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IRG 2: Globalization and Nanotechnology: The Role of State Policy and International Collaboration

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To Our Readers

The Societal Implications of Nanotechnology: Origins, Innovation, and Risk // Synthesis Reports of the Center for Nanotechnology in Society at UC Santa Barbara

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UCSB's Center for Nanotechnology in Society (CNS-UCSB), funded by the US National Science Foundation in 2005, constitutes an unparalleled national commitment to research and education intended to enhance responsible development of sophisticated materials and technologies seen as central to the nation's economic future. After more than a decade of funding, CNS-UCSB provides a deep understanding of the relationship between technological innovation and social change, illustrated by an unrivaled set of scholarly, educational, and societal outcomes. These outcomes were largely the work of three main Interdisciplinary Research Groups (IRGs): 1) Origins, Institutions and Communities; 2) Globalization and Nanotechnology; 3) Risk Perception and Social Response.

In advancing a role for the social, economic and behavioral sciences in understanding and promoting development of equitable and sustainable technological innovation, CNS-UCSB serves as a solid framework for future social science/ science & engineering (S&E) collaborations at the national center scale. Indeed, successful development of the transformative technologies anticipated by the country's leaders depends on systematic knowledge about complex societal as well as technical factors.

Toward this end, each of the three IRGs has generated a Synthesis Report on the cumulative scholarly results and broader impacts of their nearly 11 years of programmatic research, education and engagement.

This synthesis report *on IRG 2* should be cited as:
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CNS-UCSB Center for Nanotechnology in Society

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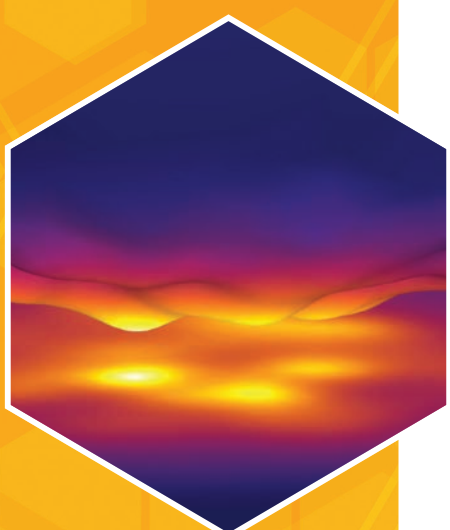


IRG 2: GLOBALIZATION AND NANOTECHNOLOGY

I. Summary

IRG 2's research and outreach has addressed two key issues resulting from the globalization of nanotechnology (and, indeed, emerging technologies generally):

- The conditions under which national, state-driven policies can and do make a difference in advancing national goals with regard to R&D and commercialization of nano-enabled products, and conversely,
- The extent to which the cosmopolitan nature of science, which increasingly depends and thrives on cross-border collaborations, can enable advances to transcend national boundaries.

INDEED, ONE OF THE EMERGING CONCLUSIONS FROM OUR RESEARCH IS THAT NATIONAL AMBITIONS AND GLOBAL COLLABORATIONS DO NOT NECESSARILY COINCIDE.

Another overarching concern of IRG 2 (indeed, of CNS in general) is the use of nanotechnologies and other emerging technologies to foster more equitable and sustainable development. To address these issues, we have focused on nanotechnology innovation in the U.S., China, and selected Latin American countries. We have also conducted supporting research in Japan, India,
and Korea.

State policies (and budgets) are intended to elevate a country's global position as a nanotech player, enabling it to reap the anticipated economic rewards of what is predicted to be a multi-trillion dollar commercial sector. Since the U.S. officially launched the NNI at the end of 2000, global governmental spending on nanotechnology is estimated to exceed $100 billion; when private funding is included, the total is estimated to be as much as a quarter of a trillion dollars (Cientifica 2011). Revenue from nano-enabled products

is now estimated to exceed $1.6 trillion (Lux 2015). Clearly, public officials across the world have come to see nanotechnology as the next technological revolution; firms and investors – no doubt in part attracted by the availability of public funding – have followed suit.

We have been especially interested in comparing the U.S., where the NNI favors basic research, with China, where state policies range from supporting basic research to providing infrastructure and capital for commercialization. Countries like Mexico, Argentina, and Brazil offer a range of intermediate approaches for comparative analysis.

International collaboration, by way of contrast, places primacy on the advancement of scientific discovery, and therefore is arguably less nationalistic and more cosmopolitan in nature. This "***new invisible college***" is comprised of global science and engineering networks, resulting in opportunities that extend beyond national borders. They can be of particular benefit to developing countries, to the extent that international partnerships contribute to technology transfer and scientific development.

APPROACH

To address these issues, IRG 2 has engaged in a number of interrelated projects and activities that draw on field interviews, documentary analysis, survey research, patent analysis, and studies of publications and patents. Much of our work has focused on China's S&T policy – the extent to which China's emphasis on indigenous innovation has resulted in nanotechnology R&D and commercialization, particularly in Shanghai and Suzhou Industrial Park (SIP). There we have interviewed academic scientists and engineers, entrepreneurs, public officials responsible for S&T development, and science park officials. Our most recent research involves a large sample survey of Chinese STEM faculty in China's leading universities, in order to better understand the strengths and weaknesses of China's science education. We have also surveyed Chinese (and other foreign) STEM graduate students at U.S. universities, to better understand their motives for studying in the U.S., their experiences, and their reasons for staying or leaving after graduating.

We have compared China's efforts – which involve substantial public investment, from basic research to commercialization – with the U.S. NNI's emphasis on basic research. We extended our research to include Mexico, Brazil, and Argentina, supported by two grants from UC MEXUS/CONACYT, examining the role of government policy in support of nanotechnology development in all three countries. Our research in Mexico employed a global value chain framework, categorizing firms according to whether they produced raw nanomaterials, nano-intermediates, nano-enabled commodities, or nano instruments. This research also enabled us to establish a relationship with the Latin American Network for Nanotechnology and Society (ReLANS), one result of which was a conference in Curitiba, Brazil, cohosted by ReLANS and CNS, that brought together trade unionists and academics from the U.S., Europe, and Latin America, to raise awareness of occupational health and safety (OHS) issues in industries that use nanomaterials.

SOME KEY POLICY-RELATED FINDINGS FROM OUR RESEARCH CAN BE SUMMARIZED AS FOLLOWS:

- **State policies aimed at fostering S&T development should clearly continue to emphasize basic research, but not to the exclusion of supporting promising innovative payoffs.** The NNI, with its overwhelming emphasis on basic research, would likely achieve greater success in spawning thriving businesses and commercialization by investing more in capital programs such as the Small Business Innovation Research (SBIR) and Small Business Technology Transfer (STTR) programs, self-described as "America's seed fund."

- China, which has made substantial public investments in science and technology parks, venture capital programs, and incentives to bring home its most talented STEM expatriates, is proving to be a rising star in nanotechnology.

- **Yet the case of China also shows that public investment, by itself, may not be sufficient for a successful innovation system: there remain significant cultural and institutional barriers to China's efforts to translate basic research into commercial success.**

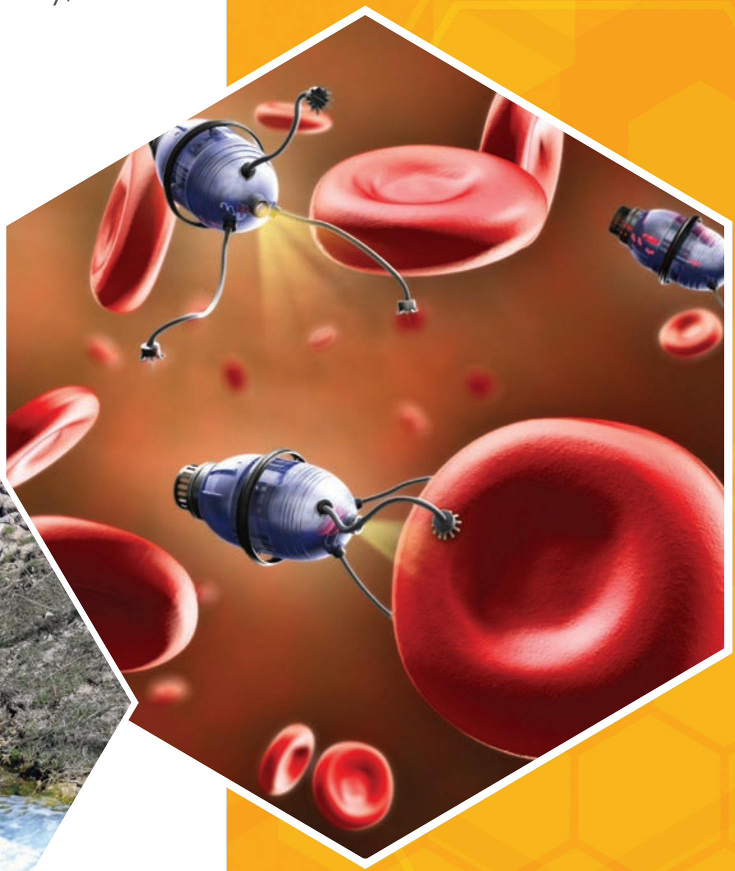
- **The lessons of Latin America – particularly Mexico, Brazil, and Argentina – show that in the absence of strong governmental programs in nanotechnology, even where basic research has some strengths, sustained innovative breakthroughs are unlikely.** Such countries are likely to be "takers" of economically advanced countries' S&T efforts, producing outputs that are at the low end of the value chain (such as nano-materials and nano-intermediates). Coordinated government programs would increase the likelihood of success in moving up the value chain to achieve more innovative (and competitive) breakthroughs.

- Modern research does not take place in a vacuum, but relies on collaboration, much of which takes place across borders. **This should be encouraged – there is a global talent pool among scientists and engineers that can most effectively address global problems in such crucial areas as energy, health, water, and food security.**

- Creating opportunities for the best and the brightest to come to the U.S. requires addressing immigration policies that create uncertainty for young scholars. The U.S. should revisit its H1-B visa policy, for example passing the STAPLE and I-Squared Acts, which have been languishing in Congress (U.S. Congress 2015a, 2015b). While the U.S. remains the most attractive educational site for international STEM doctoral students, the EU has become increasingly attractive, and countries such as China offer substantial incentives to convince their best expatriate students to return home. **While nearly half of all international STEM graduate students would like to stay in the U.S. upon graduation, fully 40 percent are undecided – and a main barrier is current U.S. immigration policy.**

IRG 2 also developed original methods for data analysis and developed new data sources and repositories, partly in collaboration with our colleagues from Georgia Tech. These were employed to investigate policy issues related to emerging technologies and innovation. Scripts, code and other working files will be archived at: https://github.com/cns-ucsb. Spreadsheets, working papers, reports and other documents will be archived in the CNS escholarship repository http://escholarship.org/uc/isber_cns in the IRG 2 section. Some were brought to bear on our comparative studies; others resulted in an interactive website, "California in the Nano Economy," http://californiananoeconomy.org/ that mapped all California firms involved with nanomaterials at any stage along the value chain, providing information related to the physical location, business descriptors (i.e., year established and employment), and products or services.

IRG 2 DEVELOPED ORIGINAL METHODS FOR DATA ANALYSIS AND DEVELOPED NEW DATA SOURCES AND REPOSITORIES, PARTLY IN COLLABORATION WITH OUR COLLEAGUES FROM GEORGIA TECH.



