Upgrading in the Global Knowledge Economy: Insights from China and India

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Paper Prepared for Global Value Chains Workshop
“Industrial Upgrading, Offshore Production, and Labor”

Social Science Research Institute, Duke University
Durham, North Carolina
November 9-10, 2006

DRAFT: Please don’t cite without permission.
Introduction

Asia has never been hotter. From corporations to universities, small businesses to NGOs, it seems that everyone is trying to understand the amazing economic growth that China and India have experienced in the last decade. Indeed, “China” and “India” have become two of the latest buzzwords among those studying the global and the economy. No matter what industry is being discussed, Asia’s economic growth looms as a factor for the future, and China and India represent both huge opportunities and major challenges. In the last twenty years, the world has witnessed the beginnings of a major shift in the global economy, as first China and now India have experienced major economic takeoffs.

The Chinese economy has averaged a growth rate of 9-10% for nearly two decades, and now ranks among the world’s largest economies. Leading the way for China has been its manufacturing industries, many of which have closed down factories in the industrialized world only to open new ones in the fertile new growth cones of the Pearl and Yangtze River Deltas. Indeed, China has been called the “factory of the world” for the legion of factories in apparel, footwear, and consumer goods that dot its coastal provinces, and for its large share of the world’s manufacturing power. China currently manufactures roughly a quarter of global exports in textile and apparel, and is expected to account for up to half of those exports within the next ten years (Appelbaum 2005). The country’s monster figures in export manufacturing are by no means limited to textiles, either; as China has posted startling gains in other manufactures, from air conditioners and washing machines to construction equipment and mobile telephones (see Appelbaum et al. 2006).

Since the year 2000, India has followed right on China’s tail, posting solid economic growth rates. After years of plodding along at an average annual GDP growth rate of 3.5% -- termed the “Hindu growth rate” by economists – the 1980s saw the beginnings of key economic reform and liberalization under Rajiv Gandhi. India has posted an average growth rate of 6% per annum since 1980, and more than 7% since 1994. Growth is projected to remain at 5-6% for the next several decades (Wilson and Purushothaman 2003). At the same time, a combination of other factors, including a falling rate of population growth, have allowed per capita income to nearly triple (Das 2006). India’s growth has been led by the economic explosion in its software and BPO sectors. Ten years ago these sectors were small and relatively isolated; today, India exports $20 billion worth of software and BPO services, and this figure is forecast to hit $35 billion by 2008 (Das 2006). With India’s fairly young population and its English-language skills, a strong growth rate is expected to continue for years to come (Grose 2006).

The China story – and, to a lesser extent, the Indian one – share many aspects of the traditional development model for lower and middle-income countries. In this paradigm, developing countries first enter global industries and global value chains by attracting lower value-added industries and activities, because of lower factor costs. These countries might enter industries like the apparel, footwear, and light consumer goods sectors, and start with assembly or OEM activities. As they gain market share, they accumulate capital and expertise, which they can then use to upgrade along the value chain, both into new, higher-value added products (i.e. niche markets) and activities.
within existing industries (i.e. OBM and design). This upgrading process is generally inter-chain, and can be divided into three areas, along the lines of Humphrey and Schmitz’s upgrading classification. These include process upgrading, or upgrading of processes and machinery; product upgrading, or upgrading products or niches within an industry; and functional upgrading, or upgrading activities within a given value chain (Humphrey and Schmitz 2002). These types of upgrading have been documented in cases from all over the world, from Taiwan to Mexico, and remains a persistent feature of the manufacturing sector in places like China. Indeed, conversations with apparel manufacturers in China’s Guangdong Province are scripted in exactly this way, with manufacturers and companies seeking ways to add design, testing, and R&D capabilities to their manufacturing base.

Yet this represents only half of the story in China and India. Indeed, a traditionalist look at the upgrading story in these countries would leave out one of the most intriguing features of China and India’s development plans. These countries are not content merely to follow the “classic” path, as it takes time for entrepreneurs and managers to accumulate the expertise and the supplier-buyer networks to climb the upgrading ladder, rung by rung. Instead, these countries have sought to break into new industries and new value chains – pursuing chain upgrading to build new, knowledge-intensive jobs (Humphrey and Schmitz 2002; Gereffi 2006). The two countries seek to maintain a core advantage in low-end industries while at the same time consciously investing in new, knowledge-intensive sectors. In China, the dual magnets of low-cost, high-skill labor and market access have driven multinational corporations (MNCs) to found hundreds of new R&D centers in high-tech industries. Though estimates vary on the exact number, China may now boast well over 700 MNC R&D centers, from a range of countries and industries (Zhu and Zeng 2003). At the same time, China’s desire to improve the quantity and quality of its science and technology workforce has led to policy changes and government commitments to funding. These shifts have propelled an upsurge in publications from the Middle Kingdom and have spurred an increase in the number of new scientists and engineers.

Like China, India hopes to parlay its supply of low-cost, high-skill labor into a competitive position in the knowledge economy, but with a different strategic focus. Whereas China has focused on R&D and scientific research in a variety of industries, especially goods-based industries, India’s high-tech efforts are largely associated with services industries, and specifically the information technology (IT) and business process outsourcing (BPO) sectors. Like China, India hopes to attract R&D centers; unlike China, its targets are R&D centers that focus specifically on software and application development. India now boasts hundreds of R&D centers; according to one government official, approximately 150 of American Fortune 500 firms now have established R&D centers in India (Lane 2005). A 2006 McKinsey & Company report predicts that by 2008 more than 1.5 million service workers in India are expected to work for US companies, representing three times the current amount (Naughton 2006).

