
Medicine, Chinese Traditional	48	23.7	0.6
Gene Therapy	36	2.6	0.8
Models, Theoretical	36	1.4	8.3

Interestingly, the most frequent area of life science research in China – genetic polymorphisms[11], closely followed by the related topic, mutation – is likely a direct result of China's national S&T policies. Many prominent scientists, including Chen Zhu, Director of the National Human Genome Center in Shanghai and vice-president of the Chinese Academy of Sciences (CAS), have noted that China's 56 ethnic groups are a valuable genetic resource that could contribute to knowledge about human evolution and disease [12, 13]. In 1998, a collaboration of seven different Chinese research institutes published a seminal paper in the *Proceedings of the National Academy of Science* which sampled genetic profiles of 28 populations in China [14]. In 1999, China joined the Human Genome Project (HGP) and completed sequencing 1 percent of the genome by 2003 [15]. According to Chen, by investing in the HGP and population genetics, the Chinese government intended to build the country's strength in genetic research to complement its rich genetic resources [12]. These data suggest that this goal was accomplished.

9 Scope of the term as defined in the Medical Subject Headings index is included in Supp. Table 1.

10 For the cases in which an article was annotated with more than one MeSH major topic, each MeSH term was assigned an equal fraction of the count. Scores are normalized to the top major focus area

11 A difference in DNA sequence among individuals or populations that gives rise to different traits such as blood type

There are only three research focus areas that are not traditionally considered strengths of China's biomedical research community. Two of these areas, algorithms and theoretical models, suggest a focus in the relatively new field of computational biology. This result can be rationalized by considering the relatively low capital investment required for computational research, as compared to the specialized infrastructure required for experimental molecular and cellular biology. The third area, apoptosis (or programmed cell death), is an important biological process with applications in both organism development and cancer. It is not immediately evident why this area would be overrepresented in China biomedical research, and thus presents an interesting avenue for further research.

Although the total number of Chinese biomedical research publications is informative of overall trends, limiting publications to those published in the English language provides a clearer picture of the research that is available to international scientists, since few people outside the P.R.C. can read Chinese characters. The ratio of articles published in Chinese to those published in English is approximately 1.1. Recalculating research focus areas for English-only publications, reveals only slight differences.

Table 2: Focus areas of biomedical research in China (English-only publications)

Major Focus Area (MeSH term)[12]	**Total Score[13]**	**Fold enrichment over worldwide background**	**English/ Chinese**
Polymorphism, Genetic	53	1.4	0.9
Apoptosis	49	1.3	0.9
Phytotherapy	41	2.1	1.3
Algorithms	37	1.4	3.3
Models, Theoretical	32	1.2	8.3
Models, Chemical	24	1.8	6.8
Bioreactors	22	2.3	2.8
Phylogeny	21	1.2	3.2
Gene Expression Regulation, Neoplastic	19	1.3	2.1
Medicine, Chinese Traditional	17	8.5	0.6

Gene polymorphism and apoptosis were still at the top of the list, but Chinese traditional medicine dropped to tenth place (Table 2). The most interesting change is that algorithms, theoretical and chemical models rise to fourth-sixth place on the list. The growth of the computational biology field in the United States and internationally has been accompanied by an influx of mathematicians, physicists, and engineers doing research in the biological sciences. Given China's traditional strength in these fields (see Figure 1), it is possible that these computational- (model-) based publications represent a similar mixing of disciplines. In this case, a portion of the growth in biomedical research will not come from training new biologists, but rather from by experienced investigators in the physical science fields engaging in interdisciplinary research.

[12] Scope of the term as defined in the Medical Subject Headings index is included in Supp. Table 1.

[13] For the cases in which an article was annotated with more than one MeSH major topic, each MeSH term was assigned an equal fraction of the count. Scores are normalized to the top major focus area

After establishing that these data provide a reasonable quantitative metric of biomedical research focus in China, I evaluated the degree to which the new fifteen-year S&T plan leverages China's existing strengths or, conversely, targets underdeveloped research areas in biomedical S&T. The plan targets broad research areas that are not covered by single MeSH terms; therefore, I used text searches to combine MeSH terms that were subsets of broader categories, and then evaluated China's focus on the broader group of terms relative to the worldwide focus[14]. As with major research categories, I analyzed the data both with and without limiting it to English-only publications.

The first national priority in the biological sciences, protein research, does not currently appear to be focus of biomedical research in China based on this data set (Table 2). The focus on protein research is statistically below the worldwide focus on this area when considering China's publications as a whole ($p < 10^{-94}$), suggesting that a significant investment in this research is warranted. However, there appear subsets of protein research in which China already has a strong foothold, most notably protein structure ($p < 10^{-100}$). Protein structure analysis often involves a significant computational component, and therefore this expertise may be related to the focus in computational biology research discussed above. Notably, when limited to English-language- only publications, the significance (both over-representation in protein folding and under-representation in protein research) disappears. Based on these results, however, it seems reasonable to hypothesize that gaining a broader foothold in other areas of protein research will likely involve a significant investment in China's experimental laboratory infrastructure.

China appears to have a stronger presence in development and reproductive biology than in protein research, although the slight overrepresentation relative to worldwide publication rates is not sufficient to quantify it as a research focus ($p > 0.05$).

Table 3: Current strength of key science and technology research areas in China

Key Science & Technologies	Score* (Total)	Score (English only)	Ratio (English/Chinese)
Protein research	*144*	75	1.1
Protein structure	**23**	13	1.2
Development & reproductive biology	59	28	0.9
Stem cell biology	**33**	10	0.5
Viral infectious diseases	**63**	31	1.0
HIV/AIDS	*7*	3	1.0

**Scores indicating a research focus are highlighted in bold type. Scores indicating an underrepresented research area are in italics.*

Separating stem cells from this research category reveals that China has a small but significant enrichment in this area ($p < 0.01$). China's S&T leaders flagged the country's

[14] For example, 'protein research' includes MeSH terms such as protein folding, secondary protein structure, and signal transduction, among others. See Supp. Table 2 for a full list of terms included in each key S&T category.

aging population as a problem several years ago and began investing heavily in regenerative medicine, including stem cell research [16]. Yang Xiangzhong, a Chinese national and director of the Center for Regenerative Biology at the University of Connecticut, asserts that a strong technical base and relatively liberal cultural attitudes towards embryonic stem cell research predispose China to take a leading role in this field [17]. Importantly, however, both developmental and reproductive biology as a whole, and stem cell biology as a sub-field, publish significantly less in English than the average rate of Chinese investigators. This suggests that although there has been significant hype in this area, the research is not yet reaching an international science audience.

In addition to laying out a national scientific research agenda, China's State Council also announced eight S&T goals to be accomplished by 2020. In the area of biology, the plan calls for improved prevention and control of major diseases and epidemics, specifically stating that HIV and hepatitis infection are to be "well under control" [18]. Evaluating another grouped research category of viral infectious diseases suggests that China currently has significant focus in the area ($p < 10^{-15}$). However, it appears to be significantly underrepresented in HIV research specifically ($p < 10^{-20}$). In the past, China has been criticized for understating the country's HIV/AIDS crisis, hindering proper control and prevention [19]. The under-representation of HIV/AIDS publications relative to other research areas may be reflective of a correlation between the central government's policies and the biomedical output of China's research institutions. In any case, this is an area in which Chinese scientists could benefit from international collaborations. Indeed, in April of this year, the U.S. Department of Health and Human Services (HHS) and the Chinese Ministry of Science and Technology (MOST) formally stated their intention to facilitate cooperation between scientists of both countries pursuing research on diseases such as HIV/AIDS and avian influenza [20].

V. Discussion

At the China–U.S. Forum on Science and Technology Policy, held in Beijing in October 2006, participants discussed how to improve the scientific and technology relationship between the two countries. One conclusion from the forum was that universities should play a larger role in shaping U.S.–China S&T policy. Given the current environment, it is likely that a significant portion of U.S.–China university research agreements will be in the area of biological research. However, scientific investigators do not engage in collaborations out of charity. It is crucial that U.S. investigators feel they are gaining strategic, state-of-the-art research partners in their Chinese collaborators. The results presented here suggest several areas of biomedical research in which the P.R.C. is building a strength that could lead to fruitful collaborations for both parties.

Although bibliometric analysis can provide useful metrics for S&T policy, it is also important to consider the limitations of these metrics. For example, it can take four or five years to move from new experiments to a research publication, and therefore there is a significant lag time between what is going on in the laboratories and what is reflected in the bibliometric data. Given that China is actively continuing to open state-of-the-art research facilities, including the Beijing Life Sciences Research Institute in December

2005 and the China National Academic Center for Biotechnology in May 2006, there will almost certainly be an exponential growth in international biomedical publications from China over the next few years, which may significantly change the research focus landscape identified there. However, these results will serve as a useful reference point to follow the trajectory of the progress of biomedical research in the P.R.C.

Finally, bibliometric data are one-dimensional metrics: they tell us only indirectly about the quality of graduate education and scientific innovation in an institution or country. Active collaborations between the United States and China will provide opportunities for both countries to assess progress in these more qualitative – but critically important – metrics, and hopefully improve scientific research and international relations between both countries.