IRG 2: GLOBALIZATION AND NANOTECHNOLOGY

II. Main Accomplishments Over The Life of Both Awards

A. Scholarly Merit - Contributions to Scholarly Knowledge.

1. Comparative Study of Approaches to High-Tech Development: China, United States, Mexico, Argentina, Brazil

- **China's State-Led Approach to High-Tech Development**

A major focus of our research since the beginning has been to understand whether China's state-centered approach to innovation, R&D, and commercialization of nanotechnology has been successful. China, with its vast resources in foreign reserves and long tradition of state planning, has emerged as a global player in nanotechnology. While its overall capacity for innovation remains behind that of the U.S. and other advanced industrial economies, China's trajectory appears to be upward. Nonetheless, **while China's state policies (and funding) have had some success in advancing basic research, they have been less successful in bringing viable products to market.** We conclude that while progress has been made, **China has yet to become a nanotechnology innovator.** China's effort to commercialize nanotechnology has been much slower than anticipated by nanoscientists and China's leadership. While basic research is improving, it still fails to drive long-term innovation; as a result, products typically mirror the functionality of existing products, rather then representing breakthroughs. We recognize that many subfields of nanotechnology remain at an early stage, one in which advances in basic research still outpace technological applications in all countries. China, however, is faced with some additional challenges described below. As we titled one of our articles (paraphrasing a Chinese proverb), "research is high and the market is far away" (Cao, Appelbaum, and Parker 2013).

China's goal is to become an "innovation-oriented" society by the year 2020; "indigenous innovation" *(zizhu chuangxin)* is seen as the source of China's future development. Through its fifteen year "Medium- to Long-Term Plan for the Development of Science and Technology (MLP)" and a series of five year plans, the Chinese government has sought to move away from the export-oriented manufacturing that provided the basis for to double-digit economic

WE RECOGNIZE THAT MANY SUBFIELDS OF NANOTECHNOLOGY REMAIN AT AN EARLY STAGE, ONE IN WHICH ADVANCES IN BASIC RESEARCH STILL OUTPACE TECHNOLOGICAL APPLICATIONS IN ALL COUNTRIES.

growth for nearly three decades, instead focusing on STEM education, home-grown innovation, and fostering commercialization through national, state and local government investments that range from support for promising projects to entire science and technology parks. Nanotechnology was identified as one of four "Science Mega-Progams" that were seen as key drivers of indigenous innovation. Given its interdisciplinary nature and long-term commercial prospects, nanotechnology was unlikely to be part of MLP's Engineering Mega-Programs. In order to raise nanotechnology's profile, it was necessary to emphasize its basic science aspect while using the potential application bonanza as the attraction (Appelbaum, Parker, Cao, and Gereffi 2011; Appelbaum, Cao, Parker, and Motoyama 2012; Cao, Appelbaum, and Parker 2013).

We initially examined China's efforts through interviews with scientists and engineers at leading universities (such as Peking and Tsinghua Universities in Beijing; Fudan and Jiao Tong Universities in Shanghai), members of the Chinese Academy of Sciences, policy makers, and scientists and entrepreneurs at incubators such as the Shanghai Nanotechnology Promotion Center, the National Center for Nanoscience and Technology (NCNST) in Beijing, and the Nanotechnology Industrialization Base of China (NIBC) in Tianjin (Appelbaum and Parker, 2008; Appelbaum, Parker, and Cao 2011; Appelbaum, Parker, Cao, and Gereffi 2011; see also Cao, Suttmeier, and Simon 2009). We then turned our focus to the commercialization of nano-materials and nano-enabled products, interviewing entrepreneurs and venture capitalists in Beijing and Shanghai (Parker and Appelbaum 2012), before turning to a case study of Suzhou Industrial Park (Appelbaum, Gebbie, Han, Stocking, and Kay 2016; Appelbaum, Parker, and Cao 2016, under resubmission; Cao, Appelbaum, and Parker 2013). Our China-related publications reflect a growing understanding that China's impressive S&T infrastructure does not always reflect what is happening inside laboratories, commercial incubators, or S&T parks.

> There are big problems in China's research environment. It is too focused on utilitarianism; many of the research policies, management systems, and appraisal methods are unreasonable; unfair allocation of funds.
>
> —ASSOCIATE PROFESSOR AT SHANGHAI JIAOTONG UNIVERSITY

One indicator of China's success in basic research is the rapid growth of nanotech publications, one area in which China is a rising star. China's share of global publications has risen sharply during the past two decades. China's output now approximates that of the U.S., although its impact (as measured by citations) is considerably lower (see, for example, Kostoff et al. 2006; Zhou and Leydesdorff 2006). As China's nanotech S&T system grew in strength and numbers beginning around the year 2000, international collaboration briefly declined because China's scientific community turned inwards in search of collaborators – a trend that has reversed itself in recent years. We speculate that as China ramped up its efforts at indigenous innovation,

DIRECT GOVERNMENT FUNDING FOR R&D AND COMMERCIALIZATION IN CHINA, OFTEN THROUGH THE MINISTRY OF SCIENCE AND TECHNOLOGY (MOST), GREATLY EXCEEDS PEER REVIEWED COMPETITIVE FUNDING FOR BASIC RESEARCH THROUGH THE NATIONAL NATURAL SCIENCE FOUNDATION.

it increasingly partnered internationally in terms of basic research – a trend that most likely contributed to a growing share (now exceeding 90 percent) of Chinese authored or coauthored English-language papers (Appelbaum, Parker, and Cao 2011; Mehta, Herron, Motoyama, Appelbaum, and Lenoir 2012).

Yet we also note that **the research environment in Chinese classrooms and laboratories is not always conducive to innovative thinking and scientific breakthroughs**. In an on-line survey of 731 STEM professors at the top 25 ranked Chinese universities, we found that while the majority reported being satisfied or very satisfied with their personal position, a high percentage were unsatisfied or very unsatisfied with the overall research culture in China, with many believing that the government should be much less involved with research. We also found that among those who held foreign degrees, four-fifths were from U.S. universities. Those who studied abroad saw a foreign degree as providing higher quality education and research opportunities, along with a better knowledge of the field. We speculate that as a growing number of Chinese expatriate scientists and engineers return to China, attracted both by China's growing global prominence and generous incentives provided by national and local governments, the Chinese research culture may improve as a result (Han and Appelbaum 2016).

The Chinese government has pursued several strategies to foster a better payoff between basic research and eventual commercialization. All of

Photo: IRG 2 collaborator Denis Simon (right) was one of 15 foreign experts selected to assist China's Ministry of Science and Technology conduct its first midterm review of the country's 15 Year Medium-to-Long-term Science and Technology Plan (MLP).

these have come with some costs (Appelbaum, Gebbie, Han, Stocking, and Kay 2016; Appelbaum, Parker, and Cao 2016, under resubmission). For example, the devolution of policy to the provincial and municipal levels has resulted in uncertainty, since rapid shifts in national priorities can (and often do) affect local funding. Direct government funding for R&D and commercialization, often through the Ministry of Science and Technology (MoST), greatly exceeds peer reviewed competitive funding for basic research through the National Natural Science Foundation. This both hampers the basic research needed for innovative advances in nanotechnology, and often results in *guanxi* (personal) relationships guiding decisions.

Other challenges that stifle S&T advances include a business culture that emphasizes personal connections (and thereby invites

China's Science, Technology, Engineering, and Mathematics (STEM) Research Environment

CHINESE FACULTY SURVEY

18,821 STEM faculty researchers from China's top 25 institutions of higher education (Figure 1) were contacted to participate in our study.

STEM FACULTY FROM TOP 25 CHINESE INSTITUTIONS WERE SURVEYED:

- Educational background
- Work history
- International and domestic collaborations
- Perceptions of the Chinese scientific environment
- Publishing and patenting
- First comprehensive study of Chinese STEM research environment
- 504 partial surveys; 374 completions (~10,000 sent)

FIGURE 1. University logos and locations of the top 25 institutions used in this study.

RESULTS

- Of the 731 completed responses, 16.7% of respondents hold their terminal degree from abroad, while 83.3% received domestic degrees from China.
- The US was the number one destination country, accounting for 37.7% of respondents.
- Of those who studied abroad, higher quality of research (77.7%) and higher quality of education (68.6%) were the primary reasons why individuals decided to study abroad.
- More job opportunities for one's self (46.3%) and family (44.6%) were the primary reasons why individuals chose to return to China.
- Higher percentages of homegrown scholars believed that foreign degrees provided better recognition from colleagues ($X^2_1=3.9$, $P=0.047$), better job opportunities ($X^2_1=4.8$, $P=0.03$), better professional networks ($X^2_1=9.5$, $P<0.01$), and better pay ($X^2_1=16.2$, $P<0.001$) than those who received degrees from abroad.
- Respondents are satisfied with their current positions and the overall research culture in their respective fields (Figure 2). However, they are largely unsatisfied with the overall research culture in China.
- A large percentage of individuals (40.3%) believe the government should have less involvement in China's research environment than it does currently.

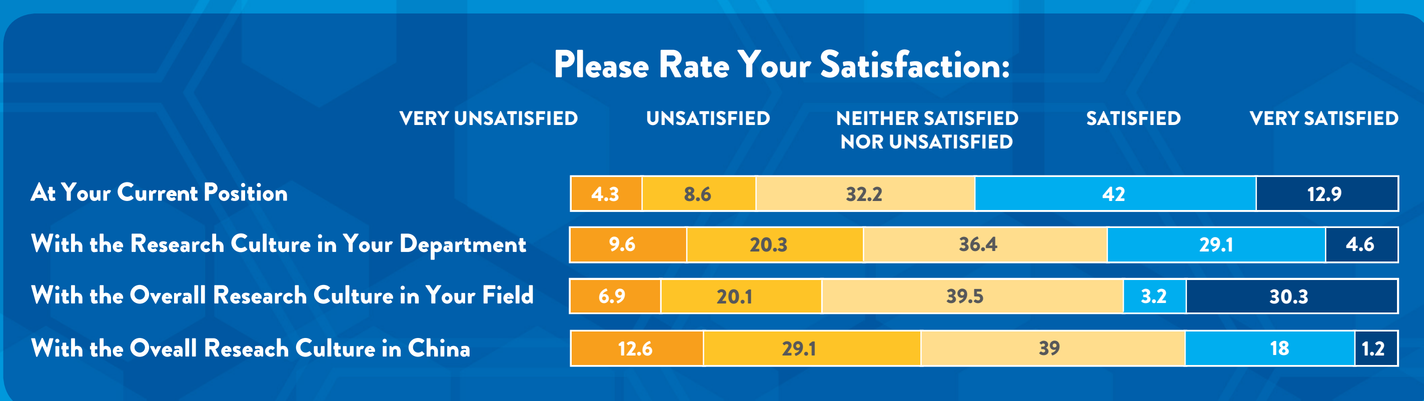


FIGURE 2. Percent of respondents who were very unsatisfied, unsatisfied, neither satisfied nor unsatisfied, satisfied, or very satisfied with their current position (N=723), the research culture in their department (N=718), the overall research culture in their field (N=717), and the overall research culture in China (N=721).

Photos: Suzhou Industrial Park

corruption); an educational culture that is based on rote learning and respect for authority, traits that inevitably carry over into research labs, discouraging innovative thinking; and a nascent venture capital environment that remains heavily dependent on state funding, which encourages low-risk (and thereby safe) investment strategies, while reinforcing the importance of personal connections.