These trends are not going unnoticed among policymakers in the West. In the 2004 election, for example, presidential candidates George W. Bush and John Kerry fiercely
debated the relative opportunities and threats caused by the perceived outsourcing of US jobs, especially to India. A flurry of news articles in the popular press, from *Time* to *Nature*, have focused on the rise of Asian science, the expansion of engineering education, and the construction of gleaming new science parks and R&D centers in Shanghai and Bangalore (Beech 2006; Wu 2004). In 2005, the National Academies of Engineering published “Rising Above The Gathering Storm: Energizing and Employing America for a Brighter Economic Future,” a monograph of more than 500 pages that discusses the rise of Asian engineering and its potential implications for the US. The vast majority of these articles carry a tone of concern and alarm. Policymakers and business leaders alike worry that the US is losing its edge, and that if action is not taken soon, then Asia will control the next round of scientific leadership – and all of the economic benefits associated with that position. How much of a threat does the US face? How significant are China and India’s growing achievements in these knowledge-intensive areas? How concerned should the US be, and if so, how should its leaders respond?

These are the types of questions that Duke University’s Center on Globalization, Governance & Competitiveness (CGGC) is seeking to address by researching China and India’s new knowledge-intensive model for industrial upgrading. CGGC is working on two complementary research projects that tackle different aspects of the knowledge economy: the Duke Engineering Outsourcing Project and the Nanotechnology in Society Initiative. Collectively, these projects examine two key outputs of these countries’ research and educational institutions that serve as indicators of the upgrading story: human capital output and knowledge. How high are these outputs now? How many scientists and engineers are China and India’s educational institutions producing? How much research are universities and corporate R&D centers producing, and in what areas? How have these changed over time? How could we describe the educational landscape that is shaping this output, and what are the important institutional and policy factors? What role do industry and the market play in affecting the amount and type of students being produced? Of research being conducted?

This presentation will introduce CGGC’s efforts to address complex questions like those posed above, by describing our efforts on each of the above-mentioned major projects. It will describe the Engineering Outsourcing Project and the Nanotechnology in Society Initiative in detail, including the methodology and initial results of our research. After this brief introduction, we will present a series of preliminary findings about China and India’s attempts to upgrade by means of building a knowledge economy.

**Engineering Outsourcing: Human Capital and the Knowledge Economy**

In the last several years, few topics in science and technology have received more attention from the American press than the debate over engineering outsourcing. Policymakers, business leaders and the media have voiced concern over the US’s future competitiveness, in light of job outsourcing and growing Asian competitiveness in science. A steady stream of media articles and events have documented concerns over surging numbers of engineering graduates in countries like India and China, and falling
numbers in the United States. These articles all used similar statistics to support this claim, pegging US engineering graduates at 70,000, China at 600,000, and India at 350,000. These numbers sparked a debate that has now spread to all ranks of the American engineering community – is the US facing a flood of Asian engineers? Many said yes, and called for reform of American engineering education and workforce policy (National Academies 2005). Others criticized the numbers as unverified and claimed that the debate was overblown (Bialik 2005).

Field Research

With this debate in mind, CGGC researchers paired with colleagues Vivek Wadhwa and Ben Rissing from Duke’s Pratt School of Engineering to analyze these statistics and, by extension, American competitiveness in science and technology. The project focused on three key countries: India, China, and the United States. Indian data on engineering graduates was provided by the National Association of Software and Service Companies (NASSCOM); Chinese data, by the Ministry of Education (MoE); US data, by the US Department of Education’s (DoE) National Center for Educational Statistics (NCES). The research team, which included a dedicated student research group from Pratt, contacted a series of university officials, journalists, consultants to confirm and refine these numbers. This allowed an initial round of published work focusing on the undergraduate numbers (Gereffi, Wadhwa and Rissing 2005).

The media attention surrounding this report subsequently enabled a second round of targeted field research in both India and China, sponsored in part by the Sloan Foundation. In each country, we met with key individuals who could shed light on the numbers story and the associated market and policy dimensions: government officials, representatives from educational policy and statistics organizations, university leaders, journalists, and representatives of multinational corporations’ R&D centers. We also spent time conducting library research to uncover new statistical sources that are not readily available in the US. Together with follow-up research and literature searches, these new sources of information have allowed us to extend our initial research on graduation statistics to the graduate level, and have also helped to flesh out a fuller picture of the trends, causes, and implications of the increase in graduation statistics.

Findings: Quantity of Engineers

Based on our research, we see two separate but related issues: the quantity of engineers produced, and their relative quality. Examining quantity, we found that the commonly cited statistics about engineering graduates in China, India, and the US were flawed, because they were not comparing the same categories of graduates in each country (see

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Table 1). When these numbers were adjusted so that the statistics for each country included only engineering bachelors degrees, statistics show that the United States has a much higher number of graduates than initial statistics would indicate, while China has slightly more and India has less (see Table 2).\footnote{For the purposes of our work, we took engineering to include not only traditional engineering fields, but also information technology and computer science degrees.} Over the past five to six years, these numbers have increased slightly for the United States and moderately for India, while China’s have taken off rapidly. For example, the United States has added just over 23,000 engineering graduates since the 2000-01 schoolyear, while India has added just under 57,000. China, on the other hand, has more than doubled the number of bachelors graduates in that time, adding more than 200,000. An examination of subbaccalaureate data shows a similar set of trends over the same period, with China experiencing massive growth while India and the US show moderate increases. On each of these levels, the China’s initial takeoff seems to date to the 2001-03 period (see Figures 1 & 2).