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Supplementary Table 1: Definition of medical subject headings cited in this paper

Medical Subject Heading	**Scope of term**
Polymorphism, Genetic	The regular and simultaneous occurrence in a single interbreeding population of two or more discontinuous genotypes. The concept includes differences in genotypes ranging in size from a single nucleotide site to large nucleotide sequences visible at a chromosomal level.
Apoptosis	One of the mechanisms by which cell death occurs. Apoptosis is the mechanism responsible for the physiological deletion of cells and appears to be intrinsically programmed. It is characterized by distinctive morphologic changes in the nucleus and cytoplasm, chromatin cleavage at regularly spaced sites, and the endonucleolytic cleavage of genomic DNA at internucleosomal sites. This mode of cell death serves as a balance to mitosis in regulating the size of animal tissues and in mediating pathologic processes associated with tumor growth.
Mutation	Any detectable and heritable change in the genetic material that causes a change in the genotype and which is transmitted to daughter cells and to succeeding generations.
Phytotherapy	Use of plants or herbs to treat diseases or to alleviate pain.
Surgical Flaps	Tongues of tissue (skin and subcutaneous tissue, sometimes including muscle) cut away from the underlying parts but attached at one end. They retain their own blood supply during transfer to the new site. They are used in plastic surgery for filling a defect in a neighboring region. The concept includes pedicled flaps, rotation flaps, tube flaps, etc.
Plants, Medicinal	Plants whose roots, leaves, seeds, bark, or other constituent possess therapeutic, tonic, purgative, or other pharmacologic activity when administered to higher animals.
Algorithms	A procedure consisting of a sequence of algebraic formulas and/or logical steps to calculate or determine a given task.
Medicine, Chinese Traditional	A system of traditional medicine which is based on the beliefs and practices of the Chinese culture.
Gene Therapy	The introduction of new genes into cells for the purpose of treating disease by restoring or adding gene expression. Techniques include insertion of retroviral vectors, transfection, homologous recombination, and injection of new genes into the nuclei of single cell embryos. The entire gene therapy process may consist of multiple steps. The new genes may be introduced into proliferating cells in vivo (e.g., bone marrow) or in vitro (e.g., fibroblast cultures) and the modified cells transferred to the site where the gene expression is required. Gene therapy may be particularly useful for treating enzyme deficiency diseases, hemoglobinopathies, and leukemias and may also prove useful in restoring drug sensitivity, particularly for leukemia.
Models, Theoretical	Theoretical representations that simulate the behavior or activity of systems, processes, or phenomena. They include the use of mathematical equations, computers, and other electronic equipment.

Supplementary Table 2: List of MeSH terms included in key S&T research categories

Key Science & Technologies	**MeSH terms included in category**
Protein research	Signal Transduction; Protein-Serine-Threonine Kinases; DNA-Binding Proteins; Bacterial Proteins; Protein Biosynthesis; Nuclear Proteins; Membrane Transport Proteins; Adaptor Proteins, Signal Transducing; Drosophila Proteins; Saccharomyces cerevisiae Proteins; Intracellular Signaling Peptides and Proteins; Proto-Oncogene Proteins; Escherichia coli Proteins; **Protein Structure**
Protein structure	Protein folding; Protein Conformation; Protein Structure, Secondary
Develop & reproductive biology	Gene Expression Regulation, Developmental; Embryonic and Fetal Development; Child Development; Embryonic Development; Reproduction; Reproductive Techniques, Assisted; **Stem cell biology**
Stem cell biology	Hematopoietic Stem Cell Transplantation; Stem Cell Transplantation; Peripheral Blood Stem Cell Transplantation; Mesenchymal Stem Cell Transplantation; Cord Blood Stem Cell Transplantation; Hematopoietic Stem Cell Mobilization; Hematopoietic Stem Cells; Stem Cells
Viral infectious diseases	Virus Replication, Herpesvirus 4, Human; Influenza A Virus, H5N1 Subtype; Virus Assembly; Papillomavirus, Human; Influenza A Virus, H9N2 Subtype; Hepatitis B virus; Genome, Viral; Genes, Viral; Gene Expression Regulation, Viral; **HIV**
HIV/AIDS	HIV-1; HIV; HIV Seroprevalence; HIV Long Terminal Repeat

The Changing Role of State-Owned Enterprises in Chinese Industrial Research: New Goals, Ownership, and Management

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I. An Introduction to Industrial R&D in China

China has identified science and technology (S&T) innovation as key to stimulating its economy. Since the establishment of the Peoples Republic of China in 1949 and particularly since reform and opening in 1978, China has acquired technology from abroad through either direct import of turnkey projects or through joint-venture partnerships between Chinese state-owned enterprises (SOEs) and multi-national corporations (MNCs). Government research, prior to the 1980s, was limited to government and military directed projects that did not immediately produce products for civilian consumption. Current plans unveiled by the Chinese government, however, include efforts to foster "indigenous innovation" in S&T and to encourage its integration with the economy. As the government attempts to shape a sustainable Chinese high-tech industry, the simple definition of a SOE has become obsolete due to the new ownership and management roles of the Chinese government. Modern SOEs are very different from traditional SOEs: they are as innovative in structure and operation as the R&D they wish to conduct. Reforms aimed at increasing the efficiency and incentives in SOEs also increased the ability for SOEs to innovate, but research and innovation did not become a mission for SOEs until the mid-1980s. S&T was deemed so important for the sustainability of the Chinese economy the new social goal of SOEs almost became to create a healthy economy through R&D. Thus, the role of R&D in Chinese SOEs has skyrocketed from an expendable role to an invaluable one because of need. This need has been imposed by the Chinese government through S&T policies that encourage owner diversification, modern corporate structures, and collaboration between industry and academia, and that provide support through intellectual property sharing and favorable financial policies to encourage enterprise formation. The SOE of today have come a long way from those of the 1950s, but they are still not ready for a no-holds barred competition in the global market. Progress, through innovation, has been astounding, and the achievements that Chinese SOEs will see in the future are only imaginable. Because of Chinese SOE R&D, Haier, Lenovo, and Suning, household names in China, might become household names around the world.

II. SOE Structural Reform and Industrial Research

The Chinese SOE has always been used to implement policies of the Chinese government. Since their founding in the 1950's, the government of the Peoples Republic of China has asked many different things of SOEs: from employing and providing services to massive numbers of Chinese workers to being high-tech international champions. Obviously, it is very difficult for one type of organization to fulfill all of these demands at once. Thus, the structure, and therefore definition, of the Chinese SOE has changed over the years to best be able to meet the directives of the Chinese government. The call for the integration of China's R&D institutes and industry has been heard for a couple of decades, but the enterprises that might be able to meet these goals may hardly be recognizable as traditional Chinese SOEs. Since the birth of the first SOEs, the Chinese government has been an influential player in the structure, organization, mission, and, thus, innovative capabilities of SOEs through reforms beginning in the late 1970's and continuing through modern day.

Chinese SOEs were originally formed in the 1950's to support the development of heavy industry in response to the disparity in output between China and industrialized countries. A state-planned development strategy was needed for the development of heavy industry as it was very capital intensive, and China had neither the strong economic foundation nor capital to support it otherwise. Competition with foreign countries, in addition to spurring the development of heavy industry, also spurred industrial research. This research, however, focused mainly on military applications with no consideration given to production of consumer goods or the economy. Key areas of research were focused on defense and computer related technologies and were mainly conducted by institutes of the Chinese Academy of Sciences (CAS).

Operation and organization of Chinese SOEs remained essentially the same until the late 1970s when reform began the first of three stages. In the 1970s, measures were taken to address the issues of inefficiency and lack of production incentives in SOE's. Though not the main goal of these economic reforms of the 1970's, the reforms also affected the rate of technological development, or R&D, within SOEs. For example, a few structural factors of traditional Chinese SOEs that specifically slowed technical progress included the lack of exposure to the market demand, the lack of autonomy or decision (investment) making ability, and, thus, the lack of incentives for technical innovation and increased efficiency. There was no need to innovate to reduce costs, increase quality, or increase efficiency since they did not compete with other enterprises. These reforms of the 1970s improved the environment for S&T innovation in SOEs, but it was not until the reforms of the 1980s, however, that SOEs began to restructure with the purpose of specifically addressing their ability to conduct innovative R&D.

Beginning in the early 1980s the second phase of reform began that attempted to establish a concrete methodology for increasing the autonomy and bettering the management of SOEs. These reforms attempted to address problems associated with information asymmetry, interest and goal inconsistency, and disproportionate responsibility/failure magnitudes between owners and managers. Two methods suggested to address these issues, which encouraged decentralization and institutional reform, were the enterprise contracting system and the shareholding system.

The third phase of Chinese SOE reform that began in the mid-1980s further encouraged decentralization and a market based planning approach in SOEs. It emphasized the goal to establish a modern enterprise/corporate system based on the socialist market economic system. This turned many of the SOEs into limited-liability stockholding companies with a diverse group of owners (the majority, however, still belonging to the government). As discussed later, this has been a popular trend even in modern time with the establishment of shareholding groups like the Chinese Academy of Sciences Shareholding Group.[1]

Throughout the 1980s and 90s the government provided great opportunity and aggressive goals for industrial R&D. These were a result of the fact being acknowledged in China that S&T innovation could be the key to continued economic improvements. Sustaining this improvement was a key issue on the minds of government officials. As the link between S&T innovation and the economy became clearer, the government specifically instituted policies directed towards industrial S&T innovation and competitiveness, to build an autonomous and sustainable source of economic growth for China.

III. Changing Demands on SOEs: Government S&T Goals

The most recent Medium- to Long-Term Plan (MLP) (2006-2020) sets the goal for China to become a world leader in S&T by the year 2050. And, as Shang Yong, Vice Minister at the Ministry of Science and Technology stated, the integration of S&T with the economy and the commercialization of technology are the top priority of S&T as stated in Text Box 1.[2] This integration is expected to occur in high-tech industrial zones and in high-tech incubators as the government encourages and facilitates both the close cooperation between existing enterprises, universities, and R&D institutions and the commercialization of university and national lab research through spin-offs.