Finally, China's state-owned enterprises (SOEs), which are favored when it comes to public funding, tend to be bureaucratic, risk (and hence innovation) averse, and beholden to party connections (Appelbaum, Parker and Cao 2016). These challenges were highlighted in a controversial (in China) 2010 editorial in Science, by Yi Rao and Yigong Shi, life science deans at Peking and Tsinghua Universities respectively, two of China's most prominent returnee scientists (Rao from Northwestern, Shi from Princeton):

Although scientific merit may still be the key to the success of smaller research grants, such as those from China's National Natural Science Foundation, it is much less relevant for the megaproject grants from various government funding agencies... This top-down approach stifles innovation and makes clear to everyone that the connections with bureaucrats and a few powerful scientists are paramount, dictating the entire process of guideline preparation (Shi and Rao 2010).

Science and Technology Parks, such as Suzhou Industrial Park (SIP), have been created to directly foster commercialization by providing supportive infrastructure and VC funding (Appelbaum, Gebbie, Han, Stocking, and Kay 2016; Appelbaum, Parker, and Cao 2016, under resubmission; Cao, Appelbaum, and Parker 2013). SIP has devoted an entire geographic sector, Nanapolis, providing shared resources and a collaborative environment intended to help young companies. Importantly, SIP provides a stable environment that reduces uncertainty and promotes nanotechnology development. We found that many of the nanotech startup firms we interviewed involved international partners, often through former Chinese expats (now returnees) with Silicon Valley connections. We also noted that SIP would not have become a nanotechnology hub without the support of the Chinese Academy of Sciences (CAS), which chose SIP as the site for its new Suzhou Institute of Nano-Tech and Nano-Bionics (SINANO).

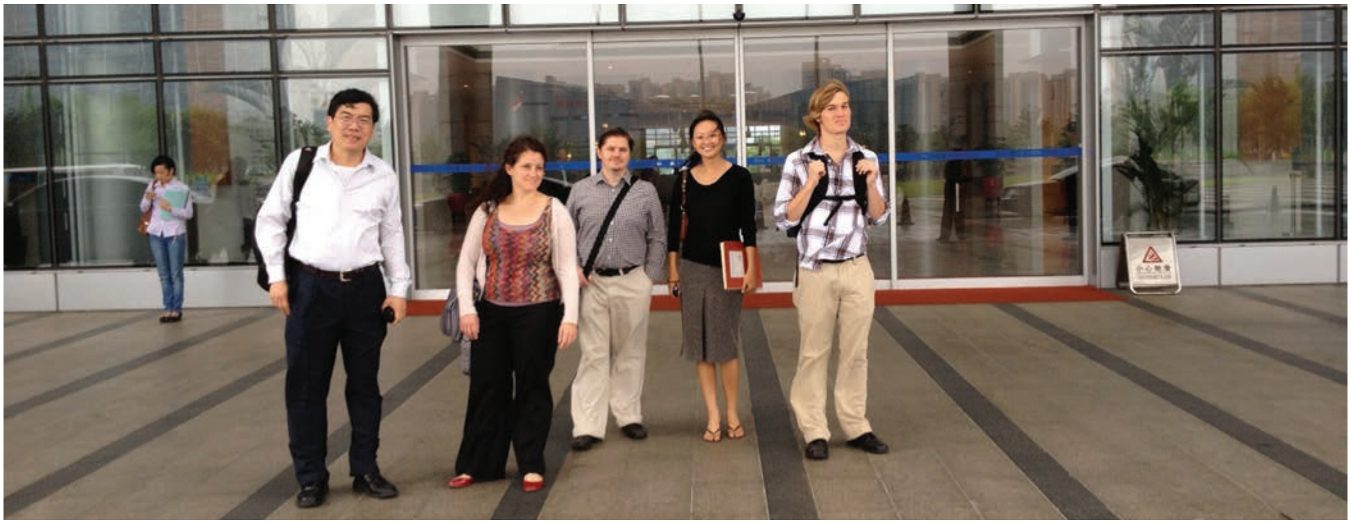


Photo: IRG 2 researchers arrive in China to interview scientists and entrepreneurs in Suzhou Industrial Park. From left to right, Cong Cao, Rachel Parker, Galen Stocking, Xueying (Shirley) Han, Matthew Gebbie.

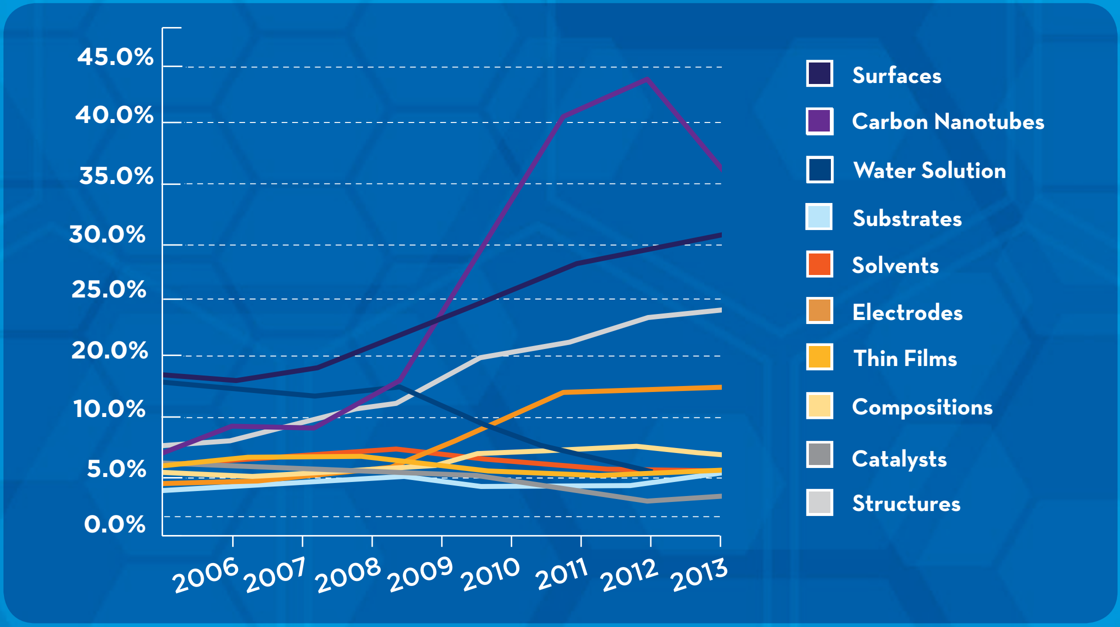
While the CAS might have originally been guided by a long-term strategic vision involving the intersection of biology and nanotechnology, the Suzhou municipal and Jiangsu provincial governments are more concerned with short-term local economic impacts, partly because showing an immediate payoff is seen as necessary to justify high levels of public investment (Cao, Appelbaum, and Parker 2013).

China has made some progress in terms of nanotech R&D, at least as indicated by patents. Drawing on our patent dataset (106,000 patent families based on EPO's PATSTAT), when compared with the top four countries in terms of global nanotechnology patent family counts, in 2013 China accounted for 27% worldwide; the U.S., 16%; South Korea, 13%; and Japan, 9%. China's share has nearly doubled since 2008. Our research also found that nearly two-thirds of China's nanotech patents were from the academic sector (universities or the Chinese Academy of Sciences), and that all but one of the top five most frequent nanotechnology patent applicants were from academic institutions representing China's most elite universities. **Only a sixth of all patents were found to be corporate, with roughly another sixth from government.** This suggests that the large majority of nanotechnology patents in China remain closer to basic research than to development, with relatively few pertaining to marketable consumer products – evidence that **China continues to face challenges in achieving its goal of transferring academic research into viable products** (Appelbaum, Parker, and Cao 2011; Parker and Appelbaum 2012). Moreover, an examination of China's patents indicates that the share of carbon nanotubes, surfaces and substrates has become more prominent among China's top ten patent areas (Figure 3). These are primarily areas that are fairly low on the nanotechnology value chain, providing materials that are incorporated in the products of (non-Chinese) multinationals. (One promising area is the growth of substrates, where our analysis suggests increasing activity in areas such as electrodes, electric batteries, and other battery parts.) **Emerging as a world leader in carbon nanotubes and graphene, at a time when these are becoming low-cost commodities, is unlikely to result in the indigenous innovation that China seeks to achieve**.

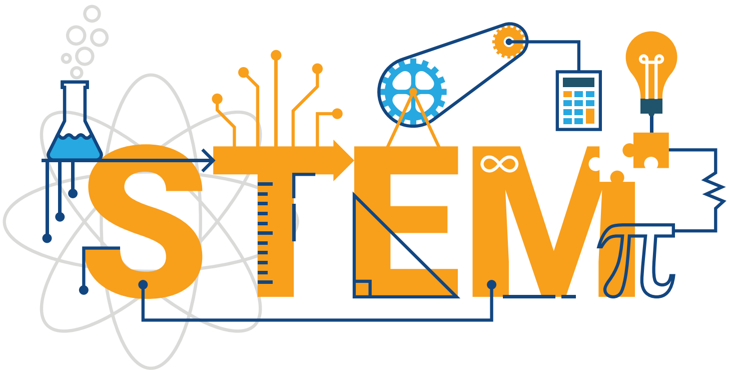
Nanotechnology-related R&D, however, remains spatially concentrated, resulting in limited technological spillovers that might contribute to the growth of regional R&D centers. Between 1986 and 2008, nanotechnology patents became concentrated on China's east coast, with the Beijing and Shanghai regions becoming increasingly dominant; the greater Shanghai region (which includes Jiangsu and Zhejiang provinces) had surpassed the Beijing–Tianjin region by 2007. When we analyzed the geographic distribution of patents within regions, we found the concentration to be small (around 20 km.), suggesting limited spillover effects. Patents originating in universities increased over the period, while those originating in industry stagnated, suggesting an **absence of technology transfer from university to industry**; academics typically lack the experience and resources to turn ideas into products (Motoyama, Cao, and Appelbaum 2013).

Finally, we also note that China's challenges in achieving indigenous innovation, in nanotechnology or other emerging technologies, have not discouraged U.S. business organizations (and the U.S. government) from raising concerns about China's intentions. In a well-publicized report issued by the U.S. Chamber of Commerce, entitled *China's Drive for Indigenous Innovation: A Web of Industrial Policies* (McGregor 2010), China was accused of engaging in "technology theft on a scale the world has never seen before" (p. 4), using junk patents to retaliate against companies that file IPR violation lawsuits against Chinese

FIGURE 3. PERCENTAGE OF PATENT FAMILIES THAT RELATE WITH THE TOP-10 TOPICS IN CHINESE NANOTECHNOLOGY PATENTING ACTIVITY BETWEEN 2003 AND 2014 (3 YEAR MOVING AVERAGE)



SOURCE: Appelbaum, Gebbie, Han, Stocking and Kay 2016



companies in foreign courts; using compulsory certification and standards requirements to make it difficult for foreign products to enter the Chinese market; requiring the disclosure of proprietary information in an effort to exclude foreign products from major Chinese markets; and via lax enforcement of IPR protections. China, in turn, is concerned that the U.S. is mainly seeking to maintain its superpower status, in the face of China's economic and geopolitical ascendance. We speculate that as China becomes less dependent on foreign multinationals for investment and innovation, and relies more on its growing middle class as a principal market for goods it produces, China will be increasingly free to use its economic and political influence to attempt to shape world events in its own interest. In other words, China – whose economic fortune has thus far been closely coupled to that of the U.S. and other advanced industrial nations – will be less dependent on such relations. China's growth trajectory seems clear; how this "great uncoupling" plays out geopolitically will depend in large part on the response of others (Appelbaum and Parker 2012).