In terms of data for graduate students (master’s and PhDs), we are still processing the data that we were unearthed while in India, watching for similar trends. Natarajan has looked in some detail at these numbers, and has noted a similar upswing. According to him, the number of graduate degrees awarded by the Indian Institutes of Technology (IITs), considered the top schools in the science and technology areas, rose 15.4% between 1999 and 2003. This represents only a slice of the overall graduation picture in India, but the IITs are an important slice; due to their jump in numbers, we can reasonably expect that India’s overall graduate degrees in engineering are rising (Natarajan 2005).

It is important, however, to give these numbers context: even if India and China’s absolute numbers of engineers are higher than those of the US, their populations are also much higher. India and China rank, respectively, as the most populous and second most populous nations on earth, and by extension might be expected to have more engineers. In engineers per capita, the US retains a significant lead on both China and India. China’s growth has narrowed its gap with the US, but it still trails the US by a significant margin. India has actually declined in engineers per capita over the same period. The US’s figure for engineers per capita, in contrast, has risen continuously over the past five years, from less than 400 engineering bachelors degrees per million citizens to nearly 475 degrees/million.

**Findings: Quality of Engineers**

On top of these quantity issues, however, is another equally important concern that is often overlooked in the alarm over the numbers of Chinese and Indian engineering graduates: quality. Instead of simply asking how many engineers these countries are producing, we should be asking how many globally competitive engineers they are graduating. In discussing this question, our research team had to consider what it means to be an engineer, and what types of engineers might exist. In our initial round of research, we discussed the differences between “transactional” engineers and “dynamic engineers.” Dynamic engineers, in general, are engineers who are capable and
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accustomed to abstract thinking and problem solving using their scientific and technical background. They tend to have better “soft skills,” including communication, interpersonal, cross-cultural, and team-building skills. Dynamic engineers are capable of leading and managing innovation. In contrast, transactional engineers may have solid technical training (“hard skills”), but have trouble using their technical training to solving larger problems or dealing with novel situations. In general, these individuals possess weaker “soft skills” and are frequently assigned to work on repetitive tasks. While both types of engineers have a role to play in the engineering value chain, the US should be most concerned about the growth of dynamic engineers abroad, because it is these individuals who are best able to chart out a blueprint for building a knowledge economy (Gereffi, Wadhwa and Rissing 2005).

Quality, however, is difficult to assess, due to the lack of a standard set of metrics for global competitiveness. Instead, we used several different means to tackle this question. First, we attempted to address the issue of employability: how many of the engineers graduating from higher educational institutions in China, India and the United States possessed skills and training that made them employable by major global firms? To tackle this, we used the results of a 2005 study by the McKinsey Global Institute, which surveyed HR professionals from 83 companies across the globe with the question, “Of 100 [engineering] graduates with the correct degree, how many could you employ if you had demand for all?” Respondents claimed that 80.7% of US engineers would be employable, compared with only 10% of Chinese engineers and 25% of Indian engineers. Major concerns about employing Chinese and Indian engineers focused on language proficiency, quality of technical education, cultural issues and a lack of accessibility (Farrell et al. 2005).

While conducting field research, we attempted to verify and build on these findings, by talking with university officials and representatives of MNC R&D centers about the job paths of new engineers. Our conversations confirmed these facts. In China, for example, multiple R&D centers confirmed that there is a limited list of schools from which they recruit and hire, a list that is remarkably consistent across companies and even across industries that are employing engineers. Many of these names would be familiar: Peking University, Tsinghua University, Fudan University. In India, the list is considerably broader, and includes is not limited to graduates of top-tier schools like the national Indian Institutes of Technology (IITs) and the regional National Institutes of Technologies (NIITs, formerly known as regional engineering colleges or RECs). Indeed, graduates of second and third-tier institutions can also compete for job openings. This can be traced in part to better language skills, and in part to private sector educational institutions that, like “finishing schools,” allow graduates of less prestigious universities to bolster their resumes. NIIT is perhaps the most famous of these finishing schools, with more than 700 training centers in India. It is, however, by no means alone, as thousands of smaller institutions operate across the country.

In addition to quantity of engineers graduating from Chinese and Indian universities and finishing schools each year, both countries have another source of human capital input: returnees. These returnees are individuals of Chinese and Indian origin who have
received part of their educational, work, or living experience abroad returning to their home countries. Though these numbers are currently small, they seem to have been growing in recent years, based on our interviews. As China and India’s economies have taken off, many émigrés have realized that they could live quite comfortably in their countries of origin, based on the value of their salaries and the relative standards of living. China has several programs to actively encourage overseas Chinese to return, including the “100 Person Scheme” and the “Cheung Kong Scholars Program,” providing funding and lab space for returning scholars. Yet returnees are difficult to gauge, as there are no comprehensive statistics measuring the number of those returning and how they enter the two countries’ S&T workforce. A full analysis of the S&T workforce and its trends and dynamics must include these individuals, but a great deal of further research is needed in this area to assess their overall impact.