Text Box 1: Major Aims of Chinese S&T Policy

- ***Accelerate technology commercialization and integrate S&T with economy (Top Priority)***
- Promote people's living and health standard
- Support sustainable development
- Safeguard national security
- Enhance innovative capability
- Encourage scientists' innovation passion
- Expand international S&T cooperation
- Legislation & regulation on S&T as well as IPR

Two thirds of the major actions executed by The Ministry of Science and Technology (MOST) are related to "activities aimed at tackling major S&T problems relevant to economic development, in order to accelerate technological innovation and product regeneration in traditional industries…" and "…initiatives focused on the development of

[1] Lin, Justin Y., Fang Cai, and Zhou Li. State-Owned Enterprise Reform in China. Hong Kong: The Chinese UP, the Chinese University of Hong Kong, 2001.
[2] SHANG Young. An Introduction to China's Science and Technology Policy. The Kennedy School of Government, December 15, 2005. http://bcsia.ksg.harvard.edu/BCSIA_content/documents/MinisterShangYong_Dec_15_05_lecture.pdf (September 2006.)

high and emerging technologies and high-technology industries."[3] The government has also committed itself to financial backing for high-tech ventures through the Government Innovation Fund, loans, and tax incentives and to develop technology transfer centers and IPR dealing organizations, to strengthen the innovative capability of enterprises establishing R&D centers. The market will guide development of S&T activities.[4]

Government goals for R&D are very ambitious. The Chinese government hopes to substantially increase R&D spending and investment in the S&T industry, but there are also directives to spend and invest more wisely. The Chinese Academy of Sciences (CAS), for example, plans to restructure 80 national institutes, of which 30 will become internationally acknowledged and three to five will become world class. By 2001, 37 institutions were restructured into 17 and 39 were approved to become independent legal entities.[5]

This strategy is in line with the recommendation given by Adam Segal that it is essential for S&T companies to identify and nurture "core competencies" to become successful in today's market.[6] Financial success within China is of marked importance for enterprises in the S&T and high-tech industries, for the Chinese government wishes for these SOEs to become globally competitive. Thus, the weight of "grasp the large, release the small" becomes much heavier for managers as they participate in the fierce struggle for survival to be one of China's "national champions". It is noted, however, on the CAS website that, "A large proportion of the Academy's institutes have rather old and backward infrastructure and facilities, which can not meet the requirements posed by modern S&T innovation activities." This is reflective of both the work that has been done and the work that must be done to reform SOEs into enterprises that may be able to meet China's ambitious S&T policy goals.[7]

IV. SOE Industrial Research and S&T Policy Reform

Though some of the previously discussed structural reforms helped SOEs evolve into enterprises that are better able to conduct research, policy directed at the commercialization of research and the technical innovation ability of enterprises did not occur until the mid-1980s. The development of the National Innovation System (NIS) has been essential to creating an environment conducive to both innovation and the flow of these results from this innovation from government to industry. The creation of the NIS has not been accidental, but the result of carefully crafted policies (some of which

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[3] Gabriele, Alberto. "Science and Technology Policies, Industrial Reform and Technical Progress in China", Discussion Papers, No. 155, United Nations Conference on Trade and Development, August, 2001.
[4] Yong, Shang. "An Introduction to China's Science and Technology Policy." Belfer Center for Science and International Affairs. Kennedy School of Government, Cambridge, Massachusetts. 15 Dec. 2005. 1 Sept. 2006 <http://bcsia.ksg.harvard.edu/BCSIA_content/documents/MinisterShangYong_Dec_15_05_lecture.pdf>.
[5] The Chinese Academy of Sciences. The Knowledge Innovation Program. http://english.cas.cn/eng2003/page/KIP.asp. (September, 2006).
[6] Segal, Adam. Minying Enterprises and High-Technology Zones. Council on Foreign Relations. January 15, 2004.
[7] The Chinese Academy of Sciences. Progress in the Initial Phase of the KIP Pilot Project. http://english.cas.ac.cn/eng2003/news/detailnewsb.asp?InfoNo=20964. (September 2006.)

are summarized in Appendix A). In addition to the "Decision on Reform of the S&T Management System" (1985), which formalized the objectives to form horizontal relationships between government research institutes and enterprises,[8] three policies that have had a direct influence on the ability of SOEs to engage in industrial research and innovation include: the National High-Tech R&D Plan (the 863 Plan), the Torch Program, and the CAS Knowledge Innovation Program (KIP).

The National High-Technology R&D Plan (The 863 Plan), which began in March of 1986, allocates grants and loans to universities and private enterprises to develop economically promising technology. Alberto Gabriele calls this state-centered program, a program of "paramount relevance" as it achieves its high-tech goals through a combination of the traditional state structure and decentralized entrepreneurship and market signals to choose projects from the bottom up structure to help integrate R&D and economics. He also notes that it may represent one of the most ambitious and advanced Chinese S&T policies, producing great achievements like the Shuguang 100 large-scale parallel computer and the Shuguang Tianchao supercomputer systems.[9]

The Torch Program (1988) followed the 863 Plan and focused on small and medium sized enterprises that had technology in the second phase of development. To attempt to bring R&D results to market in the form of consumer commodities, the plan also established high-tech incubators or development zones to support new enterprises. S&T industrialization bases and research facilities are based around, as the 2002 *China Science and Technology Indicators* states, "needs, optimization, and priority". Each of the national high-tech industrial development parks are a little different as they depend on market needs which may vary with geographic location. This variety encompasses "technological innovation service centers", "productivity promotion centers", "university S&T parks", and topic specific parks such as the "agriculture S&T park" and the "sustainable development experiment park."[10] Also, a program that provided benefits like those received by enterprises in the high-tech industrial zones is the Innovation Fund for Small Technology-Based Firms (STFs). It is a government fund set up with approval from the State Council that supports technology innovation through financing. This financial support comes in the forms of loan interest subsidies and equity investment and also private venture capital.[11] As result of this program, in 1998 there were over 65,000 new technology enterprises (NTEs) registered in both 53 nationally sponsored and hundreds of locally sponsored high-tech development zones and spent, in terms of their profit, 3.78 percent more than large to medium enterprises (LMEs). The most famous is

[8] Suttmeier, P., Cao, C.. China Faces the New Industrial Revolution: Achievement and Uncertainty in the Search for Research and Innovation Strategies. National Science Foundation Tokyo Regional Office. November 26, 1999.
[9] Yu, QY. "The Implementation of China's Science and Technology Policy", xv, 238. Quorum Books. Westport, Conn., 1999.
[10] Ministry of Science and Technology of The People's Republic of China. 15 Sept. 2006. <http://www.most.gov.cn/eng/index.htm>
[11] People's Daily. China Encourages Innovation Funds. 2000. http://english.people.com.cn/english/200103/20/eng20010320_65458.html. (September 2006.)

located in Beijing at Zhongguancun Science Park near "Electronics Avenue".[12] Between 1991 and 2002 these national technology parks had a total income of $184.78 billion.[13] By the late 1980s, the Chinese government had provided both financial support and locations for innovation to occur, but in 1998, these types of support were combined and interaction between universities, research institutions, and enterprises were formally encouraged through the Chinese Academy of Sciences Knowledge Innovation Program.

The CAS Knowledge Innovation Program (KIP) launched its pilot project in 1998 with the goal of completing all three stages, Initial Phase (1998-2000), All-Around Implementation (2001-2005), and Optimization (2006-2010), by 2010. One of the main goals of the KIP is to construct, "an organizational management system of S&T innovation and a new structural system full of vitality for meeting the demands of social and economic development of China in the 21st century." The KIP is a major part of the Chinese NIS as it truly attempts to create a sustainable bridge between research and commerce. As it addresses many of the issues faced by China, its goals are broad and ambitious, which attract some criticism for being so. For example, some goals of the KIP include institute restructuring and integration with industry, promotion of scientific culture in China, and education, and also for CAS to become a reference for national policies and a major representative for China in the international science community.[14] One goal that specifically addresses industrial R&D establishes that the CAS will become China's major incubator for high-tech enterprises by establishing mechanisms for technology transfer and by providing a reliable stream of both high-tech personnel and achievements. Enterprises that enter these incubators may be former government R&D institutions or NTEs. In 2001, for example, 39 R&D institutions were approved to become legally independent organizations, and 13 were successfully transformed by the end of that year. Also in that same year, annual business revenue of these enterprises was $5.24 billion, an 18 percent increase over 2000. From this, the government collected $265 million in taxes, leaving profits to be approximately $255 million.[15] Though these enterprises are successful, CAS hopes to also set up venture capital funds and establish procedures for utilization of these funds to further nurture these types of enterprises. Also, as another way to raise funds, CAS hopes to expedite efforts to list enterprises on the stock market.

These S&T policies instituted by the Chinese government have been innovative and aggressive in their goals for industry and research. These policies, however, are not products of purely Chinese thought and actually have been seen around the world. In fact, China has had the luxury of utilizing policies and programs that have been

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[12] Suttmeier, P., Cao, C.. China Faces the New Industrial Revolution: Achievement and Uncertainty in the Search for Research and Innovation Strategies. National Science Foundation Tokyo Regional Office. November 26, 1999.

[13] Segal, Adam. Minying Enterprises and High-Technology Zones. Council on Foreign Relations. January 15, 2004.

[14] Chinese Academy of Sciences. The Pilot Project of the Knowledge Innovation Program. 15 Sept. 2006. <http://english.cas.cn/eng2003/page/KIP.asp>

[15] People's Republic of China. CAS News Office. Chinese Academy of Sciences. Achievements Notched by KIP Pilot Project of Past Four Years. 10 Aug. 2006 <http://english.cas.ac.cn/english/news/detailnewsb.asp?InfoNo=20931>.

successful in other countries. For example, as Walsh states, "China's approach to industrial R&D mimics the US system, which is by design."[16] From peer review to institutional structure, China has been able to adapt time proven methods and policies to best encourage their NIS and, specifically, industrial research. Legislation and prior success, however, means little if policy implementation is not carefully monitored and evaluated. To help support SOEs, both high-tech and not, and to watch over and direct state assets, the government has created boards to do exactly that. Two notable groups, the State-Owned Assets Supervisory and Administration Committee (SASAC) and the Chinese Academy of Sciences Shareholding Group (CASH), are two of these groups that have considerable influence over SOEs.

V. New Government Ownership and Management

New holding companies are not meant to direct research or development. Instead, they are boards that act as a buffer between the government owners and the market oriented managers. They are important because it shows an intimate integration between research and the economy and helps to apply business principles to best make use of government institution and university research. Perhaps, these shareholding groups are good examples of the compromise between a planned and a market economy. Though they do not provide support for the enterprises, they have the opportunity to best direct government efforts and resources to produce "global champions" and a new potential independence for high-tech companies.

The Chinese Academy of Sciences Shareholding Group, Ltd. (CASH), for example, monitors enterprises that were specifically spun-off of CAS intuitions or used CAS innovations. Text Box 2 includes a list of all the enterprises that are under the authority of the CAS, including CASH.[17] Before listing CASH enterprises on Chinese stock

Text Box 2: Companies directly under the Chinese Academy of Science (CAS)

- CAS Holdings Corporation, Ltd.
- China Sciences Group (Holdings) Corporation
- Legend Holdings Ltd.
- The Oriental Scientific Instrument Import & Export (Group) Corporation
- China Investment Corporation For Science & Technology
- Huajian Group Co., Ltd.
- GK Opto-electronic Co., Ltd.
- Chinasoft Co. Ltd
- Institute of ZhongKe Architectural Design & Research Co., Ltd.
- Beijing Zhongke Resource Co., Ltd.
- CAS Shenyang Computing Technology Co., Ltd.
- CAS Shenyang Scientific Technology Development Co., Ltd.
- CAS Nanjing Astronomical Instrument Co., Ltd
- CAS Guangzhou Chemistry Co., Ltd.
- CAS Guangzhou Electronics Co., Ltd.
- CAS Chengdu Organic Chemicals Co., Ltd.
- Chengdu Information Technology of Chinese Academy of Sciences Co., Ltd.
- CAS Chengdu Weishi Instrument Co., Ltd.
- Beijing Zhong Ke Printing Limited Company
- CAS Scientific Service Co., Ltd.