UNITED STATES, MEXICO, ARGENTINA, BRAZIL: MARKET-ORIENTED APPROACHES TO HIGH-TECH DEVELOPMENT

The U.S. – unlike China – lacks a national strategy for science, technology, and industrial development. Yet the NNI provides an example of what has been termed a "stealth" industrial policy (Block 2008): government investment in nanotechnology was not shaped by market forces, but by the entrepreneurial efforts of senior level officers at the NSF and the White House, who built a supportive constituency among key stakeholders: OSTP and other federal agencies, congressional lawmakers, academic researchers, and industry executives. The NNI began as a top-down effort, incorporating participation from the bottom as the effort gained traction (Motoyama, Appelbaum, and Parker 2011). This approach

CHINA IS CONCERNED THAT THE U.S. IS MAINLY SEEKING TO MAINTAIN ITS SUPERPOWER STATUS IN THE FACE OF CHINA'S ECONOMIC AND GEOPOLITICAL ASCENDANCE.

CHINA – WHOSE ECONOMIC FORTUNE HAS THUS FAR BEEN CLOSELY COUPLED TO THAT OF THE U.S. AND OTHER ADVANCED INDUSTRIAL NATIONS – WILL BE LESS DEPENDENT ON SUCH RELATIONS.

proved to be highly successful in funding basic research, but, unlike in China, little has crossed the "valley of death" to fund product development.

Although the prediction of trillions of dollars in nanotech-driven commercial value was a major justification for the creation of the NNI, only a small amount of federal funding has been directed to the private sector through such programs as SBIR and STTR. **Funding basic research, while avoiding placing bets on specific products or even industrial sectors, reflects an underlying belief that market forces – not government fiat – should drive any federal S&T investment** (Appelbaum, Cao, Parker, and Motoyama 2012). The contrast with China is instructive. In China, nanotechnology's inclusion in five- and fifteen-year plans required it to be classified as a science, even though in practice it is funded as an engineering technology capable of yielding commercially viable products. In the U.S., although nanotechnology was sold to Congress based on its commercial potential, public funding continues to emphasize its role as a science in the basic research stage. Unlike China, there is no central planning apparatus to translate NNI successes into a sustained effort to promote economic development (Appelbaum, Cao, Parker, and Motoyama 2012).

MEXICO

Mexico, Brazil and Argentina lack strong central nanotechnology policies. Mexico is highly dependent on the research interests of its foreign collaborators, which do not necessarily coincide with the Mexican government's desire to advance its economic growth through high-tech development. Our Mexico research was supported by two bi-national grants, from the University of California (UCMEXUS) and Mexico's Science and Technology Foundation (CONACYT). These awards facilitated collaboration with two colleagues from the Doctoral Program on Development Studies at the University of Zacatecas (Guillermo Foladori and Edgar Záyago Lau), which in turn enabled us to create a larger network of Latin American scholars in Mexico, Brazil, and Argentina. Our research strategies included crawling Mexican nanotech research center websites, surveying policy-related efforts to foster US-Mexico nanotech partnerships, and gathering publication and patent data about Mexican nanotech firms. We subsequently developed a methodology, based on OECD indicators and global value chain analysis, to permit a comparative analysis of different countries' nanotechnology policies.

As with the U.S. and China, the Mexican government views nanotechnology as a priority area for S&T development. The Special Program of Science and Technology, part of Mexico's National Development Plan (2001–2006), identified nanotechnology as a strategic area worthy of a national program. Nanotechnology was later identified as one of nine priority areas for S&T development, in the Special Program of Science, Technology and Innovation (2008–2012). To foster S&T advances, Mexico has created a national research network, constructed two national laboratories, developed S&T parks, and established a Bi-National (U.S.-Mexico) Sustainability Laboratory (Záyago Lau, Frederick, and Foladori 2014). By 2010, there were more than sixty universities or public research centers in Mexico with nanotechnology research and development programs, involving some 500 researchers (Foladori, Figueroa, Záyago Lau, and Invernizzi 2012).

To evaluate the payoffs of nanotechnology, we created a comprehensive inventory of Mexican

Innovation Pathways of Developing Countries in Emerging Technologies: The Case of Nanotechnology in Argentina and Brazil

FIGURE 4. NANOTECHNOLOGY PUBLICATIONS AND PATENTS IN ARGENTINA, BRAZIL (1990-2012)

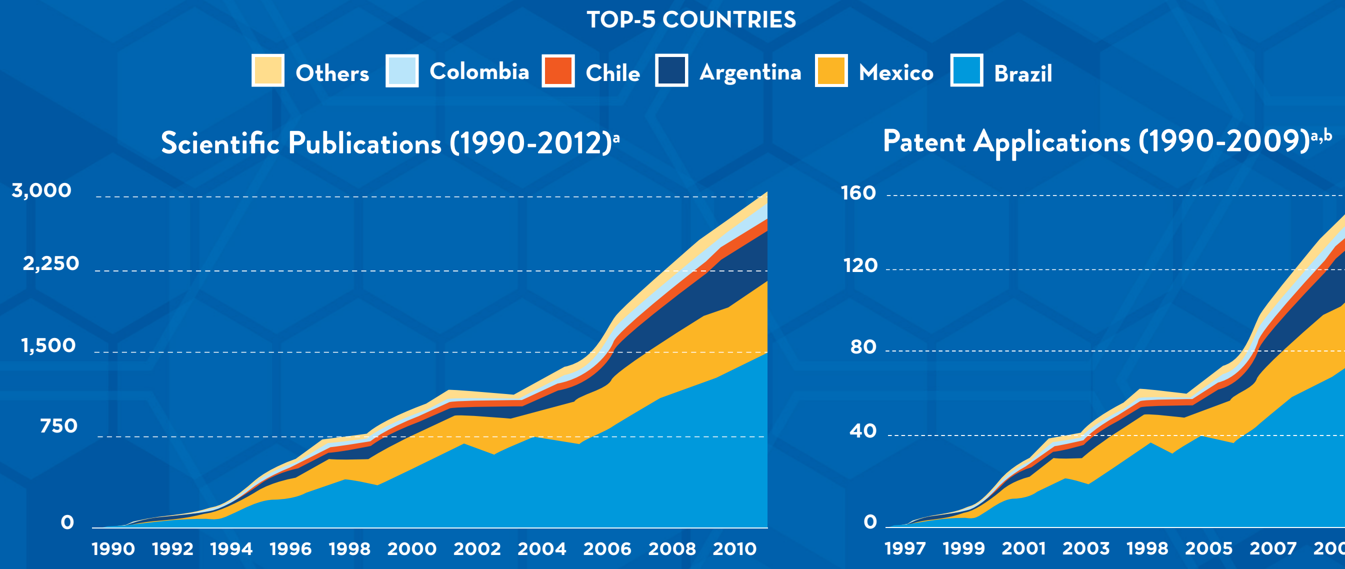


FIGURE 5. CORPORATE ACTIVITY IN NANOTECHNOLOGY IN ARGENTINA, BRAZIL (1990-2012)

Nanofirms[c]		Corp. publications[a]	Corp. patents[a]
ARGENTINA	41	4 Firms 11 Publications (2006-2012)	4 Firms 5 Patent Apps. (2003-mid 2010)
BRAZIL	165	51 Firms 312 Publications (1991-2012)	73 Firms 165 Patent Apps. (1997-mid 2010)

a. Source: Georgia Tech Global Nanotechnology database. b. All patent offices. c. Based on all sources available tow this research.

♦ 17 nanotechnology case study firms have been conducted addressing dimensions such as innovation sources, technology focus, partnerships and internationalization.

RESEARCH FOCUS:

This research investigates the innovation pathways that developing countries follow in emerging technologies and focuses on nanotechnology in Argentina and Brazil, leaders in this emerging field in Latin America. The project draws mainly on interview and company visits, company website and document analysis. Seventeen interviews were conducted with companies in nanobiotech, new materials, energy storage, among others.

PRELIMINARY FINDINGS:

- Diverse firm trajectories with predominant role of the scientific sector and universities.
- Market focus is generally on mature markets and technology with narrow market definitions.
- There are potential issues in S&T system-industry interactions.
- Policy and economic contexts are generally not conducive for corporate R&D.

ALTHOUGH UNIVERSITIES IN ARGENTINA AND BRAZIL REWARD PATENTING, AND FIRMS CAN SOMETIMES DRAW ON RESEARCH DONE BY THEIR FOUNDERS, THE ACADEMIC SECTOR DOES NOT GENERALLY FACILITATE FACULTY ENGAGEMENT WITH STARTUP COMPANIES.

nanotechnology companies. Among the 139 firms we were able to identify, the largest industrial sector involved the manufacture of chemical products (43 percent). Overall, 52 percent of Mexico's nanotech firms produced final products, ranging from clothing and sports equipment to materials for use in construction; 15 percent produced nano-materials, 30 percent nano-intermediates, and 4 percent nano-related instruments. As with China, firms tended to be geographically concentrated, primarily in the Mexico City region and the northern state of Nuevo Leon (Appelbaum et al. 2016). We also analyzed nearly 4,500 nanotech-related scientific publications over the period 2000-2012, in which at least one author had a Mexican institutional affiliation (roughly half had at least one foreign co-author). **We found that while the number of publications increased more than fivefold over the period, all but a handful originated in academic institutions**, with three out of five publications coming from the National Autonomous University of Mexico (UNAM), CONACYT Centers, or the National PolyTechnical University (IPN). **We conclude that practically no research is being conducted by the business sector, and that scientific production is heavily concentrated in Mexico's center and northern regions** (Záyago Lau, Frederick, and Foladori 2014).

In sum, Mexico has performed poorly when compared with most of the 24 countries surveyed by the OECD. Despite prioritizing nanotechnology as a priority area for development in its S&T plans, Mexico has done little to actually implement those priorities. **Yet even though Mexico invests less than 0.5% of GDP in research and development, and lacks a nanotechnology development strategy, it nonetheless ranks eighth among OECD countries in terms of the number of nanotech companies** (Foladori et al. 2015).