In both countries, quality concerns are not limited to the lack of “soft skills.” Indeed, the breadth and depth of technical training can be a concern, especially for graduates of lower-tier institutions. These concerns have only grown sharper with increasing enrollment, as faculty numbers and facilities in India and China have not grown as rapidly. This is particularly acute in India, where young graduates and top faculty are lured into the IT industry with higher salaries and better opportunities for job advancement, and where a round of older faculty is approaching retirement (Mooney and Neelakantan 2006). While colleges have sought new ideas to maximize their existing faculty – including increasing the retirement age and adding more classes in off-peak times – it is clear that many second, third and fourth-tier schools are facing a crisis (Natarajan 2005; Verma 2006). While top-tier schools can partially avoid these issues, they face their own hiring concerns. These graduates are seen as the most globally competitive, yet several firms told us that they are leery of recruiting IIT graduates – not because their quality is poor, but because they frequently leave to pursue other opportunities, especially PhDs in the United States and the West. In addition, these graduates often have high demands for salary and benefits, which firms cannot or will not pay.

Prospects for Employment for Engineering Graduates

In addition to our discussions with top-tier schools, we sought interviews with representatives of universities lower on the quality spectrum in order to understand the issues facing a range of educational institutions. In both countries, a curious employment figure is emerging: despite the fact that both countries have increased the number of engineering graduates in the past decade, the engineering labor market is segmented. Top-level graduates in both countries are in high demand, and there is a severe shortage and high turnover among firms like Microsoft, Oracle, and GE (Grose 2005). Representatives from Tsinghua, for instance, told us that their graduates did not have the problem of finding a job, only choosing the best job. Similarly, IIT graduates are widely recognized as India’s crème de la crème, with a mix of both hard and soft skills that allows them to compete with engineers from all over the world.

Conversely, an engineering graduate from a lower-level institution faces a grim picture.
Students from schools lower on the quality spectrum, like China’s Beijing Institute of Technology, have trouble finding stable jobs in engineering. In an interview with one department chair, he told us that up to 30% of graduates from his specialization would be unable to find full employment after graduation. China’s National Development and Reform Commission, a major economic planning body, reported earlier this year that job openings for new graduates had fallen over the previous year by 22%, to a level of only 1.6 million. At the same time, university graduates had risen substantially, meaning that 60% of China’s 2006 university graduates would be unable to find work (Chan 2006). In India, the situation was similar, although the expanded hiring practices of employers – combined with the opportunities for graduates of many universities to utilize private sector training programs – made for less pessimism. Yet even India still has nearly 1 million unemployed engineers, with more on the way (Mooney and Neelakantan 2006). Clearly, quality matters in the supply of – and demand for – these engineers.

Questions of Policy: Why has there been an increase?

Underlying these numbers about engineering graduates are also a host of policy questions and trends that merit further study. Though the numbers of engineering graduates show similar trends in India and China, the reasons for their growth reveal a great deal about the differences between the two countries and their policy mechanisms. China’s surge of engineering graduates began in 2001, and can be traced back to top-down policy changes that began in 1999. These policies were designed to promote China’s transition from “elite education” to “mass education” by increasing enrollment in higher education. The Chinese leadership had several reasons for this shift, including China’s long-term development needs, medium-term imperatives to help China upgrade by building a competitive position in knowledge-intensive industries, and immediate causes like the Asian Financial Crisis and the ascension of Zhu Rongji to the position of Premier (Yang 2005; Ni and Wang 2005; Li 2004).

Subbaccalaureate degrees responded to the increased recruitment first, with graduate numbers climbing sharply in 2000-01 and 2001-02 as students finished their two and three-year degrees. Bachelors degrees followed suit in 2002-03, as students who entered universities as part of the expanded intake in 1999 were processed through the system. By 2005, overall enrollment in higher education institutions (HEIs) had reached 23 million students, giving China the most students in HEIs of any country in the world (Li 2004). Though the Ministry of Education announced in June 2006 that it would begin to curb enrollment growth, graduates are expected to increase for several more years as the expanded classes continue to work their way through the system (Xinhua 2006).

India’s enrollment in engineering education has grown considerably in the last decade. Whereas overall higher education enrollment has grown at a steady rate of 5% per year for the past two decades, the number of bachelors degrees awarded in engineering fields has grown by an average of more than 20% per year for the last several years (Kapu and Mehta 2004; Gereffi, Wadhwa and Rissing 2006a). Unlike China, the growth in Indian education has been largely market-driven, as opposed to policy-driven. Expansion in engineering enrollment can be traced to a number of key reasons, including India’s fairly
young population structure, its growing middle class, the expansion of the IT industry, and the growth of private engineering colleges and training institutions. By 2004, India boasted 974 private engineering colleges across the country, compared with only 291 public and government institutions (Somaiya 2005; Gupta 2005). Private colleges now take up 86.4% of all engineering seats (Kapu and Mehta 2004). In addition, training institutions have now sprung up to address skills gaps between college graduates and company hires. NIIT is the largest of these, and now maintains more than 700 training centers all over India, but other institutions fill a similar role: providing training not only for corporations but also for potential job seekers trying to break into the IT industry. The projected growth of the IT industry and the continued participation of the private sector in education are expected to continue this expansion for many years to come.