[16] Walsh, Kathleen. Soaring Eagle, Flying Dragon: Industrial R&D and Innovation in the United States and China (Draft Background Paper). September 15, 2006. US-China S&T Policy Forum. October 2006.
[17] The Chinese Academy of Sciences. High-Tech Industry Development. 10 Sept. 2006. < http://english.cas.ac.cn/eng2003/page/T46.asp>

exchanges, CASH sets goals for the percentage of government shares that must be sold to employees of the enterprise. This may be a strategy that might address issues of dumping state stares on the market that devalued shares when privatization first began.

The State-Owned Assets Supervisory and Administration Committee (SASAC) was created in April of 2003 and assumed many of the responsibilities earlier held by The State Economics and Trade Commission (SETC), industrial ministries, and the State Asset Management Bureau. The SASAC attempts to address many of the woes previously stated concerning conflicts between managers and owners, and, specifically, the SASC monitors and assess the value of state assets. It also controls and approves large decisions in a rapid, flexible fashion compatible with market demand rather than dictating what to invest in and what to research. Some of these decisions could include mergers and managerial buy-outs (MBOs) and they would be monitored to prevent insider privatization for personal gain and stripping of state assets This was common in prior to the formation of the SASAC, and the SASAC has actually slowed the speed at which state assets are being privatized. Due to the variety of enterprises that the SASAC oversees, it addresses each enterprise and issue that comes before the committee individually. Some high-tech companies that are overseen by the SASAC include Great Wall Computer and Alcatel Shanghai Bell. Also, SASAC-like organizations exist at the provincial and local levels to fulfill the same role that the SASAC does, however, they are not subdivision or subordinates of SASAC.

Li Rongrong, the Chairman of the SASAC and Party Secretary[18], views the role of the SASAC essential not only to the future of SOEs, but also to affect the rest of the Chinese economy. He states that that SASAC should seek to, "expand the state-owned economy's ability to control, to influence, and to catalyze [the rest of the economy]. Critics of the SASAC might state that the power held by and the mission statements of the SASAC are very broad. The combination of these two factors creates the potential for abuse. But, again, Li states that, "a continued role for state ownership is clearly compatible with a dynamic, strategically informed market position" and that the SASAC will be integral in, "strengthening the competitive advantage of these [Chinese] firms." [19,20,21]

Results of S&T Policy on SOE Industrial Research

The role of industrial R&D in SOEs, especially those in the high-tech sector, has risen from a non-existent role in traditional, inefficient SOEs, to the key component for success in the SOE of today's world. There are new goals in SOEs that are accompanied by new enterprise structures, new definitions of management and ownership, different evaluations and new measures of performance, and a totally new and electric

[18] The State-Owned Assets Supervision and Administration Commission of the State Council (SASAC), The People's Republic of China. News Updates. 30 Sept. 2006. <http://www.sasac.gov.cn/eng/eng_index.htm>
[19] Naughton, Barry. "SASAC Rising." *China Leadership Monitor, No. 14.*
[20] Naughton, Barry. "The State Asset Commission: A Powerful New Government Body." *China Leadership Monitor, No. 8.*
[21] Naughton, Barry. "Claiming Profit for the State: SASAC and the Capital Management Budget." *China Leadership Monitor, No. 18.*

environment in which to conduct R&D. Though new and different, there remains, the potential for SOEs to fulfill government goals. This time, however, the social services that SOEs may provide may not include health care or dependable incomes, per se, but society may potentially benefit through a stable economy created by innovative, research oriented SOEs that will provide opportunity for the people of China.

The traditional definition of the Chinese SOE is an enterprise that is owned by all the people of China, and the State Council acts as the owner on behalf of the people of China. Traditional Chinese SOE corporate-governance structure was a multilayered management system. Local governments and relevant government ministries were then the managers of the SOEs. (Relevant ministries could include the State Planning Commission, the State Economic Commission, the Ministry of Finance, and the Ministry of Machinery)[22] Now, however, there is a vast array of types of enterprises whose classification may be vague and confusing, especially to the foreigner. For example, Minying enterprises are also known as "non-governmental enterprises". The first Minying enterprises were CAS spin-offs, similar to those produced in programs like the KIP. Though, as Segal notes, Minying refers more to the organizational structure of the enterprise and less with the issues of property rights or ownership. These companies, however, do have a great deal of government involvement, contrary to what one might think. Lenovo, for example, is a well-known Minying enterprise that was formed as a CAS spin-off. The Chinese government is a significant shareholder in Lenovo through the Legends Holding Group and the Chinese Academy of Sciences. Table 1 on page 9 lists the top ten Minying enterprises, of which Lenovo is number one with an annual income of over $4 billion. [23]

Table 1: 2002 Annual Ranking of Member Minying Enterprises, Source: All-China Federation of Industry and Commerce.

	Minying Enterprise Name	Region	Minying Income (USD)	Type of Business
1	Lenovo (Lengend Group Ltd.)	Beijing	4,299,217,389	Information Technology
2	Sha-Steel	Jiangsu	1,761,249,274	Steel
3	Wanxiang Group	Zhejiang	1,430,529,079	Auto Components
4	Guansha Limited	Zhejiang	1,261,904,877	Construction, Real Estate, Tourism
5	China Orient	Heilong-jiang	1,242,558,545	Banking, Insurance, Securities
6	Fosun	Shanghai	1,223,745,645	Medicine, Real Estate
7	Hengdian Group	Zhejiang	1,132,185,020	Pharmaceuticals, Power Generation
8	Suning Appliances	Jiangsu	1,018,292,771	Home Appliance Retailer
9	Chint Group	Zhejiang	974,799,207	Electrical Power Equipment
10	Xinjian Delong Group	Xinjiang	872,813,044	Food Stuffs, Machinery, Building Materials

[22] Lin, Justin Y., Fang Cai, and Zhou Li. State-Owned Enterprise Reform in China. Hong Kong: The Chinese UP, the Chinese University of Hong Kong, 2001.
[23] Segal, Adam. Minying Enterprises and High-Technology Zones. Council on Foreign Relations. January 15, 2004.

Now that Chinese SOEs have gotten a modern, market-economy face lift through their new structure, management, and ownership, the important question begs to be asked: "Have these new SOEs been meeting their research and commercialization goals set by government?"

The 2002 *China Science and Technology Indicators* stated that in 2000 there were 32,385 enterprises that were associated with S&T, 26 percent of which were SOEs. Of these SOEs, 59 percent were involved in R&D activities, which is above average for enterprises associated with S&T. SOEs also employ almost half of all scientists and technicians and about 40 percent S&T personnel, scientists and engineers, and R&D personnel. (See Table 2.) [24]

Table 2: Distribution of the number of firms and SYT personnel by size and type (2000), from China S&T Indicators, 2002. Pg. 92.

	Number with S&T	Number with R&D	Percentage w/R&D	Employee population (10,000 persons)	Engineers & Technicians	S&T Personnel	Scientists & Engineers	R&D Personnel
Total	32385	17272	53.30%	2612.1	307.8	193.5	111.9	70
By size								
Large	5143	3620	70.40%	1698.5	196	108.6	61.1	42.6
Medium	5865	3496	59.60%	428.4	48.6	30.1	15.7	11.7
Small	21377	10156	47.50%	485.2	63.2	54.8	35.1	15.7
By type								
State	8418	4965	59.00%	1241.3	146.6	81.6	45.5	27.7
Collective	4300	2043	47.50%	182.5	19.1	13.3	7.7	4.7
Shareholding	2225	1348	60.60%	278.1	37.6	25.1	14.9	9.4
Hong Kong, Macao, Taiwan invested	2429	1278	52.60%	110.2	13.3	9.2	5.7	3.7
Foreign invested	2454	1330	54.20%	114.4	15.1	10.3	6.8	4.3
Others	12559	6308	50.20%	685.6	76.1	54	31.3	20.2

In 2000, the five industries that produced the highest intensity of R&D expenditure included electronic and communications, instrument and office machinery, general machinery, special equipment, and pharmacy. Most of these expenditures, over all industries, focus mainly on product development, rather than applied or basic research. Also, most of the R&D in China occurs in the larger enterprises, while smaller enterprises, that include 490 reformed government R&D institutes, focus on implementation of these R&D results.[25]

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[24] Ministry of Science and Technology of The People's Republic of China. The Yellow Book on Science and Technology: China Science and Technology Indicators. Vol. 6. Scientific and Technical Documents Publishing House. Beijing, China. 2002.

[25] Ministry of Science and Technology of The People's Republic of China. China Science and Technology Indicators: 2002. The Yellow Book on Science and Technology, Vol. 6. Scientific and Technical Documents Publishing House. Beijing, China. 2002.

Another aspect of performance that is interesting to look at is productivity and efficiency, which are traditionally, two areas of difficulty for SOEs. These parameters may be looked at through labor productivity, which is an indicator of the level of productivity and integration of technology, work skills, and operational management, industrial R&D expenditure, output (exports), and product sales revenue. The World Bank estimated the average total factor productivity (TFP) growth rate in China to be 4 percent between 1980 and 1995, which was significantly higher than other countries in the region, and even the United States. This indicates a high sustained rate of technological improvement. Average TFP for SOEs between 1980 and 1988 was only a little more than half that at 2.4 percent.[26]

Results from a slightly older survey, done in 1997 by Jiancheng Guan et al. at the School of Management in the Beijing University of Aeronautics and Astronautics, also indicate that SOEs have a relatively low commercialization value when compared to their overall innovation. Enterprises want to have both high profits and high market shares. The values reported in Table 3 indicate that though innovation may be healthy within SOEs commercialization of this innovation has not fully matured. For example, not counting foreign enterprises, SOEs have one of the largest shares of innovation sale, but one of the reported lowest sale and profits.