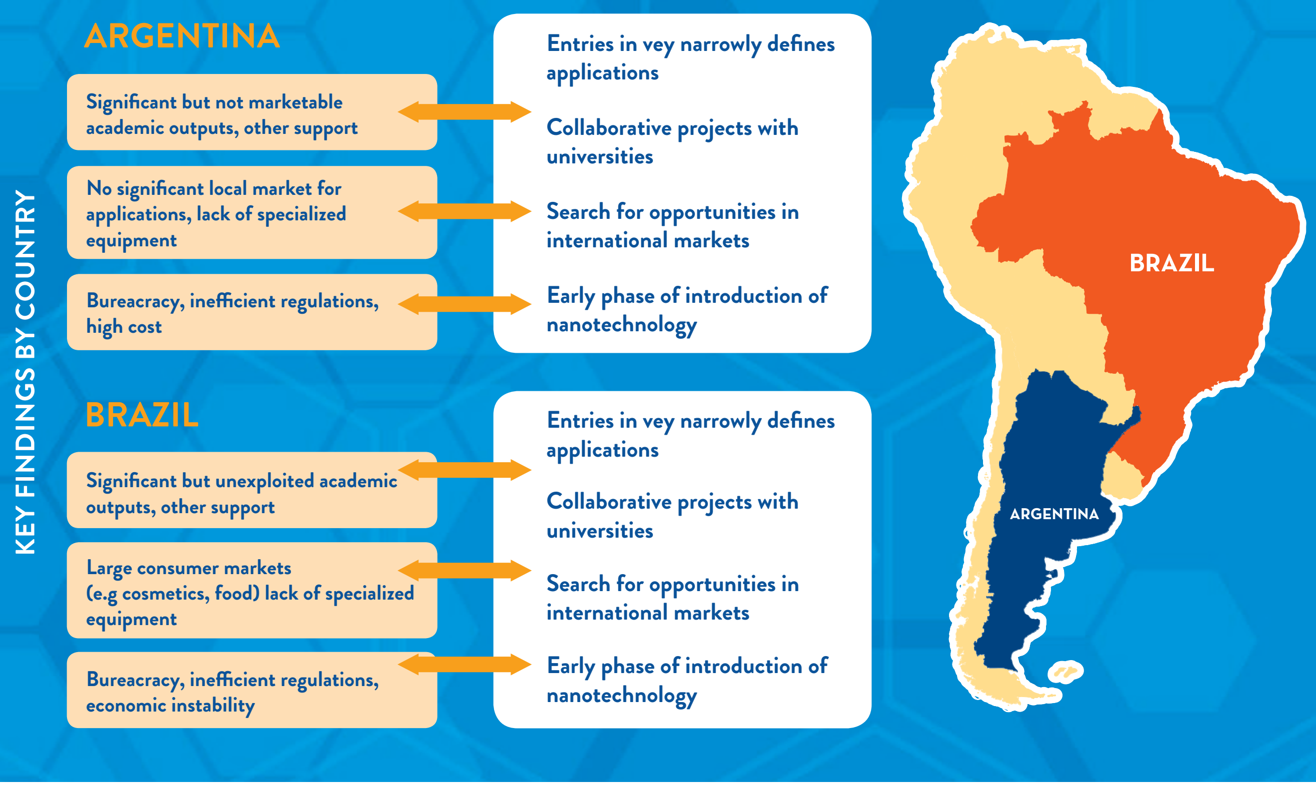
BRAZIL AND ARGENTINA

During the first decade of the 21st century, many other Latin American countries included nanotechnology as a strategic area of their S&T policies in search of increased competitiveness. This was the case not only of the more developed countries such as Brazil and Argentina, but also of others (for example, Uruguay, Ecuador, and Colombia, Peru, Venezuela, and some small Central American countries). In collaboration with colleagues from Georgia Tech, Duke University, and the Federal University of Paraná, Brazil, we extended our research to Brazil and Argentina. Brazil is by far the most advanced, at least in terms of nanotechnology publications and patents, followed by Mexico and Argentina; these three countries outpace all others in Latin America. As elsewhere, basic nanotech research had begun as early as the 1980s, long before public policies were introduced to advance nanotechnology. Yet – as was the case in China – when the U.S. launched the NNI in 2000, it boosted the development of nanotechnology throughout Latin America.

The 1998 World Bank's Millennium Scientific Initiative, launched in Chile, was designed to promote developing country centers of S&T excellence. Brazil responded aggressively, ramping up public nanotechnology expenditures. Brazil's Ministry of Science and Technology sought (unsuccessfully) to establish the basis for a national nanotechnology policy; ultimately, 21 National Institutes of Science and Technology (out of 123) were involved in nanotechnology. In Argentina, the Secretary of Science and Technology established nanotechnology as one of the priority areas for public funding in 2003, with networks or working groups organized in such fields as molecular nanotechnology, nanomaterials, micro-electromechanical systems (MEMS) and Nano-electromechanical systems (NEMS), bio-materials, and nanomedicine. **Yet Brazil and Argentina often failed in their efforts to be innovative: their business communities lack scientific research experience, while their scientists lack business experience.** Firm-level data show that businesses tend to begin with simpler, multi-purpose nanotechnologies (such as nano-emulsions and nano-particles) that are distant from becoming viable commercial applications. Nor have trade unions been involved in these efforts: workers have not been trained to work in nanotech-related fields, and there has been little or no attention to health and safety issues (Foladori, Figueroa, Záyago Lau, and Invernizzi 2012).

In sum, through bibliometric and patent analysis, analysis of policy documents, and interviews with company managers in Argentina and Brazil, we found that general economic and social factors

FIGURE 6. NANOTECH INNOVATION IN LATIN AMERICA: ARGENTINA & BRAZIL EMERGING AS NANOTECH LEADERS (KAY)

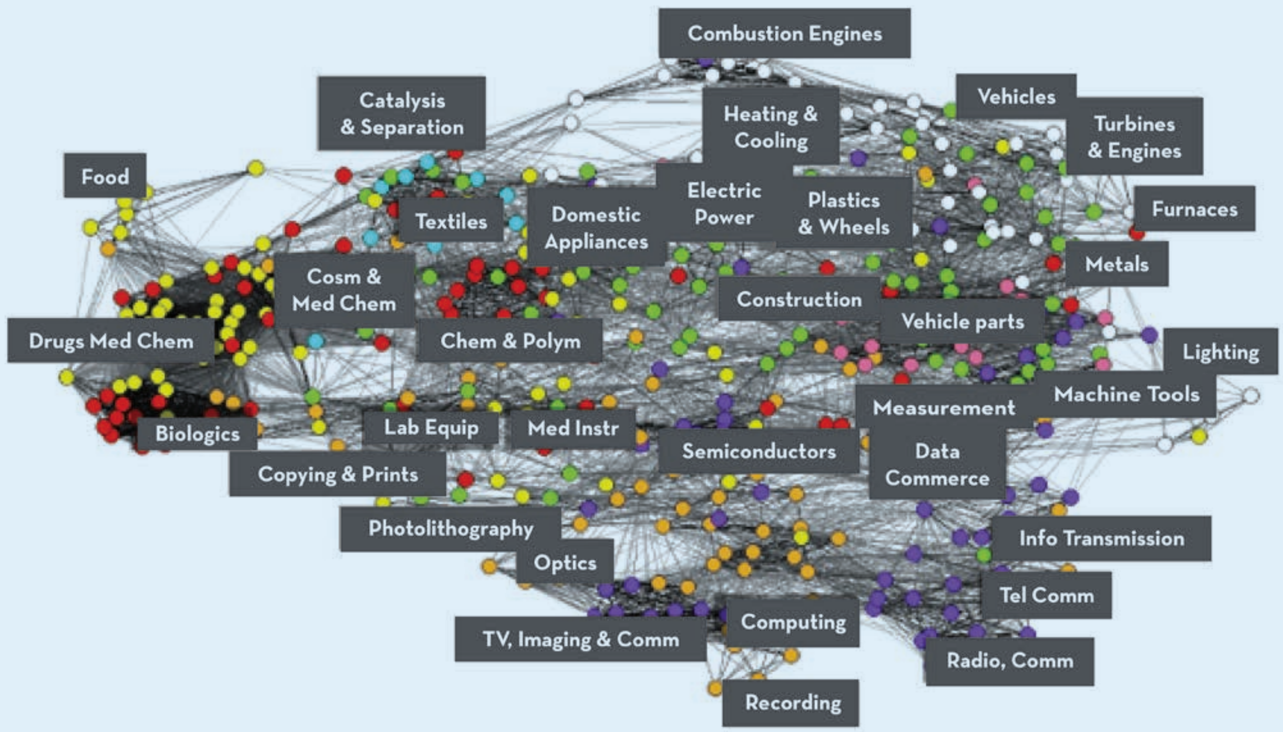


(such as taxes and bureaucracy) impact negatively on the research-to-commercialization pathways of nanotechnology companies. **Although these countries have well-developed scientific and academic sectors, weak ties with industry impede commercialization of research and exploitation of local knowledge.** A lack of nanotechnology-specific risk capital and equipment sectors make scientific knowledge exploitation more difficult as well, but field-specific factors tend to be secondary.

While businesses may value the scientific knowledge and expertise they find in universities and research centers, they struggle to effectively tap into such resources. Although universities reward patenting, and firms can sometimes draw on research done by their founders, the academic sector does not generally facilitate faculty engagement with startup companies.

While government funding for nanotechnology has been relatively modest in both countries, it may have played an important role in signaling an opportunity for both the academic and private sectors. Brazil in particular – at least until the current political and economic crisis – has been able to generate, despite its relatively unfavorable business context, the conditions for a nascent nanotechnology sector (Kay, Appelbaum, Youtie, and Shapira *in preparation*).

FIGURE 7. PATENT OVERLAY MAPPING: VISUALIZING TECHNOLOGICAL DISTANCE



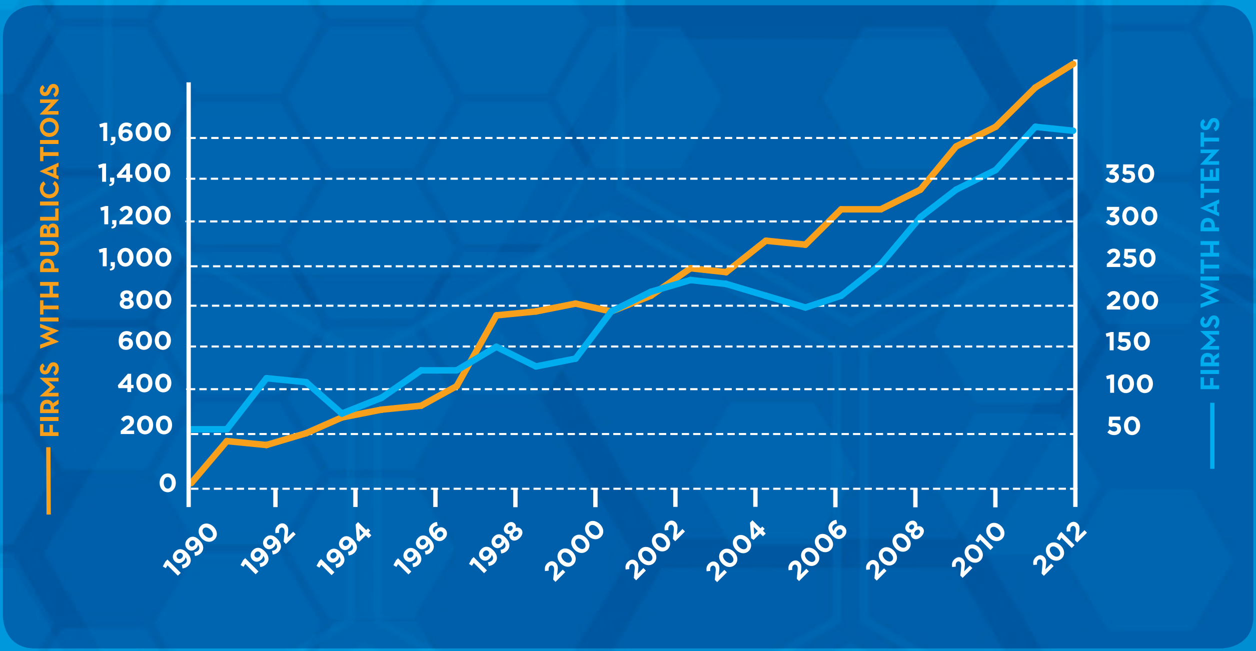
Journal of the Association for Information Science and TechnologyVolume 65, Issue 12, pages 2432-2443, 7 MAY 2014 DOI: 10.1002/asi.23146http://onlinelibrary.wiley.com/doi/10.1002/asi.23146/full#asi23146-fig-0002

2. Development of Original Data Analysis Technology

IRG 2 developed innovative methods for ransacking and analyzing large datasets, drawing on existing data sources and repositories while developing new ones. We applied these methods to a number of policy issues related to emerging technologies and innovation, collaborating with colleagues at Georgia Tech to develop an original approach to patent mapping that involves creating a global map of the innovation landscape with data overlays representing different levels of activity and concentration (see, for example, Kay et al., 2014, and Kay et al., 2016 *in press*). We developed our own global patent database with 70+ million patent records, integrating Thomson Reuters and European Patent Office (EPO) data with our own hardware and software. Our approach received widespread attention in the scholarly and popular press. It was featured on the NSF's home page (Jan. 24, 2014) as well as its *Science 360* newsletter (Jan. 16, 2014); the MIT *Technology Review* (MIT 2013), and *Wired UK* (Wired 2014).