It is important to note that it is not only educators in China and India who are addressing these issues of skills gaps and quality. Companies are also exploring how best to train and promote engineers within their firms. Every firm we spoke to in both countries gives its new employees a detailed orientation on American corporate culture, as well as the specific culture of their given firm; many also include basic technical training in their mandatory programs. In addition, nearly all of the MNCs we spoke with offer – and strongly encourage employees to take advantage of – additional training opportunities for “soft skills,” especially for communication and presentation skills. Opportunities for cross-cultural learning, and chances to gain international experience, are less common, though they exist. In a few cases, where R&D center operations are clearly oriented towards global markets, multi-R&D center firms are able to construct research teams across their global facilities. This arrangement, however, is not universal, as many R&D centers – especially in China – are oriented as much towards domestic markets and product adaptation work as to developing global platforms. Advancement criteria represent another critical dimension with which firms often struggle. In discussions with Lenovo, for example, we learned that identifying and developing future leaders from among the pool of engineering employees remains one of the firm’s most troublesome issues; even though Lenovo’s China operations have a pool of US-based experience from which they can draw, they continue to work on this issue.

Thus, this seemingly simple story about numbers of engineering graduates speaks a great deal to the dynamics of upgrading in the knowledge economy. Scientists and engineers serve as a crucial input to the innovation “machine,” not only operating it but also driving it in new directions. These countries have the right idea in terms of increasing the critical inputs that are required to grow and sustain global competitiveness in knowledge-intensive industries. Innovation, however, is about quality, not just quantity. China and India may be increasing the number of engineers they are producing, but if their engineers are “transactional” and not “dynamic,” then their global competitiveness is severely hindered. In both of these countries, a large number of engineers still masks a serious shortage of competitive engineers. China and India have each recognized this problem and have begun to deal with it in various ways. China’s push to slow the expansion of university enrollment and focus on quality is one indication of this; the vibrancy of India’s private sector education market is another. Their efforts only prove
the challenges of solving the upgrading puzzle. Upgrading is already a difficult task; without the right pieces, it becomes nearly impossible.

**Nanotechnology: Using New Technologies to Upgrade through Value Chains**

Nanotechnology has been portrayed as a coming revolution, a new set of technological breakthroughs that will have massive social and economic implications. Promoters have claimed that nanotechnology has the potential to impact every sector of the economy, surpassing even IT and biotechnology in the breadth and depth of its input. Nanotechnology can be defined as “the development and application of materials, devices and systems with fundamentally new properties and functions because of their structures in the range of about 1 to 100 nanometres” (Renn and Roco, 2006). Yet the science that drives nanotechnology does not simply concern the size of the particles involved. Nanotechnology functions because of its small scale; at such a small scale, materials can have altered chemical, mechanical, optical, magnetic, and electronic properties, which, when harnessed appropriately, can add functionality to the materials involved or to their interactions with other materials. This added functionality could translate into the upgrading of current products and, more importantly, the creation of new products. According to estimates by Lux Research, nanotechnology already accounts for $158 billion in product revenue; by 2014, products incorporating nanotechnology could be worth $2.9 billion in revenue (Lux 2004).

Nanotechnology thus has incredible potential, both as a direct economic driver and also as an indirect catalyst for further innovation. Because nanotechnology is inherently about a scale of measurement, it is an extremely interdisciplinary field, involving physicists, chemists, material scientists, biologists, engineers, and others in a common dialogue. These interactions are also highly international: partly because of the size of the current pool of nanotechnology researchers, partly because the field is so interdisciplinary, and partly due to the scientific era into which the field is being formed, in which international collaborations are increasingly common. This international interaction has drawn global attention to the potential of nanotechnology. Because nanotech is so new, the scientific “playing field” is fairly flat, and so countries from the United States to China to South Korea have begun investing in the field. In 2005, for example, global spending by governments alone reached $5 billion, with the private sector contributing another $3 billion (Renn and Roco 2006).

Both developed and developing countries see nanotechnology as the next seat of global leadership in innovation. Developed countries seek to maintain their lead, while developed countries hope to “leapfrog” the traditional paths of development and capture leadership in a newly established area. It is this last aim – the idea of development by pursuing global competitiveness in an area of higher-order technology – that reflects upon the upgrading story that CGGC seeks to address. As nanotechnology represents one of the brightest possibilities for this developmental strategy, and so makes an ideal case study.
In addition to CGGC, a host of US-based organizations and institutions are seeking to trace the development of nanotechnology and assess its social and economic impact. The Center for Nanotechnology in Society (CNS) at the University of California-Santa Barbara is a leading center doing work in this area, and it is through CNS that the CGGC first became involved in this field. CNS was initially granted a 5-year, $5 million dollar grant from the National Science Foundation (through the US government-funded National Nanotechnology Initiative) to establish and operate a “national research and education center.” CNS was also charged with pursuing several simultaneous lines of research concerning the social and economic impact of nanotechnology, with special attention to the role of nanotechnology in the developing world. For CNS to research nanotechnology and its impact on developing countries like China, however, its researchers needed to understand both the dynamics of today’s global economy and the value chain that would govern production and innovation in nanotechnology. Nanotechnology was “born global,” and critical links in its value chain, including research and development, product engineering, manufacturing, information flows, are already global in scope. Therefore, researchers from UCSB sought to collaborate with CGGC to incorporate an understanding and analysis of the global value chain concept into their work.

The global value chain framework provides an analytical framework for examining economic globalization, with a distinct focus within industries on the linkages and interactions between economic actors across geographic space (Gereffi 2005; Gereffi, Humphrey and Sturgeon 2005). In the past, it has been applied to a range of different industries, from traditional manufacturing industries like textiles and apparel to knowledge-intensive industries like biotechnology. Nanotechnology, however, presents a new challenge, in that it is still largely in the R&D stage and is still short on commercial applications. The innovation-production-commercialization links are not fully developed, making construction of a formal value chain challenging. Nevertheless, academics and policymakers have begun applying this global value chain framework, with its multiple dimensions and levels, to the nanotechnology field.