This innovation, however, may actually not be going to waste. One may also note that there is relatively high success seen in collectively-owned enterprises (COEs). This may be attributed to technological spill-over from SOEs that may be a result of "gray markets" or imperfect markets that contain vague property rights. These vague property rights and horizontal collaboration encourages COEs to commercialize the high-tech results from SOEs and be technological followers. Industrial growth in COEs was faster than that in SOEs from 1980-1999. [27]

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[26] Gabriele, Alberto. "Science and Technology Policies, Industrial Reform and Technical Progress in China", Discussion Papers, No. 155, United Nations Conference on Trade and Development, August, 2001.
[27] Gabriele, Alberto. "Science and Technology Policies, Industrial Reform and Technical Progress in China", Discussion Papers, No. 155, United Nations Conference on Trade and Development, August, 2001.

Table 3: Proportion of sale, profit and export from innovative products, distributed on economic types. (*The real profit of other products except innovative products for joint managed with foreign involvement is negative. ** Excluding high-tech firms in economic zone.) [28]

	Sale	Profit	Export Sale	Share of Innovation Sale: New in the Enterprise	Share of Innovation Sale: New in the Province	Share of Innovation Sale: New in China	Share of Innovation Sale: New Worldwide
State-Owned	21.35	15.68	30.43	19.92	12.68	58.41	8.99
Collective	33.45	49.50	28.16	14.40	25.75	53.25	6.60
Private	24.76	63.06	0.00	44.25	2.65	50.16	2.94
Joint Venture btwn PRC firms	27.64	44.33	33.31	16.31	16.61	58.85	8.23
Stock & Share	44.64	52.30	42.44	32.75	11.49	49.92	5.83
Joint Venture w/foreign involvement	57.30	41.56	64.54	2.03	6.29	89.77	1.64
Joint Venture Managed w/foreign involvement	27.57	100*	46.52	5.85	5.34	14.76	74.05
Wholly Foreign-Owned Venture	75.89	80.77	75.92	3.32	0.20	41.58	54.90
Joint Venture with HK, Taiwan, & Macao	27.84	67.19	48.34	4.70	14.91	77.23	3.17
Joint managed with HK, Taiwan, & Macao	13.66	10.01	100.00	0.00	0.00	100.00	0.00
Wholly Owned Venture (Including HK, Taiwan, & Macao)	68.83	69.72	100.00	1.91	0.00	97.77	0.32
Other Economics	18.96	64.99	33.91	45.16	29.33	25.51	0.00
Total	28.94	30.19	35.40	16.82	14.64	61.43	7.07
Total**	26.84	26.54	33.69	16.43	15.42	61.44	6.71

Even though innovation occurring in COEs and SOEs is generally new in China with a 53.25 and 58.41 percent share of innovation sale, respectively, as Table 3 indicates, the innovation is not necessarily new to the rest of the world. The global "degree of novelty", especially when compared to wholly foreign-owned enterprises is fairly low. This indicates that though products may be new to China and the region, they are not necessary new to the rest of the world. Also, as shown in Figure 1, SOEs have a large research presence, as mentioned previously, but they lack the same prominence in innovation applications and invention patents. This may reflect a lack of "indigenous innovation" or creativity in product development. [29]

[28] Jiancheng, Guan, et al. "Industrial Innovation in China: A Comparative Study Based on Survey Data." EAP Report Memorandum #01-02. National Science Foundation, Tokyo Regional Office. January 16, 2001. (11/09/06)

[29] Gabriele, Alberto. "Science and Technology Policies, Industrial Reform and Technical Progress in China", Discussion Papers, No. 155, United Nations Conference on Trade and Development, August, 2001.

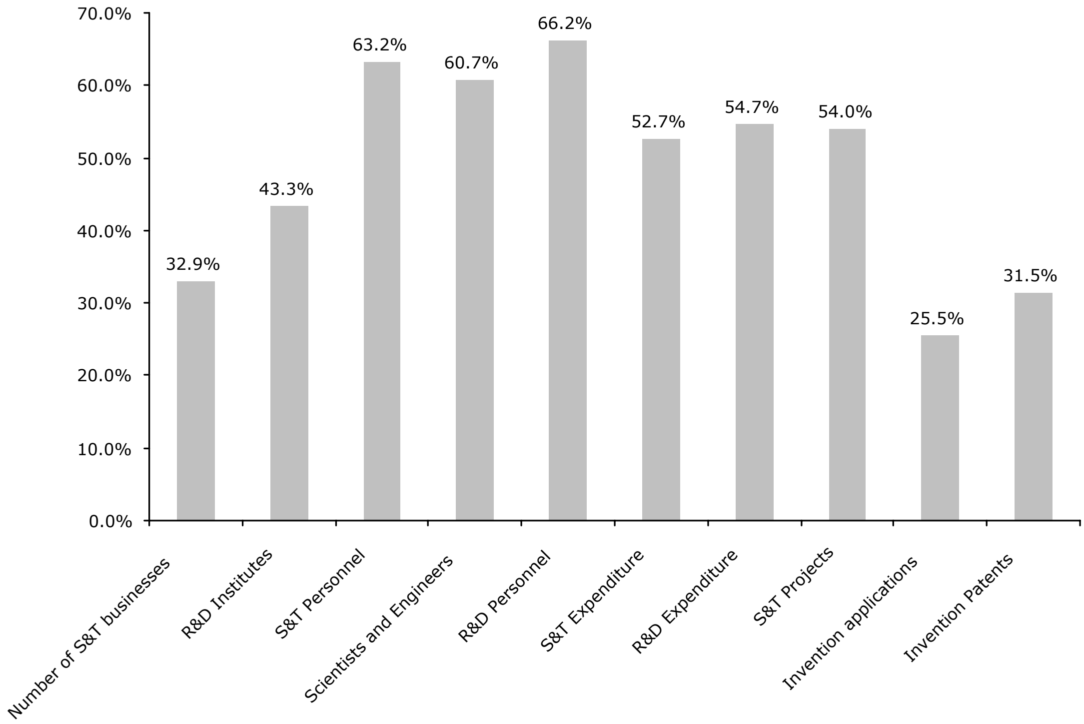

Figure 1: Major S&T indicators of SOE or state holding enterprises and their share in the total (2000)

VII. Conclusion

It seems as though the future of industrial research in Chinese SOEs is bright. Similar to the rest of the economic boom that is occurring in China, the amount of research and commercialization of that research has been expanding and growing as well. Because of reasons like this, the industrial research of SOEs will be a major focus of the government to both fulfill its social and economic obligations to the Chinese people. The government does not demand, however, exactly what topics may be researched and developed and who must conduct it. Such an approach may have been the case in the past when the government would dictate enterprise activity based upon social needs. Interpreting the R&D environment in China as this black and white, however, is rather naive as there still remain many challenges to successful industrial R&D. Industrial R&D now attempts to rely more strongly on indications from the market and the creativity and insight of scientists to lead both research and development. The combination of this market driven and central planned strategies has the opportunity to create discord between interests, but reconciliation of these conflicts have been attempted through groups like the SASAC and the CASH. Thus, the importance of industrial research in Chinese SOEs will continue to grow as it is viewed as the catalyst for great economic success and sustainability in China.

APPENDIX A

Table 1: caption, Yan, Ke. <u>Science & Technology in China</u>. China Intercontinental Press, 2004.

Name of Plan	Department in Charge	Year of Issuance	Main Characteristic
National Plan for Tackling Key Problems of S&T	State Planning Commission, State S&T Commission	1982	It is a national mandatory plan, mainly supported by financial appropriation; its main contents emphasize on important research and development of key technology related to the national economy and social development; it is carried on basically fives year as a cycle.
Plan for the Construction of National Key Laboratories	State Planning Commission	1984	Supported by national finance, based on long-term sustained development of S&T; high-level personnel training as well as basic research and applied basic research.
Spark Plan	State S&T Commission	1986	The mandatory plan is mainly supported by credit funds; it supports technologic development and application in rural areas and medium and small-sized enterprises.
National Plan for High-tech R&D (863 Plan)	State S&T Commission, National Committee of Defense, Science, & Industry	1986	The national mandatory plan is mainly supported by national finance. It renders support to research and development of high-tech fields of biology, aerospace, information, new materials, energy resources and laser.
Torch Plan	State S&T Commission	1988	It is a national mandatory plan. Its aim is to promote conversion of high-tech achievements to commodities, mass production and international market.
Plan for Popularizing National Achievements of Science and Technology	State S&T Commission	1990	The national mandatory plan is mainly supported by credit funds. It helps to popularize and apply mature and advanced scientific research results of scientific research institutes and enterprises, and supports conversion of military technology to civil use.
Plan for Key Projects of State Basic Research (Climbing Plan)	State S&T Commission	1991	It is for major basic research projects supported by the state.
Plan for National Engineering & Technological Research Centers	State Planning Commission, State S&T Commission	1992	The plan's aim is to set up a platform for key and preferential industrial trades to strengthen capability of assembly, production of complete sets, mature development and conversion of their achievements to practical production. The Capital is jointly raised from state, local government, related government departments, as well as the "center" subordinated units.
Project of Technologic Innovation	State Commission of Economy and Trade	1996	The aim is to push forward technologic progress of the enterprises and improve the innovation ability of the enterprises.
Plan for National Development in Key Basic Research (973 Plan)	Ministry of S&T	1997	It is mainly to carry out multi-subject and comprehensive research on agriculture, energy resources, information, resources, environment, population and health, and materials. It provides theoretical reference and scientific basis for solving problems.

E-commerce, Economic Development and IT Policy: A Preliminary Institutional Study of the United States and China

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I. Introduction

E-commerce is a pervasive IT phenomenon in the information economy. It represents one of the most important and profound transformations that IT makes to our society—the way that business is conducted, managed and communicated. E-commerce has played an increasingly notable role in global trade, transaction and production in the past decade. By making business more competitive and productive, e-commerce is momentous for both developed and developing countries in strengthening the economy and supporting the development. The challenge is for both academic researchers and policy-makers to better understand the phenomenon and ensure that the opportunity and potential offered by e-commerce is taken and realized in all industries and economies and that it is facilitated, not inhibited, by those external environment factors. However, the reality is that e-commerce adoption in different countries is uneven, due to different national environment. To achieve the assurance of a favorable e-commerce environment, there are a hands-off approach represented by the United States and an actively involved approach represented by countries in Europe and Asia. It has been a long-term debate on how the environment should be created and shaped to foster IT innovation. In any case, where there is enough political wisdom, social awareness and stakeholder involvement in "e-strategies", progress in the adoption and diffusion of e-commerce can be an exciting reality.