These methods and data were used in a number of research projects: the development of graphene (Kay et al., 2015), energy storage applications in China (Kay and Youtie 2013), the global development of dual-purpose, military and civilian technologies (Kay & Mehta, *in preparation*), patterns of NSF funding across a number of

FIGURE 8. GLOBAL EMERGENCE OF THE FIELD OF SYNTHETIC BIOLOGY



6,882 unique firms with synbio publications and 2,005 firms with synbio patents have been identified globally since 1990

SIGNIFICANTLY, WE FOUND THAT NEARLY HALF (48 PERCENT) OF FOREIGN PHD STEM STUDENTS WOULD LIKE TO STAY IN THE U.S. UPON GRADUATION, WHILE ONLY 12 PERCENT WANT TO LEAVE; 40 PERCENT WERE UNDECIDED.

scientific disciplines in the U.S. (Huang et al., *in preparation)*, and the impact of CNS-UCSB activities (Kay, *in preparation*).

We also examined the global emergence of the field of synthetic biology, finding as much as four times greater global synthetic biology patenting activity in the private sector compared with previous research, leading to suggestions for ways that future research could properly account for R&D in this emerging sector. Our research also unveiled clear patterns of firm specialization in basic knowledge, enabling technologies, and industry and consumer applications; we also noted the rising importance of Chinese and South Korean companies in the emerging biotech field (Kay and Woolley 2014). Finally, these methods were employed to analyze the development of nanotechnology in Argentina and Brazil (previously discussed), as well as research into synthetic biology (Kay and Woolley *in preparation*).

3. The Circulation of S&T Elites

A third major focus of our research has been on the impact of foreign STEM graduate students in U.S. universities. **This is important, we argue, both because of its effect on international collaboration (when and if foreign students return to their home countries), and because of a lost talent pool if they do eventually repatriate, a concern that has implications for U.S. visa and immigration policy.**

International students, studying in the U.S. on temporary visas, accounted for nearly two-fifths (39 percent) of all U.S. granted PhDs in Science, Technology, Engineering, and Mathematics

(STEM) fields in 2013 – a proportion that has doubled over the past three decades (figure 1). If current trends continue, international students will overtake domestic students by the year 2020. Among international students, in 2013 nearly seven out of ten (69 percent) came from China, India, South Korea, and Taiwan, with China the leading country of origin, accounting for nearly three out of every ten international graduate students (Han and Appelbaum 2016, forthcoming). The U.S. remains the first destination choice for international students, although its share of the global total has declined from 28 percent in 2001 to 19 percent in 2012.

The U.S. STEM educational system is intimately tied to issues of global competitiveness and American immigration policy. Foreign scientists and entrepreneurs play important roles in the U.S. economy: they create new businesses and jobs, and are a key source of innovation, accounting for more than half of the international patents filed by U.S.-based transnational corporations. Such contributions are widely recognized in other countries, with more then a dozen countriesffering tax breaks, grants, academic salaries, and other incentives to convince their most talented ex-pats to return (Han, Stocking, Gebbie, and Appelbaum 2015: Table 1). In a bibliometric analysis of the most highly cited (top one percent)

FIGURE 9. SCIENTIFIC PUBLICATION TRENDS FOR TOP-10 COUNTRIES (1990-2013)

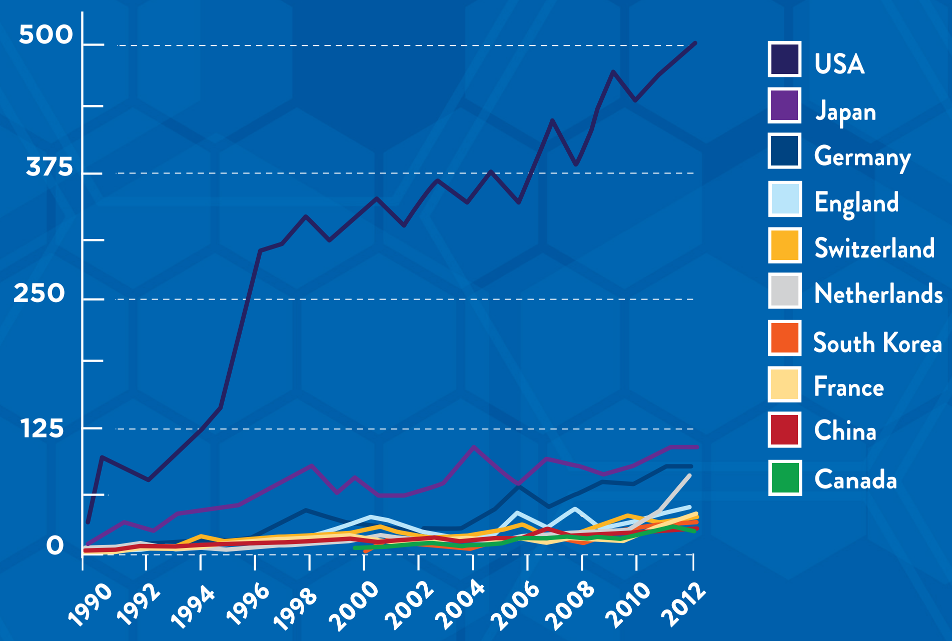
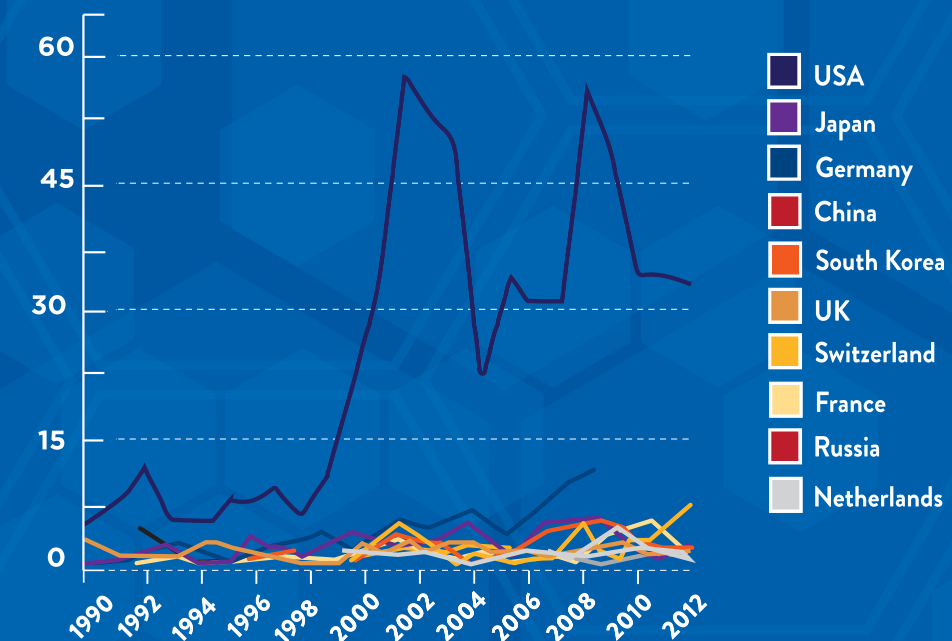


FIGURE 10. PATENTING TRENDS FOR TOP-10 COUNTRIES (1990-2013)



nanotechnology papers published between 1999 and 2009, we found that over the entire period, roughly two out of three authors were foreign-born, far exceeding the prevalence of the foreign-born within the American scientific workforce (roughly one out of four). The U.S. and China accounted for the largest share of corresponding authors (41 percent and 18 percent, respectively), as well as the largest share of co-authored papers (30 percent and 34 percent) (Walsh 2015).
To better understand the educational experience of foreign STEM students in U.S. universities, we first conducted a survey at UCSB. (The 2014 *Academic Ranking of World Universities* ranks UCSB's Engineering/Technology and Computer Science seventh in the world; its Materials Department is ranked second in the U.S., behind MIT, by *U.S. News & World Report*.) 166 international students responded to our survey (a 42 percent response rate), representing 32 different countries; we also conducted 12 follow-up interviews. **The U.S. is clearly seen as an attractive country for scientists and engineers; its university system continues to attract some of the world's top technical talent. We found that nine out of ten international students who wished to pursue non-academic careers (in industry or with an NGO) preferred to remain in the U.S. after graduating. Yet at the same time, many of our respondents noted that the U.S. is no longer an automatic first choice, especially for students from European countries who are able to study at universities throughout the EU** (Han, Stocking, Gebbie, and Appelbaum 2015).

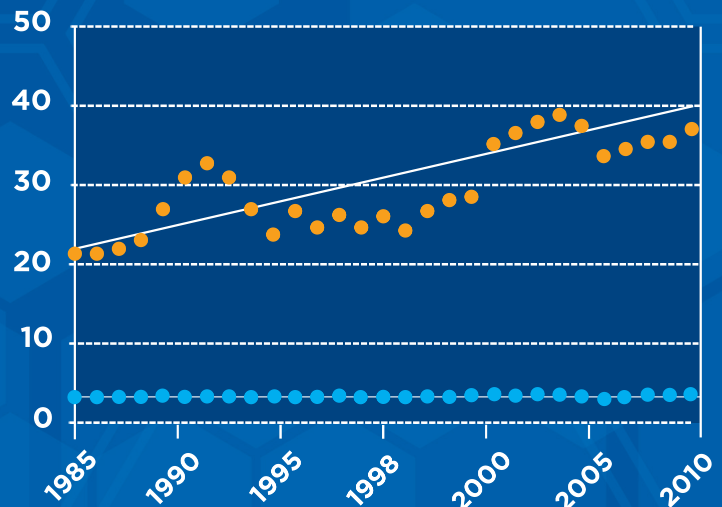
We then extended our survey to include both domestic and international graduate students in STEM fields at the top ten U.S. colleges and universities, in terms of international student enrollment (Han and Appelbaum 2016). 114 departments, across the 10 institutions, met our selection criteria; we were ultimately able to obtain email addresses for students in all but 36 departments. We surveyed nearly 16,000 students, resulting in a usable sample of 2,322 responses (15 percent). Two-thirds were U.S. citizens or permanent residents; the remaining third came from 74 different countries. China was, not surprisingly, the leading country of origin, accounting for 30 percent of all international respondents, followed by India (26 percent). No other country accounted for more than 4 percent of our respondents. 84 percent of all international students reported that higher quality of education was the main reason they chose to study in the U.S. (in fact, more than a third came to study with a particular faculty member), followed by perceived future career opportunities (74 percent). Yet nearly nine out of ten reported facing a variety of cultural, social, financial, academic, and sometimes even racial challenges in their U.S. studies.