One of the leaders in this effort has been Lux Research, the (self-proclaimed) “world's leading nanotechnology research and advisory firm.” Lux has used value chains methodology and a global perspective as a key part of their studies on nanotechnology; their conception of the nanotechnology value chain can be seen in Figure 4. Their chain provides a solid foundation, but still follows a traditional industry value chain. In constructing a complete global value chain for the nanotechnology sector, we seek to overlay their work with not only information about the added value of different links in the chain, but also the institutional, organizational and geographical layers necessary to study the key nodes of innovation, production, and commercialization. For example, looking at nanomaterials, which tend to be R&D intensive, we can analyze the types of major activities that are being conducted in this field, where they are being carried out, and which countries are major players. Comparing different links reveals interactions, as well as gaps in the value chain and areas of overlap. This type of multi-level analysis can
reveal firms that may be strong in one or more areas, institutions or universities pursuing specific research niches, or countries with significant value chain gaps. Due to our national links with UCSB and our local links with North Carolina, our analytical attention has been focused on two main geographic areas, China and North Carolina, with an initial focus on China.

Field Research

To address the different levels of our value chain analysis, we conducted initial research here in North Carolina. This research involved a literature review of articles that analyze the process and dynamics of innovation, the sociology of science, and the ways in which the “value chain” concept is being applied to nanotechnology. In addition, we held discussions with academics and government officials in North Carolina, including several from the Department of Commerce, to discuss their strategies for nanotechnology and its potential impact on the State. We also teamed up with Tim Lenoir and Eric Giannella from Duke University, who are running data visualization software and data mining techniques to reconstruct and map technology research networks, using scientific publications and patent information as their key data source (for examples of this type of work, see Lenoir and Giannella 2006; Giannella 2006). Lenoir and Giannella had begun to apply these methods to the nanotechnology field, yielding a means of understanding which countries and institutions were serving as major research hubs in nanotechnology, and which areas of research they are pursuing.

In July and August 2006, we traveled to China with a research team from UCSB to conduct intensive field research on the state of nanotechnology in China. During our two weeks in China, we visited universities and government research labs, and interviewed scientists who were approaching and working on nanoscience and technology from a variety of scientific disciplines. Our site visits and interviews were designed to understand several key research questions, including (but not limited to):

- China’s main areas of nanotechnology research
- The institutional landscape of Chinese science, including the major institutions conducting and regulating nanotechnology research
- The main government programs for funding and promoting nanoscience
- The impact of overseas Chinese who were returning to work in the sciences, and how that has changed over time
- Salaries and incentive structures for Chinese nanoscientists
- The interaction between science and industry: how the presence or absence of supporting industries might affect support the growth of nanotechnology
- How Chinese scientists perceive the future of nanotechnology in China

China and Nanotechnology: Progress and Key Players

Through this research, we were able to make progress on answering many of these difficult questions. China’s status in nanotechnology is indeed growing. One indicator of this trend is in scientific publications. In 2005, Chinese scientists published more than
9,000 English-language articles on nanotechnology in peer-reviewed journals, surpassing the United States (Giannella 2006). Another is funding; in 2004, the Chinese government invested approximately $250 million specifically in nanotechnology through a variety of initiatives. One such program is the ten-year “climbing up” program, launched initially in 1990 to support the growth of nanotechnology in the materials science field. Two other programs – the 863 program (officially known as the National High Technology and Development Program) and the 973 program (National Basic Research Program) – have pumped millions of dollars into the sciences, including nanotechnology since their inceptions in 1986 and 1997, respectively. Other programs, including the “Spark” (for state key laboratories) and “Torch” (for national large-scale projects of scientific research) programs, also contribute to nanoscience funding (Simon 2005).

Priority areas for each of these programs are often realigned in accordance with China’s “Five-Year Plans,” economic planning documents that lay out strategic directions for the country’s economy every five years. In the most recently completed Tenth Five-Year Plan (2001-2005), the 973 program specifically set nanosciences as a priority research area; the 863 program targeted “new materials,” an area that has major implications for the nanosciences as well. In 1999, the Ministry of Science and Technology (MOST) launched a special project just focusing on nanomaterials and nanostructures (Appelbaum et al. 2006; Bai 2005). By 2020, the government hopes to be spending 2.5% of China’s GDP on nanoscience research and development, compared with 1.3% today (Bai, 2006; Feng, 2006; Beech 2006).

In terms of organization and coordination, China retains a patchwork of bodies that have some impact on the current and future direction of nanotechnology in China. The most obvious of these is the Ministry of Science and Technology (MOST), with official federal-level control over this area. In 2000, the government founded a National Steering Committee for Nanoscience and Nanotechnology, which was granted control over national-level planning, coordination, and policy-making for nanotechnology; membership on the committee comes from MOST, the State Development and Planning Commission, the Ministry of Education, the Chinese Academies of Sciences and Engineering, the National Natural Science Foundation of China, and other more minor organizations. In terms of research, an array of university laboratories and state key laboratories, as well as branches of the Chinese Academy of Sciences, are engaged in nanoscience research. In addition, China boasts the National Center for Nanoscience and Technology (NCNST), founded in March 2003 by the Chinese Academy of Sciences and Tsinghua and Peking Universities. This new institution was designed to pursue multiple areas of nanoscience and technology research, both basic and applied, and had other responsibilities less directly related to research, including an educational mission and a directive to bridge government, academia, and industry (Appelbaum et al. 2006).