Adoption and diffusion of e-commerce has been a growing topic of academic research. The research interest makes assumptions that this phenomenon can be analyzed using theories and methods from social science, management science, economics and computer science, and that the scientific research can improve and contribute to global e-commerce adoption in practice (Banker et al. 2004a; March et al. 1995). This paper also takes these assumptions and plans to assess the impact and effect of the institutional environment (e.g. legal foundations, regulatory frameworks, governmental policies, industrial standards and cultural norms) on the global technology-driven shift of business operations to e-commerce. The assessment bases on the institutional theories from the new institutional economics. The finding of the study is expected to provide evidence and insight for researchers and policymakers to understand how e-commerce adoption is affected by external factors.

II. Background

It is estimated that two-thirds of the global economy is either dependent on or at least reliant upon some form of information technology, which encompasses computers, software, telecommunication and Internet technologies, and information systems applications. IT enables people to process, store, retrieve and communicate information in many forms, unconstrained by distance, time and volume. As a result, goods and services can be developed, bought, sold and delivered over electronic networks.

As steam and electric power were the technologies behind the industrial society, IT is seen as the catalyst for creating the information society. An information society is a society in which the creation, distribution and manipulation of information is a major part of economic and cultural activities. Besides the transformation of the developed countries from an industrial society to information society since 1980s, the developing countries are crossing over from semi-industrial or even agricultural age directly into information societies.

The truly revolutionary impact of IT in our society, claimed by Peter Drucker, the founding father of modern management, is not from the "information" itself, nor from the computer and the data processed by the computer; it is from *e-commerce*—that is, the electronic network, especially the Internet, is becoming the major worldwide distribution channel for goods and services (Drucker 2002). He further claimed that e-commerce is profoundly changing economies, markets, industry structures, products and services and their flow, and consumer behavior; but the impact may be even greater on societies and politics (Drucker 2002). Although it experienced a hard time after the dot-com bubble burst in 2001, e-commerce has regained its vitality and significance recently.

While there are varied definitions of e-commerce, this paper defines it broadly as any commercial process that relies on some form of IT, mostly as Internet-based information systems today. It can range from simply providing product or service information by email for marketing purpose to utilizing Customer Relationship Management (CRM)[1], Supply Chain Management (SCM)[2] and Enterprise Resource Process (ERP)[3] systems for the entire transaction. From this perspective, e-commerce is synonymous with e-business.

E-commerce, in general, bridges the physical and time-dependent distance between the suppliers and customers, enhances the efficiency and flexibility of production and operation, reduces the market entry barriers, and increases the competitiveness of the market (Hauser et al. 2000/2001). B2b e-commerce, represented mainly by manufacturing shipments and wholesale trade in the annual global e-commerce report of the United Nations Conference on

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[1] CRM includes the methodologies, technology and capabilities that help an enterprise manage customer relationships. The general purpose of CRM is to enable organizations to better manage their customers through the introduction of reliable systems, processes and procedures.

[2] SCM is the process of planning, implementing, and controlling the operations of the supply chain with the purpose to satisfy customer requirements as efficiently as possible. Supply chain management spans all movement and storage of raw materials, work-in-process inventory, and finished goods from point-of-origin to point-of-consumption.

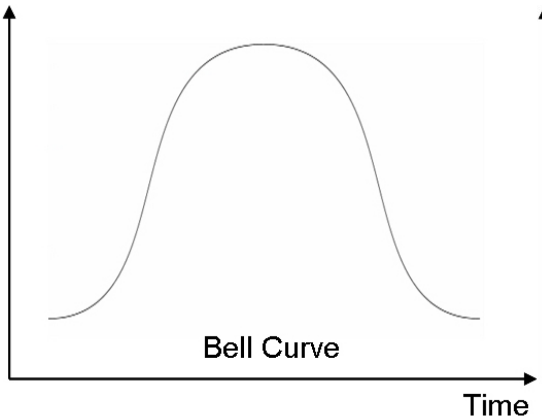
[3] ERP is information system that integrates and automates many of the business practices associated with the operations or production and distribution aspects of a company engaged in manufacturing products or services. The systems concentrate on the efficiency of a firm's internal production, distribution and financial processing.

Trade and Development (UNCTAD), accounted for 16 percent of all commercial transactions between enterprises and 93 percent of all e-commerce in the United States in 2002 (UNCTAD 2004). According to eMarketer, an e-business research firm, worldwide B2B e-commerce revenue had reached $1.4 trillion in 2003, and would double in 2004 (Hansen 2003). B2b e-commerce in the United States alone grew at an annual rate of 6.1 percent while overall commercial transactions between companies fell 1.3 percent in 2002 (UNCTAD 2004). The Stamford, Connecticut-based Gartner Group estimated in 2001 that B2B e-commerce sales in the Asia-Pacific region will rise from $9 billion in 1999 to $0.9 trillion by 2004 (Regan 2001). Corporation investment will particularly grow in CRM, SCM and ERP systems (Israel 2002). E-commerce is arguably becoming an important engine for the economy and a powerful booster for globalization.

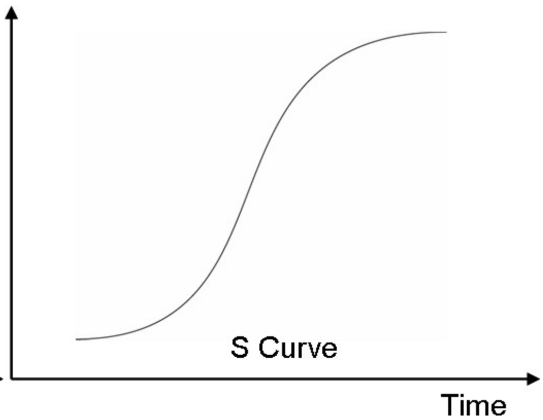
Globalization and IT are the two most important factors in conducting business today (Israel 2002). E-commerce development closely parallels globalization. The adoption of e-commerce technology and model has offered a powerful new means for international trade expansion, permitting business to forge new paths toward higher productivity, competitiveness and growth beyond national borders. The benefits of e-commerce include speed, agility, round-the-clock operation and reach to global markets, and thus creating a global production network. Globalization is hastened dramatically by the advances in e-commerce.

E-commerce, with its "born global" nature, also provides firms in developing countries particularly new exchange mechanisms that enable them to compete on a more equal basis on global markets. It facilitates a closer integration of adjacent steps in the value added chain, so allowing firms potentially to reduce costs associated with selecting suppliers, negotiating and fulfilling contracts, and ensuring that contract terms are met (Muroyi 2004). Thomas L. Friedman, when analyzing the process of globalization in his recent New York Times best-selling book "*The World is Flat*", emphasizes that the advance of information technologies and thereby the reduction in transaction costs has allowed emerging countries, such as China and India, to become a critical part of the global supply chain for manufacturing and services. With so considerable new opportunities offered by e-commerce, however, Friedman poses a common-sense question by the end of his book, *has the world gotten too small and too fast for human beings and their social and political systems to adjust in a stable manner?* (Friedman 2005)

The study of the adoption of e-commerce is about how and why the e-commerce model and technology is used by both the individuals and business. According to the Diffusion of Innovations theory, adopters of any new technology are normally categorized as innovators (2.5 percent), early adopters (13.5 percent), early majority (34 percent), late majority (34 percent) and laggards (16 percent), based on a bell curve (*See* Graph 1) (Rogers 2003). Among them, *early adopters* are characterized as "social leaders" (in e-commerce adoption, I infer that these are industry leaders and large multinational corporations); *early majority* as "deliberate, many social contacts" (I infer that these are consumers and enterprises in developed countries); *late majority* as "skeptical, traditional and lower socio-economic status" (those companies in developing countries); and *laggards* could be those small enterprises and individuals in developing countries. There has been a concern that uneven diffusion of e-commerce would create a "digital divide" between developed and developing countries and unfair competitive advantages for multinational oligarchs against local SMEs. We can see from Graph 1 that, during the time moving in the left half the bell curve, more and more companies in the developed countries will adopt the technology, while the majority in developing countries hasn't; a "digital divide" is thus formed. When newer technology emerges, if the bell curve is still followed, the "digital divide" will persist (*See* Figure 1). A key objective of e-commerce development is how to transform the normal bell curve of adoption to an S curve through the global society; that is, in a shorter adoption period, there are only two categories of adopters, early adopters and majority, in both developed and developing countries (*See* Graph 2).



Graph 1: Bell Curve of Adoption



Graph 2: S-curve of Adoption

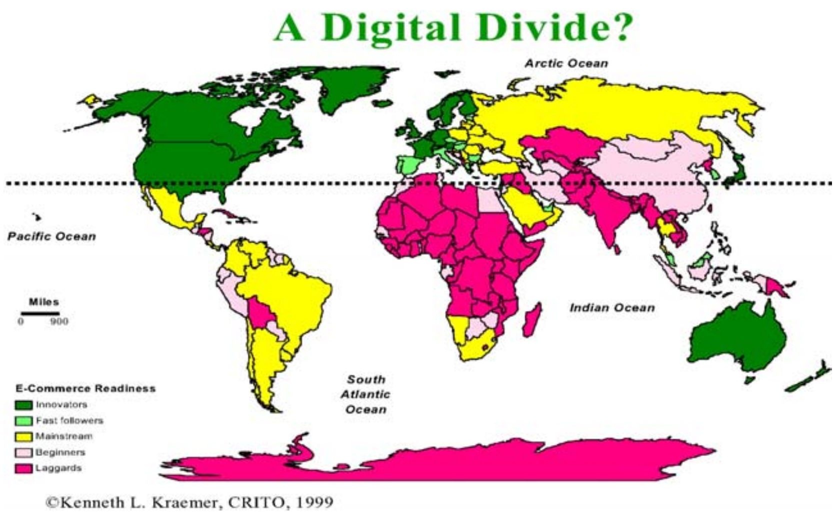


Figure 1: World Map of Digital Divide

For the facts shown above, e-commerce has been both a strategic initiative of private sectors and a key policy issue of public institutions. From a business perspective, when undergoing globalization and economic integration, companies rely on e-commerce systems for cross-border flows of products and services within the entire inter-organizational value chain. From a governance perspective, the social and economic contribution and potential of e-commerce provides substantial incentive for governmental attention and, in some cases, action and intervention. Disparate initiatives, guidelines, directives, laws, and treaties have started to emerge. The key areas that have seen regulations are digital signatures, privacy, intellectual property and taxation. For example, aiming at encouraging e-commerce worldwide, all members of the World Trade Organization (WTO), which represents more than 140 countries and their governments, have committed to a moratorium on imposing customs duties on electronically transaction since 1998. These institutional activities, in turn, create and shape the external environments for e-commerce adoption decision. The following figure outlines the major international and national policy initiatives related to e-commerce in a decade.