Significantly, we found that nearly half (48 percent) would like to stay in the U.S. upon graduation, while only 12 percent want to leave; fully 40 percent were undecided. The perception of future job opportunities was the most important reason given by those who wanted to stay. We also found that international students were significantly more likely to seek employment with a company than their domestic counterparts, and significantly less likely to want to work for a governmental agency; domestic students, by way of comparison, preferred academic research to business employment.

These findings have major policy implications, since they strongly suggests that if visa barriers were eased, as many as nine out of ten foreign STEM PhD graduates would remain, providing a rich talent pool – graduates in whom considerable investment has been made by leading U.S. universities. As we have noted elsewhere,

FIGURE 11. INTERNATIONAL STEM EDUCATION

FIGURE 12. PERCENT SHARE OF TEMPORARY VISA HOLDERS (%)

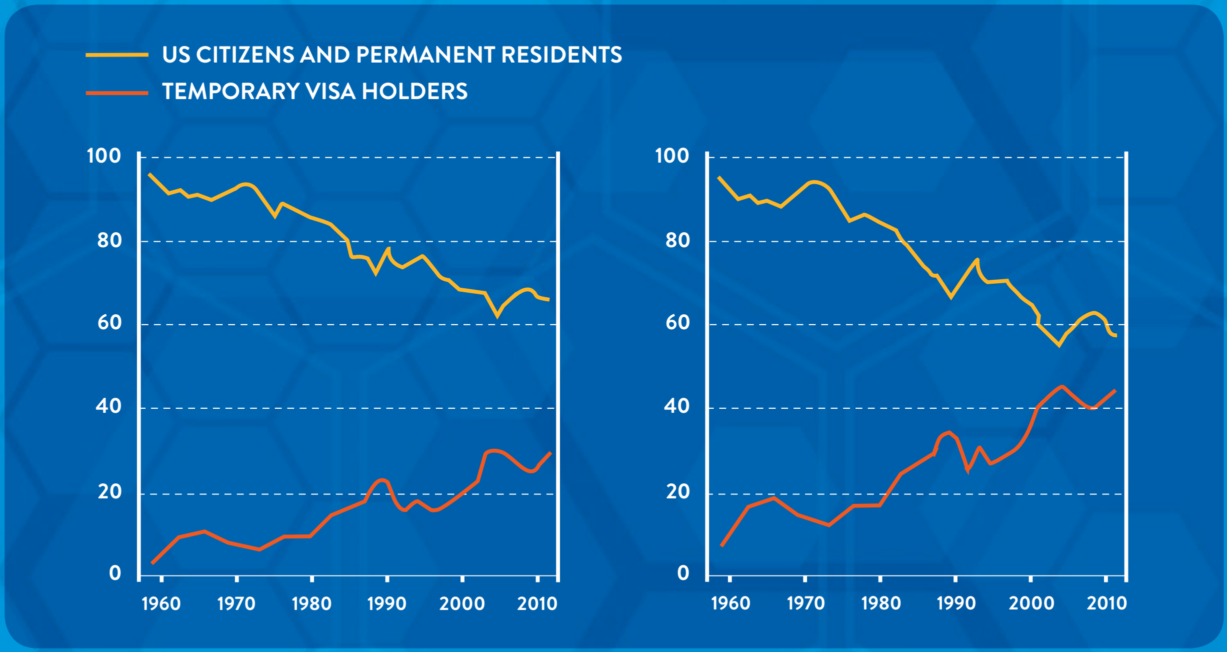


Will they leave, thereby contributing to the economies of other countries, or remain and become part of the skilled, innovative U.S. workforce? The Chinese government, for example, recognizes the importance of repatriating its many talented expats who are enrolled in top STEM PhD programs throughout the U.S., Europe, and Japan and provides professional and financial incentives to attract returnees through its Thousand Talents Program and Thousand Young Talents Program. Given that international students are well on their way to becoming a majority of U.S. STEM doctoral students, this trend could have a considerable impact on the U.S. talent pool (Han and Appelbaum, 2016 forthcoming).

Among ten advanced economies, the Business Roundtable (2015: 5) ranked the U.S. second to last "in establishing reliable ways to hire high-skilled foreign nationals." We have recommended various measures to increase the retention of the most qualified foreign STEM PhDs, urging Congress to pass the following legislation in full (Han and Appelbaum 2016):

- STAPLE Act ("Stopping Trained in America PhDs from Leaving the Economy"), which would exempt foreign-born students with US. PhDs in STEM fields from H-1B numerical limitations (U.S. Congress, 2015a)
- Immigration Innovation ("I-Squared") Act, which increases the H-1B annual cap from 65,000 to between 115,000 and 195,000, depending on demand and market conditions (U.S. Congress, 2015b)
- STEM Jobs Act of 2015: Provides up to 55,000 visas each fiscal year to immigrants who received doctorate degrees in STEM from U.S. institutions of higher education (U.S. Congress, 2015c)

FIGURE 13. DOMESTIC AND INTERNATIONAL STUDENTS AS PERCENTAGES OF ALL U.S. DOCTORAL RECIPIENTS, AND STEM DOCTORAL RECIPIENTS, 1957/58 – 2012/13



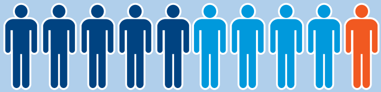
NOTE: Data from the National Science Foundation Survey of Earned Doctorates.3

- Startup Act of 2015: Creates a new visa for up to 50,000 international students per year who graduate with master's degrees or PhDs in STEM from U.S. institutions of higher education (U.S. 2015d)
- Fairness for High-Skilled Immigration Act of 2015: Eliminates the country-based restrictions on employment visas and reduces the country-based restrictions on family visas, although the total number of visas given in any fiscal year would remain unchanged (U.S. 2015e)

4. Sustainable and Equitable S&T Development

Do nanotechnologies hold great promise for emerging economies? To explore this potential, in November 2009 we organized a CNS-UCSB international conference at the Woodrow Wilson International Center for Scholars in Washington, D.C. (http://nanoequity2009.cns.ucsb.edu/index-2.html.) More than sixty participants came from the U.S., EU, China, India, Brazil, Mexico, South Africa, and Uganda, and included leading scientists and engineers, government and NGO activists, social scientists, and business entrepreneurs. The conference explored new pathways for technology-based solutions to problems related to four key issue areas: energy scarcity, finite clean water sources, diminished availability of sustainable food resources, and pandemic diseases. Discussion, dialogue, and break-out sessions were facilitated by the Meridian Institute, an organization committed to increasing a more equitable North/South dialogue. The conference sought to:

- Assess the scale of appropriate technology: should the emphasis be on small-scale projects that are grounded in local communities, or larger government-led projects aimed at addressing the needs of large numbers of people?
- Evaluate strengths and barriers for effective international development through technological advances – moving beyond technology transfer



5 OUT OF 10 STUDENTS WANT TO STAY IN THE US

4 OUT OF 10 STUDENTS ARE UNDECIDED / DO NOT KNOW

1 OUT OF 10 STUDENTS WANT TO LEAVE THE US

FIGURE 14. PERCENTAGE OF INTERNATIONAL RESPONDENTS WHO INDICATED THEY ARE:

- **Hoping to stay in the US upon graduation (48%)**
- **To leave the us (11%)**
- **Or are undecided/do not know (41%)**

- Highlight technological advances related to nanotechnology and other emerging technologies related to energy, the environment, and healthcare technologies with potential use in development

- Identify new models for development and for tapping the knowledge economy for economic development

- Discuss resources, capacity building and preparedness for technology assimilation in developing countries (linking/networking technologists and NGOs)

These issues are thoroughly discussed in *Emerging Economies, Emerging Technologies: Can Technology Make a Difference in Development?* (Parker and Appelbaum 2012a; see also Parker and Appelbaum 2012b; Appelbaum and Parker 2012). Among some conclusions:

- ***Energy/Environment.*** It sometimes is important to build national capabilities, independent of foreign expertise, in order to break down the traditional North/South relationship of technology transfer. While government funding and higher education initiatives are one way to help scholars from emerging economies build a national capacity for innovation, it was also recognized that there is a role for small-scale projects (such as portable LED lighting) that help people directly in their everyday lives. Even large-scale government efforts to introduce new energy technologies often move slowly; in China, for example, where most of the energy is derived from coal, the need to increase efficiency needs to be balanced with the economics of converting to more sustainable sources.

- ***Water.*** While nanotechnology has the potential to provide clean water through cheaper and faster diagnosis of contaminants, removal of chemical contaminants, and aiding in the disinfection and desalination, a more fundamental problem is that access to clean water is often not regarded as a basic human right. The greatest need and potential lies with affordable and easy-to-use diagnostic testing for contaminants. Yet a "one size fits all" approach to clean water will not work; solutions must reflect local needs and circumstances. What is needed is a database of appropriate technologies to address the needs of particular situations.

- ***Food Security.*** There are a number of food- and agriculture- related nanotechnologies, such as sensors capable of detecting plant and crop disease or measuring pest and fertilizer levels, ensuring food safety, and even increasing the macro and micronutrient levels of certain foods. Yet at the same time, there is little public awareness about what these products are and what potential risks they might involve. Without a deep-rooted understanding of lessons from the past, the cultural context, and a strong consideration of the needs as articulated by the intended beneficiaries, nano-enabled food technologies are not likely to add value.

- ***Health.*** Nanotechnology holds the promise of targeted drug delivery systems that create new cancer treatment therapies, peptides for biopharmaceuticals, sensors and chips that contain thousands of nanowires capable of detecting proteins and biomarkers at the site of tumors, and gold nanoshells for dual imaging and cancer therapies. Yet there is considerable risk involved in the emerging field of nanomedicine, and the public is uninformed and uninvolved in risk assessment. **Moreover, health-related problems have more to do with harm and the inequitable distribution of healthcare resources, rather than requiring technological breakthroughs.**

B. Broader Impacts - Contributions to Society.

Organized and hosted (at the Woodrow Wilson Center for International Scholars in Washington, D.C.), "Emerging Economies/Emerging Technologies: (Nano)Technology for Equitable Development" (November 4-6, 2009) (discussed above). The conference also resulted in the book *Emerging Economies, Emerging Technologies: Can Technology Make a Difference in Development?* (Parker and Appelbaum 2012).

IRG 2's research on China was heavily cited in the Naval Postgraduate School and Northwestern University's Project on Advanced systems and Concepts for Countering WMD (PASCC) Report, *Nanotechnology in a Globalized World: Strategic Assessments of an Emerging Technology* (Clunan and Rodine-Hardy 2014: 44-57).

IRG 2, in collaboration with IRG 3, produced an interactive website – California in the Nano Economy – that uses a value chain approach to present California's footprint in nanotechnology.

The website identifies firms working in each stage of the value chain, from nanomaterials through

Emerging Economies, Emerging Technologies: Can Technology Make a Difference in Development?

(Appelbaum and Parker, eds.)