*China’s Nanotechnology Research Profile: Strengths and Weaknesses*

Characterizing Chinese research, however, shows that Chinese research remains focused on the early links in the nano-value chain, and on the more fundamental, materials science-related areas of nanoresearch, including nanomaterials and nanocomposites.
Nanomaterials is clearly the golden calf for Chinese researchers, and is an area in which Chinese researchers have built up a core competency and a global research node. Of nearly 12,500 nanotechnology articles published by Chinese authors since 1988, a clear majority (64%) focus on this area (Giannella 2006). Our interviews in China with leading nanoscientists, in both university and government research labs, indicate that nanomaterials was the past, present, and immediate future of nanotechnology in China, and the area in which its scientists had made the most promising breakthroughs (Xie and Wang 2006; Liu 2006). Within this field, Chinese researchers have been most active in carbon nanotubes (CNT) and nanowires, with somewhat less emphasis on other areas like nanopowders or quantum dots. Scientific researchers have made substantial progress on methods for creating nanomaterials, as well as characterizing and analyzing nanomaterials. For example, scientists like Sishen Xie of the NCNST, Shoushan Fan at Tsinghua, and Zhongfan Liu at Peking University are increasingly recognized as global leaders in these areas. Nanocomposites is a newer field, but is also picking up steam; this area includes both the creation of “thin film nanocomposites” and of “nanoalloy materials.”

Yet much of China’s research in these areas remains in the research stage; China’s links to commercialization are still weak. Current “nano-products” are mainly limited to already-designed products with an added “nano-finish” or minor nano-features. One example is China’s National Opera House, currently under construction. The high-profile construction project has received a great deal of press for its new “self-cleaning glass,” where ordinary glass is treated with photo-catalysts that automatically break down pollutants and keep the windows clean (Liu & Zhang 2005). Yet this work, while a large step forward, is purely an “add-on” to the pre-existing architectural plans. China is currently lacking researchers and firms that are using the fundamental properties of nanotechnology to design new products. Instead, many claim that the term “nano” is being used as much a marketing tool as an actual description of product functionality. One frequently cited example concerns “nano-water,” a product that a Guangzhou-based company (Yi x Zhiye Company) claimed could extend one’s lifespan with only a few cups. After raising funds from potential investors, the company was exposed as a fraud and punished by city authorities (Bai 2005).

Concerns about Commercialization: China’s Value Chain Weaknesses

To be fair, nanotechnology’s position as an emerging field means that no one is very far along the innovation-commercialization path. Nanotechnology is a maturing technology and is still developing strong commercialization links. China has recognized this need, and has made efforts to found new organizations like Tianjin’s Nanotechnology Industrialization Base of China (NIBC) and the Shanghai Nanotechnology Promotion Center (SNPC). Each of these is charged with promoting the spread and commercialization of nanotechnology through various means, including sponsoring workshops and conferences, educating the public, and promoting the growth and success of start-ups. According to the SNPC, Shanghai alone already has more than 100 nanotech companies, with an average equity of 2-5 million yuan (US $250-625k). The track record of these organizations, however, is still new and largely untested; in visits to
the two facilities, we saw little evidence that they had been yet able to affect a major change in the direction of Chinese nanotechnology.

China lags the world more clearly in developing the cross-industry links that can promote the growth and development of nanotechnology. In the US, for example, the biotechnology and medical industries have seen a great deal of potential for nanotechnology, and firms in associated industries like laboratory equipment and testing are growing quickly. Firms from GlaxoSmithKline to General Motors are pushing nano-research in new and diverse industry directions, while global nanometrology firms like Carl Zeiss, Jeol, FEI and Veeco are driving nanotechnology equipment and supply. In China, however, these interdisciplinary and cross-industry links are rare. Of China’s registered nanotechnology companies, 70% are working specifically in traditional industries like textiles, chemical engineering and construction. Less than 10% work in electronics/high-tech manufacturing (7%), medicine (6%), environmental management (6%), and the energy industry (4%) – despite the fact these industries are development and upgrading priorities for China (Liu & Zhang 2005). While conducting interviews and the National Center on Nanoscience & Technology (NCNST), for example, we spoke with a scientist whose work bridges nanotechnology and biotechnology, who lamented that China had very few scientists working in his area, forcing him to go abroad for collaborations and conferences. Conversations with other scientists made clear that these interdisciplinary areas are far less of a scientific priority for the Chinese nanoscience community, as opposed to traditional areas like materials science.

In addition, domestic equipment and supply firms are few in number and low in relative quality. On one laboratory tour, we noted that all of the major equipment, and most of the lab supplies, were marked as coming from the US, Japan, and Europe, despite the extra cost, the increased shipping time, and the difficulty of repair and maintenance. The lab’s chief scientist stated that Chinese labs often had trouble getting their concerns across to Western suppliers, but that there were no alternative domestic suppliers that met international quality standards. The experience of Chunli Bai, head of the NCNST, is telling. According to Peking University nanoscientist Dr. Liu Zhongfan, Dr. Bai attempted to start a high-quality STM (scanning tunneling microscopy) firm in China nearly fifteen years ago, and succeeded in building the first Chinese-made STM equipment for a reasonably low cost. The quality, however, was so low that top scientists would not use it to conduct international-level research; to this day, Chinese nanoscientists continue to order equipment from abroad.