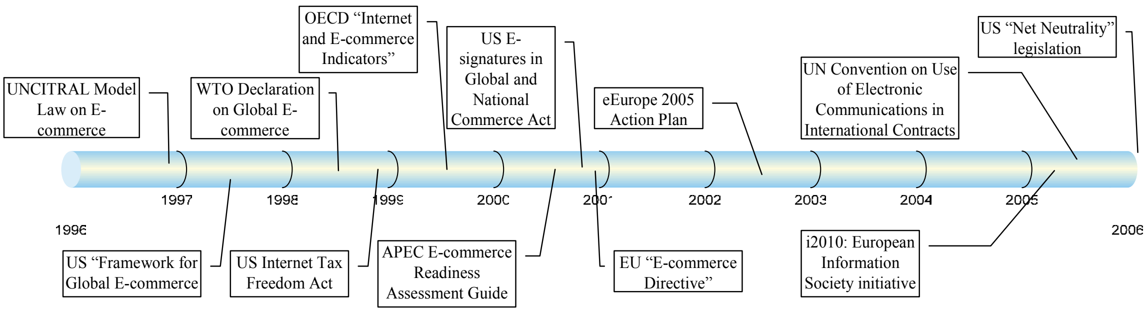


Figure 2: Timeline of Major Policy Initiatives Related to E-commerce: 1996-2006

Despite of the numerous governmental endeavors, constructing policies to enable and promote e-commerce presents significant challenges and should be proceeded carefully with consideration of the historical, cultural and institutional capacity of a country. Although it is generally believed that policy making has an original motivation to encourage e-commerce, how the policy plays and how it should play the role is still unclear. The main reason is that, in an increasingly complex information economy, it is difficult to identify and measure cause and effect of policy outcomes. Yet private sectors do make their business and management decisions in an integrated institutional context covering laws, regulations, standards, norms, funding and promotions. How to develop a supportive e-commerce environment has driven much of the debate on policy making since the latter part of 1990s. One of the first responses to the concern is the *Framework for Global Electronic Commerce* proposed by the U.S. government in 1997. Among those principles suggested to help the growth of e-commerce are that (1) the private sector should lead; (2) governments should avoid undue restrictions on e-commerce; and (3) the aim of governmental involvement should be to support and enforce a predictable, minimalist, consistent and simple legal environment for e-commerce (Clinton et al. 1997). The *Framework* recognizes that governments can have a profound effect on e-commerce, either facilitating or inhibiting it. Knowing when and how the government should act is crucial to the development of e-commerce.

A most recent regulatory attempt which shows the impact on e-commerce is about the so-called "net neutrality". During an initiative to rewrite the Telecommunication Act of 1996 by the U.S. Congress, large telecom companies, which have been the major Internet service providers so far, promoted legislation that would divide the Internet into a two-tiered system. The top tier would be a high-speed toll road that charges premium access fees for different types of content; the bottom tier would be a slow lane for everyone who can afford the service. Opposition to the measure is based primarily on the "network neutrality" principle, which emphasizes the importance of open, neutral, and affordable access to the Internet. The opponents are afraid that the discriminatory measure might have a chilling effect on e-commerce investment and innovation since it represents the imposition of a broadband bottleneck tax on e-commerce. It would particularly hurt those small companies and startups which thought e-commerce is the way to deal and compete with large companies by reducing transaction costs. Even those established business entities would increase their e-commerce operating costs because they have to pay the fare for "fast lane" Internet access. A policy whether to protect "net neutrality" or not could affect the e-commerce adoption decision significantly.

The UNCTAD's global e-commerce report showed that, while adoption of IT and economic development has a positive correlation, countries with similar levels of gross domestic product (GDP) have very different levels of adoption of IT, and vice versa (UNCTAD 2004). The variation among countries in e-commerce cannot be explained simply by relative income and infrastructure levels (Shih et al. 2005). The report thus suggested that IT policy choices could make a significant difference on the adoption of e-commerce (UNCTAD 2004). The report, however, did not investigate further the relation between IT policy and e-commerce adoption, due to the lack of e-commerce data, especially from non-U.S. countries.

As shown above, the significance of e-commerce in the real-world is so obvious and there is an imminent need to evaluate scientifically the effects of institutional factors on e-commerce adoption so that reliable evidence could be provided for reference in appropriate policy-making decisions. "Insights from the New Institutional Economics" suggests that we should look beyond those proximate indicators [i.e. physical infrastructure] to examine how the *institutional environment* in a country contributes to (or undermines) confidence in e-commerce and supports private investment in the new medium [of business transaction]." (Oxley et al. 2001)

III. Theoretical Foundation

Institutional environment may be relatively new to some researchers, but governance theory should be familiar to them. Governance is actually closely associated with the concept of institutional environment. Governance is defined as the exercise of political authority and the use of institutional resources to coordinate, manage and control society's activities, affairs and problems. It includes government regulations, public policies and public-private partnerships, which can be generalized as government intervention. Given the historical background of European economic reconstruction, government intervention was often rejected by scholars of neoclassical economics and the public-choice school after World War II, as it was increasingly seen as a major obstacle to economic and social development (Ahrens 2000). Free markets seemed to be a panacea and required minimum governance. However, since 1980s, political scientists and economists have recognized that the market and the state are not mutually exclusive mechanisms of resource allocation, but rather complementarities (Ahrens 2000). They started to call for "bringing politics back in". This new stream of thinking has been strongly supported by theoretical insights of the New Institutional Economics (represented by Nobel Laureate Douglass North) on one hand and the experiences of economic development in transitioning and developing countries on the other hand. The real-world experiences in both Central and Eastern Europe during their democratic transition and Southeast Asia during the 1997 financial crisis have revealed that economic development will be ineffective if it lacks a sound institutional environment

(Ahrens 2000). The role of institutions was made even more obvious by the expanding influence of the U.S. government in public policy making since 1990s. The limited studies of IT adoption and diffusion in the last decades also suggest that a supportive institutional environment and a variety of nurturing policies from government are especially indispensable for technological innovation.

Institutional theory traditionally views institutions as frameworks "of rules, procedures, and arrangements" (Shepsle 1986), or "prescriptions about which actions are required, prohibited, or permitted" (Ostrom 1986). Contemporary institutional theory attempts to answer how social choices are shaped, mediated, and channeled by institutional arrangements (DiMaggio et al. 1991). Among the applications of institutional theory, the new institutionalism in organizational analysis treats institutions as independent variables, turns toward cultural explanations, and expresses an interest in properties of supra-individual units (DiMaggio et al. 1991). It focuses on organizational structures and processes that are of industry-wide, national or international scope (DiMaggio et al. 1991). The institutionalists believe that institutions can reduce organizational uncertainty by providing dependable and efficient frameworks for economic exchange (North 1986). They also believe that organizations in different societies or institutional domains hold varying assumptions about the interests that motivate legitimate action, the auspices under which organizations may act, and the forms of action that are appropriate (DiMaggio et al. 1991).

A concept of "information ecology", which connects ecological ideas with the evolving information economy, can be seen as an early theoretical extension of institutional theory to the discipline of IT in the 1980s and 90s. Information ecology suggests an approach to describe and analyze information systems from the perspective of how they influence and are influenced by their environment—economic, social and environmental activities. The local information ecosystems should be considered in the context of larger systems, and of the evolution of global information ecosystems. Any company's information ecology is bound to be affected by external factors, many of which the company can't directly control—governments create new regulations, customers' requirement evolve, competitors take innovative steps, and incompatible culture values persist (Davenport 1997). Applied to e-commerce adoption, the new institutionalism lays an important theoretical foundation for conducting analysis on external environments.

IV. Research Question

Based on the background and theoretical foundation of the problem described in the previous sections, this study is interested in the following questions:

1) What are the institutional environments for e-commerce adoption and how were they created and shaped in both the United States and China in the past decade?
2) What role do institutions play in technological innovation, such as e-commerce, at different development levels (i.e. in developed and developing economies)? and
3) Whether and to what extent do those environmental factors influence e-commerce adoption decision and sophistication in the two economies?

V. Literature Review

Traditional e-commerce adoption study has mostly focused on the organizational (internal) factors and attempted to explain the intention of organizational adoption of new technology by applying general social-psychological models to the IT context (Chin et al. 2001). Such models include the technology acceptance model, the infusion model, and the task-technology fit model (Banker et al. 2004b). These models center on characteristics of the technology and user perceptions of the technology, and assume that the technology adoption is based on a psychological process of rational decision making (Gibbs et al. 2004). However, the theoretical reasoning in the previous section shows that a comprehensive e-commerce adoption model should recognize both inter-organizational and extra-organizational factors. A brief review of both the conceptual and empirical literature provided below discusses the studies on some of the most important external factors.

The institutional approach has attracted more and more attention to the researchers especially since the publication of Paul DiMaggio and Walter Powell's book "*The New Institutionalism in Organizational Analysis*" in 1991. There is a growing literature of applying institutional theory in organizational information systems. Specifically speaking, the institutional approach has been used in the studies of organizations' adoption of technological innovation. These studies used institutional theory to explain the organizational changes, and examined the institutional factors shaping organizational actions and structure (Gibbs et al. 2004). According to their findings, adoption decisions are not purely driven by internal factors, such as the organizational perception of technology, but also influenced as much or even more by the institutional environment in which the organization conducts business. A study on global supply chain systems proposed that three external factors influence organizational information sharing: nature of the industry, government support, and national culture (Shore 2001). Institutional contexts may be particularly important when IT systems crossover both organizational and national boundaries; however, studies of the effects of institutional environment on e-commerce adoption are limited (Christiaanse et al. 1997).