Photo: "Emerging Economies/Emerging Technologies: (Nano) Technology for Equitable Development" at the Wilson Center in Washington, DC

BECAUSE OF THEIR EFFECT ON INTERNATIONAL COLLABORATION WHEN AND IF FOREIGN STUDENTS RETURN TO THEIR HOME COUNTRIES), AND BECAUSE OF A LOST TALENT POOL IF THEY DO EVENTUALLY REPATRIATE, THE DECISIONS OF FOREIGN STEM PHD STUDENTS ARE A CONCERN THAT HAS IMPLICATIONS FOR U.S. VISA AND IMMIGRATION POLICY.

end-markets; provides profiles of each firm; analyzes the impact of value chain dynamics at each in terms of policies, risk, perception, and competitiveness; evaluates how these are linked together in California; and compares California with competing geographies. Additional information is provided on degree and certification programs in the U.S. related to nanotechnology, in order to better identify the potential scope of the U.S. nano-related workforce. More information is available at: http://californiananoeconomy.org/

Appelbaum, Richard (2013) "Innovative and Responsible Governance of Converging Technologies," appears in chapter 10 of Mihail Roco, *Innovative and Responsible Governance of Converging Technologies* (OECD Workshop Report on "Bridging the Divide Between Policy, Practice and Research on Public Engagement on Nanotechnologies," http://www.wtec.org/NBIC2/Docs/FinalReport/Pdf-secured/NBIC2-FinalReport-WEB.pdf). We contributed the section "Contribution of Knowledge and Technology to Sustainable Development in Emerging Economies" (pp. 389-392), which summarized some of the findings in our book *Emerging Economies, Emerging Technologies*, and made two policy recommendations: "The U.S. should be investing more in bringing promising technologies to fruition, not just in terms of basic research, but also in terms of commercialization. **The U.S. Government's support for small business innovation and commercialization (SBIR and STTR) programs should be significantly expanded. Additionally, U.S. visa policies need to be revised. Because U.S. universities remain among the best in the world for scientific innovation, a substantial percentage of science and engineering students enrolled in U.S. graduate programs come from other countries" (pp. 391-392)**.

Although not a central focus of IRG 2, we have contributed to the discussion of health and safety issues. One project explored the extent to which the health and environmental risks of nanomaterials are researched in Mexico (Záyago Lau, Frederick, and Foladori, 2014). After creating a database of all SCI nanotech articles published by Mexican authors over a twelve-year period, key words were used to identify those associated with research on nanomaterial risk, and a web-based search was conducted to identify all the researchers who work in this field in various laboratories, research centers and universities within the country. The conclusion: **the topic of nanotechnology risk is generally absent from research in Mexico**. We also translated and collaborated on pamphlet (supported by UC-MEXUS grant), *Social and Environmental Implications of Nanotechnology Development in the Caribbean* (Foladori and Invernizzi), 2012a; see also Foladori and Invernizzi, 2012b). This 37 page informational brochure was developed to explain the social, environmental and health implications of nanotechnology for workers and consumers in Latin America and the Caribbean, with the objective of strengthening their participation in the public discussion that is necessary in order to establish a preventative international regulatory framework. (http://ipen.org/sites/default/files/documents/ipen_nano_latin_amer-en.pdf)

CNS-UCSB also hosted two international conferences devoted to OHS issues:

- The Nanotechnology Occupational Health and Safety Conference, held at UCSB on November 15-17, 2007 and organized by IRG 2 in collaboration with IRG 3, brought together union leaders, human resource managers, social scientists, media, public policy officials, and science experts to examine issues relating to potential risks involved for nanotechnology workers - both in laboratory settings and in industry - and ways to limit those risks. A major objective of this conference was to initiate a conversation on these issues between specialists and practitioners. The unifying theme was that labor and management should pay close attention to the new technology and scientific evidence about its risks; and that the scientific community should be aware of workplace concerns and the history of occupational health and safety issues that have been important with past technologies. The conference included reports on the experience of previous technologies where this message was not fully appreciated. (http://www.cns.ucsb.edu/events/nanotechnology-and-occupational-health-and-safety-conference)
- The Latin American Nanotechnology & Society Network (ReLANS), in association with the MacArthur Foundation Chair in Global and International Studies and Sociology at the University of California at Santa Barbara (UCSB) and IRG 2, hosted the First International Nanotechnology & Labor Workshop in Curitiba, Brazil, on September 5-6, 2013, as part of the ReLANS' annual meeting. Experts on a wide array of issues related to the impacts of nanotechnology on labor presented their research findings, in an effort to encourage understanding, analysis, and debate on this important topic. Participants included both academic experts, union leaders from different Latin American countries, and representatives of the Brazilian government. The conference adopted a resolution calling on firms to inform their trade unions whenever nanomaterials were being used, and for governments and international organizations to adopt a precautionary approach to worker health and safety. (http://www.cns.ucsb.edu/events/first-international-nanotechnology-labor-workshop)

Richard Appelbaum testified on "China's Move to Become a Technology Leader" before the US-China Economic Security Commission hearings on China's Industrial Policy on March 24, 2009

(Russell Senate Office Building, Washington, D.C.) (Appelbaum 2009).

IRG 2's original methodological and empirical contributions have proven to be of value for companies, academic institutions, and policy makers to inform their decision-making processes. In particular, these tools and applied knowledge help them anticipate industry and economic impacts, educate diverse audiences (including both academic and industry), and help raise awareness of the potential of emerging technologies and related risks. This team has actively sought to increase the broader impact of its research through presentations in multiple events, including for example, invited talks given at schools in Santa Barbara (e.g. La Cuesta High School in November 2014 and Anacapa School in December 2014) and other public venues such as the presentation "*Nuevas tecnologías, innovación y la revolución del mundo que nos rodea,*" given in Santa Fe, Argentina, in August 2012.

Broader dissemination in the media in the latter years of CNS funding has included, for instance:

Cong Cao and Denis Simon (IRG 2) were quoted as sources for an article in *Nature Jobs* on reversing brain drain in China. (March 5, 2014).
Postdoc Han composed an op-ed for T*he Santa Barbara Independent* questioning whether political changes have accompanied economic development in China since the Tiananmen Square demonstrations ("Tiananmen Square 25 Years Later," June 4, 2014).

Photo: IRG 2 Leader Richard P. Appelbaum

Appelbaum published an interview of Democratizing Technologies keynote speaker and *The New York Times* columnist Nicholas Kristof for

The Santa Barbara Independent (November 6, 2014). Other media outlets, including *The Santa Barbara News-Press* and *UCSB Nexus* covered Kristof's visit.

Appelbaum served as an expert source on the global value chain in an article about garment worker safety published in *Just-Style* magazine ("Bangladesh: the business benefits of compliance," December 16, 2014.)

Forbes online contributor Tarun Wadhwa reported on a panel that was held at our Democratizing Technologies conference ("Using Technology to Create Safe and Ethical Supply Chains," January 8, 2016). This article was also republished on the *Huffington Post*.

IRG 2 collaborator Denis Simon was quoted as an expert source in a *Raleigh News & Observer* article about research infrastructure in China ("An Innovative China: A threat to Research Triangle Park?" January 8, 2016).

Simon also appeared on the NPR program, *Here and Now*, to explain the significance of Chinese medical researcher Dr. Tu Youyou winning the Nobel Prize in natural science ("What Chinese Scientist's Nobel Win Says About Science in China," October 9, 2015).

IRG 2 leader Richard Appelbaum was quoted in an *Outdoor Magazine* story about labor practices in textile supply chains ("The Dirty Secret Hiding in Our Outerwear," July 22, 2015).

Postdoc Han wrote a post for the website, *The Conversation* ("STEMming Reverse Brain Drain: What would Make Foreign Students Stay in the US?" March 31, 2015).

Appelbaum was interviewed by Paulo Martines for Brazilian television. The segment was titled "China: Is the Public Investment Paying Off?" (January 21, 2014).

IRG 2 researchers participated in the documentary *"Whatever Happened to Solar Innovation?"* (https://vimeo.com/115560585) by producers Christopher Newfield and Zach Horton, on the development of the solar energy sector.

IRG 2 graduate fellows have benefitted from collaborating across the "two cultures." In the words of one of our science and engineering grad fellows, "In my experience, collaborating and interacting with social science researchers significantly helped me develop a broader perspective of scientific research and research funding. I think the NSF should consider this to be a significant advantage for training graduate students. In fact, many professors have informed me that the largest barrier that must be overcome to transition from a graduate student role to an academic or industrial professional is to be able to step back and gain a broader appreciation for research trends, funding, societal impact."

Finally, IRG 2 members have moved into broad policy or non-profit positions. For example:

- Galen Stocking received his PhD from the UCSB Department of Political Science and is now a Research Associate with Pew Research in Washington DC.
- Matt Gebbie received his PhD from the UCSB Materials Department and is pursuing a postdoc at Stanford.
- Rachel Parker received her PhD from the UCSB Department of Sociology. She is currently Director of Research Programs at the Canadian Institute for Advanced Research, Toronto, Canada, having previously served as the Senior Policy Advisor, Mowat Center, School of Public Policy and Governance at the University of Toronto; Senior Research Advisor, U.S. Agency for International Development; and Research Staff Member, Science and Technology Policy Institute (STPI), Washington, D.C.
- Denis Simon is executive vice chancellor of Duke Kunshan University (DKU) in Kunshan, China.
- Cong Cao is Professor at the School of Contemporary Chinese Studies, University of Nottingham, Ningbo China.
- Emily Nightingale, a former undergraduate researcher, until recently has worked as a research Fellow at the Science Technology Policy Institute (STPI). The Fellowship, for recent college graduates, was created by Rachel Parker, who worked at STPI immediately after finishing her doctorate.

IRG 2: GLOBALIZATION AND NANOTECHNOLOGY

Key Findings, References, Participant List

Key Policy-Related Findings From Our Research

- **State policies aimed at fostering S&T development should clearly continue to emphasize basic research, but not to the exclusion of supporting promising innovative payoffs.** The NNI, with its overwhelming emphasis on basic research, would likely achieve greater success in spawning thriving businesses and commercialization by investing more in capital programs such as the Small Business Innovation Research (SBIR) and Small Business Technology Transfer (STTR) programs, self-described as "America's seed fund."

- China, which has made substantial public investments in science and technology parks, venture capital programs, and incentives to bring home its most talented STEM expatriates, is proving to be a rising star in nanotechnology. **Yet the case of China also shows that public investment, by itself, may not be sufficient for a successful innovation system: there remain significant cultural and institutional barriers to China's efforts to translate basic research into commercial success.**

- **The lessons of Latin America – particularly Mexico, Brazil, and Argentina – show that in the absence of strong governmental programs in nanotechnology, even where basic research has some strengths, sustained innovative breakthroughs are unlikely.** Such countries are likely to be "takers" of economically advanced countries' S&T efforts, producing outputs that are at the low end of the value chain (such as nano-materials and nano-intermediates). Coordinated government programs would increase the likelihood of success in moving up the value chain to achieve more innovative (and competitive) breakthroughs.

- Modern research does not take place in a vacuum, but relies on collaboration, much of which takes place across borders. **This should be encouraged – there is a global talent pool among scientists and engineers that can most effectively address global problems in such crucial areas as energy, health, water, and food security.**

- Creating opportunities for the best and the brightest to come to the U.S. requires addressing immigration policies that create uncertainty for young scholars. The U.S. should revisit its H1-B visa policy, for example passing the STAPLE and I-Squared Acts, which have been languishing in Congress (U.S. Congress, 2015a, 2015b). While the U.S. remains the most attractive educational site for international STEM doctoral students, the EU has become increasingly attractive, and countries such as China offer substantial incentives to convince their best expatriate students to return home. **While nearly half of all international STEM graduate students would like to stay in the U.S. upon graduation, fully 40 percent are undecided – and a main barrier is current U.S. immigration policy.**

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* **For a complete cumulative list of IRG 2 publications 2006-2016, please see the IRG 2 section of www.cns.ucsb.edu; a full publication list is also available at the CNS escholarship repository http://escholarship.org/uc/isber_cns**

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