Some researchers have defined institutions that are "any standing social entity that exerts influence and regulation over other social entities" (King et al. 1994). They further suggested that the relationship between environmental factors and e-commerce adoption can be explained by institutional theory. The institutional environment is the "set of fundamental political, social and legal ground rules that establishes the basis for production, exchange and distribution" (Oxley et al. 2001). In the e-commerce context, this environment consists of suppliers, customers, competitors, trading partners, society, and regulatory agencies such as government (Gibbs et al. 2004). Figure 3 illustrates the layers of institutional environment in which businesses are conducted.

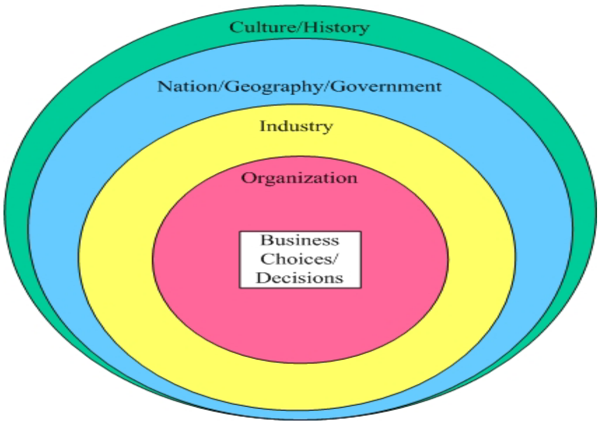


Figure 3: The Institutional Environment Layers of Business

Two specific institutional factors are identified accordingly and discussed below. They are tentative assertions subject to further verification or rejection in empirical testing.

A. Governmental Factor

Governments may play a critical role in creating the institutional environment that fosters private investment (Oxley et al. 2001). Institutional contexts thus become essential when e-commerce adoption is considered as one way a company invests in IT. Shore argued that country IT support can be characterized by the availability and quality of labor, technical infrastructure, attitudes towards cross-border data flow, and national policy for training and maintaining an adequate IT workforce (Shore 2001). Wang used longitudinal data over a 16-year period to conclude that building national ICT infrastructure and regulatory reform are policy choices supporting IT adoption in newly industrialized economies (Wang 1999). Among a very few papers published recently, Gibbs et al. mentioned that government promotion and incentive is a major enabler of e-commerce, and that national policies such as trade and telecommunication liberalization are also likely to have big impact on e-commerce by making IT more affordable to firms (Gibbs et al. 2003). Based on these findings, governmental encouragement, such as government support, initiatives and strategies, subsidies and tax deductions, and procurement requirements, is expected to have a positive impact on e-commerce adoption.

B. Regulatory Effects

Several studies have developed theoretical arguments on what is the good practice to regulate e-commerce. They examined from policy frameworks to legislating efforts (Bond et al. 1998; Mitchell 2001; Murray et al. 1999; Zekos 2003). In the real world, we see the legal system has tried to re-orient itself to suit the requirements of the dynamically changing information society. Since the first Model Law on Electronic Commerce drafted by the United Nations Commission on International Trade Law (UNCITRAL) in 1996, there have been at least 50 countries and regions (including China and the United States) with various legislations, regulations and policies regarding e-commerce (Baker&McKenzie 2004). There are more than 10 international and regional organizations, including the World Trade Organization (WTO), International Chamber of Commerce (ICC), and Asian-Pacific Economic Cooperation (APEC), involved actively in global policymaking on e-commerce development.

The regulatory changes can be found in the issues of privacy and intellectual property during the marketing phase, information security and e-contract and e-signature during the transaction phase, and electronic payment, dispute and jurisdiction during the post-transaction phase. In the countries without new principles regulating rights and obligations in the intangible cyberspace, e-commerce adoption seems to be slow (Shih et al. 2005). For example, one study shows that the U.S. legal and regulatory environment is significantly more supportive to e-commerce than in other countries; and compared to other countries, a higher percentage of U.S. firms uses e-commerce. By contrast, fewer Chinese firms adopt e-commerce, perhaps because of the less friendly regulatory environment (Shih et al. 2005).

VI. Discussion

This study looks into two typical developed and developing countries—the United States and China. These two economies cover different levels of both institutional development and e-commerce development (*See* the e-readiness rankings in Table 1 (WEF 2002)). Furthermore, considering the global e-commerce context, these two economies have close business relationships with each other. In 2001, China was the United States' fourth largest international trade partner (USBTS 2001), while U.S. was China's 2nd largest partner (MOFCOM 2002). These facts make these two countries appropriate and worthy of study.

	United States	China
GDP per capita	US$33,886	US$3,953
Global Competitiveness Index Ranking	2	39
Networked Readiness Index	1	64
Enabling Factors component index	2	56
Network Access	3	63
Information Infrastructure	4	55
Hardware, Software, and Support	1	71
Network Policy	5	49
Business and Economic Environment	6	44
ICT Policy	3	54
General Infrastructure	4	55

Table 1. E-readiness Profile of the U.S. and China in 2001

The United States is the world's largest online nation (WEF 2002), and continues to set the trends which e-commerce follows (UNCTAD 2004; UNCTAD 2005). It has a relatively mature electronic market with minimum governmental intervention. While many other countries have enacted e-commerce legislations and national IT strategies, the U.S. government has taken a hands-off approach to the Internet economy. It believes that growth come without significant government intervention. The U.S. government has followed a model of minimal regulation and looked to industry leadership to address and solve some difficult policy issues (Israel 2002). It provides loose guidelines for state-level policy, as well as general assistance to individual federal agencies. The policy environment in the

United States is thus quite unique (WEF 2002). This less-interventionist approach allowed the private sector to rapidly build out Internet infrastructure and explore new and innovative business models (WEF 2002). For a snapshot in 2001, e-commerce represented 15.1 percent of all business-to-business transactions in the U.S. By sectors of activity, e-commerce is most prominent in manufacturing, where it accounted for 18.2 percent of total sales in the sector and 71.7 percent of overall b2b e-commerce activities (UNCTAD 2004).

Other than for the United States, available statistical information on the value of e-commerce is fragmentary or even non-existent in the case of China, although there appears to be clear growth in the region. China's situation seems to be very contradictory: in terms of GDP per capita, it still belongs to the group of developing countries. On the other hand, China is about to become a global IT player (Thomas, 2003). China is the largest developing country and a rising manufacturing center in the global production network. Most outsourcing manufactures are clustered in China's east and south coastal areas which are close to Taiwan and Hong Kong. China's export-oriented sectors have begun to embrace e-commerce (WEF 2002). Meanwhile, the Chinese government has long committed itself to the development of national information infrastructure. It actively supports and even invests in e-commerce ventures (WEF 2002). E-commerce adoption is also an important part in the national West Development plan. There have been a few successful e-commerce firms linked to foreign multinationals with active government promotion. According to China Internet Network Information Center (CNNIC), a quasi-governmental organization, as of April 2001, enterprise websites were the largest portion (77.8 percent) of all websites in China (238,249). B2B-related services provided by these websites ranged from introduction of products (93.9 percent) to online sales (4.9 percent) to online procurement bidding (1.4 percent) (*See* Chart 1 and 2) (CNNIC 2001).

Chart 1. Websites in China (2001)

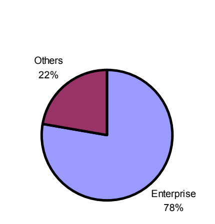
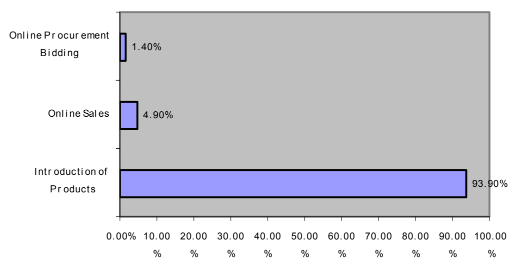


Chart 2. Website Proportion by Service



Since 1999 with the growth in popularity of the dot-com industry there has been speculation about an e-commerce law for China. Instead of a comprehensive law there have been regulations incorporated into the existing legal framework, e.g. the Contract Law of China (Thomas 2003). At the regulatory level, the Ministry of Foreign Trade and Technological Co-operation (MOFTEC), whose responsibilities were incorporated into the newly set up Ministry of Commerce, has played a crucial role in shaping B2B opportunities for the Chinese market (Thomas 2003). The ministry has been leading a governmental program - so-called Golden Project. This project aims to connect over 100,000 companies nation-wide. Accordingly, the government helped to set up several B2B portal websites, such as China Market and China Business Guide. These websites promote Chinese companies and their goods and services, to cultivate their overseas markets and increase their exports (Thomas

2003). These B2B e-commerce platforms, actively promoted by the government, are regarded as decisive factors for changes in business processes in China (Thomas 2003). Some scholars have argued that China is a government policy-oriented economy. Good government policies and intervention measures should be directed to the correction of market failures and the provision of necessary legal, social and physical infrastructure to ensure making full use of market mechanisms (Lu 2003). In the Chinese government's Tenth Five-Year Plan that began to be implemented in 2001, the government would further push forward the development of e-commerce and create favorable technical, network, business and legislature environments for it (Lu 2003). Although there is no formal, centralized regulation or law of e-commerce, certain agencies have begun regulating e-commerce. The problem is not only there are no clear uniform policies, but also there is no strong enforcement system of any policy (Lu 2003).

All policy prescription should rely on solid theory base, sound scientific analysis, and rational discussion. The application of institutional theory in e-commerce adoption makes a clear relevance to policy makers. If we understand better at a theoretical level how those institutional factors interact with each other to produce an outcome of e-commerce adoption, we then have the basis for a conditional prediction in the real world on how e-commerce will develop in a certain environment. It will help policy makers to formulate appropriate policies to accelerate e-commerce adoption.

Experience has taught us that it is vitally important to build a climate for technology innovation and diffusion and support the entrepreneurial spirit that drives economic growth and development. First, government policies that encourage investment on IT adoption are crucial to e-commerce. Second, government efforts to promote an open and free trade environment will also help e-commerce. Third, government's assurance on recognizing e-contracts will facilitate e-commerce activities. Last, cooperation between government and industry is a key to e-commerce. With immature institutional structures, governmental and industrial encouragement together tend to play an even greater role in developing countries (Xu et al. 2004). Promotional efforts could be more noteworthy if they were carried out by government in partnership with the private sectors (Gibbs et al. 2003). Finally, just as what Kofi Annan, the Secretary-General of UN, suggested, "if all countries are to be benefit [from e-commerce], … more needs to be done to … create an enabling environment, nationally and internationally." (UNCTAD 2004)

VII. Reference

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