As the example of China clearly illustrates, location and value chain linkages represent an important dimension of the nanotechnology story. Like other high-technology fields, nanotechnology requires specific knowledge-based inputs and specialized capital and infrastructure. These inputs tend to be more localized and location-specific than general industry inputs, and thus nanotech R&D facilities are often tied to a given location. High-tech firms can help to generate outputs that can promote other industries, strengthening linkages between research and industry and further embedding firms in a given location. Because nanotechnology is inherently such an interdisciplinary field, its outputs can feed into a wide range of industry value chains, from textiles and apparel to
biotechnology, from the automotive industry to medical devices. From an upgrading perspective, nanotechnology can provide a way of sustaining and supporting many of these other industries, whether those industries are primarily knowledge-based or just utilize knowledge outputs, but can also allow regions to build new, higher-value competencies in R&D and new areas of innovation. This upgrading will provide greater job opportunities for the labor force as well, and jobs that may be more geographically embedded.

Government policymakers have also begun to think about nanotechnology in geographic terms, and the interaction between nanotechnology and industry as a means of supporting and upgrading existing industry concentrations, from Michigan’s automotive cluster to North Carolina’s furniture and textile hubs. A prime example, in fact, comes from North Carolina, a state that seeks to position itself as a nanotech hub. The Governor’s Task Force on Nanotechnology and North Carolina’s Economy carried out specific survey research of North Carolina companies that emphasized value chains, asking firms where they fit into the value chain as a way to situate the local sector in terms of an industry footprint (North Carolina Board of Science & Technology, 2006). Firms, industry analysts and economic planners are seeking to use global value chains as a way to understand nanotechnology, fed by research such as that conducted by Lux Research. In our own future research, we plan to delve deeper into this dimension, researching and surveying North Carolina firms that are involved in nanotechnology to build a picture of the state’s own nanotechnology footprint and its trends and dynamics over time.

**Key Findings and Early Impressions**

China and India are thus seeking new ways of approaching the upgrading question, pursuing an unprecedented model that couples investment in science and technology fields with the traditional paradigm of moving up the value chain in low-end industries. Many authors and analysts have focused on different pieces of this puzzle, documenting China’s leadership in low-end manufacturing, for example, or India’s high-tech boom. To gain a full understanding of this upgrading story, however, one must simultaneously follow both development tracks and study their dynamics and interactions. CGGC research in this area has sought to bring out the new aspects of this story, looking at how China and India are seeking to boost aspects of the knowledge economy to propel development. Human capital and R&D output serve as important catalysts for the knowledge economy, ensuring the steady supply of new ideas and of people who research, develop, and run new systems of innovation. In examining human capital inputs through the Engineering Outsourcing Project, and research and innovation inputs through the Nanotechnology in Society Initiative, CGGC hopes to advance the dialogue on these topics.

CGGC’s work on these projects is still in the early stages, and at least as many questions and new research directions remain as have already been addressed. Nevertheless, our US-based research and our field research in China and India has already taught us a great deal about these subjects, and has allowed our research team to present a number of
preliminary findings about India and China’s progress towards upgrading into new, knowledge-intensive areas. A number of these early findings are outlined below:

1) China and India are serious about using S&T to upgrade, and have the will and desire to push this new model for upgrading at both ends of the technological spectrum. The state is playing an important role in both countries to advance this new model.

Even a cursory look over the money being poured by the Chinese government into nanotechnology, the persistent efforts by Indian government and business officials to promote the IT sector, and the number of new engineers streaming out of Chinese and Indian institutions provides an indication that China and India are aggressively seeking to use science and technology to upgrade their economies. In these efforts, both countries’ governments are leading the way. The Chinese government’s pledged investment of 2.5% of GDP for R&D investment indicates its level of commitment to the sciences, including nanotechnology, and has backed this up with new institutions, policies, and funding mechanisms. Top-down directives to increase the number of university graduates and of engineers also reveal the time, effort, and commitment that China is spending in this effort. China hopes that this investment will have a massive windfall in economic benefits and will propel it to leadership in global science across a variety of disciplines.

India’s government, despite seeming chaos of its federal, democratic system, seems similarly committed to promoting a tech-savvy, service-based economic model, with governments on multiple levels pledging sustained support for the growth of the industry domestically and for attracting MNCs to the country. The federal government’s National Task Force on Information Technology and Software Development (1998), which blueprinted the IT sector’s development, and the Information Technology Act (2000), which modified legal provisions to facilitate electronic commerce, provide examples of the national government’s commitment in this area (Bajwa 2003). In addition, regular reviews and panels of the AICTE and the IIT system have helped to fine-tune the educational incentives and structures to encourage healthy growth of engineering education (Natarjan 2005). On the state and municipal levels, places like the Andhra Pradesh and Karnataka, Chennai and Hyderabad have led the way with incentive programs for start-ups and MNCs.

2) Demand for high-quality knowledge inputs (human capital, intellectual capital) is growing sharply, fueled by MNCs and up-and-coming domestic firms.

In both China and India, the demand for science and technology inputs is growing rapidly as knowledge-intensive sectors expand. The growth of R&D centers, of FDI, and if local firms in knowledge-intensive industries are providing the pull factors for the S&T labor market, especially for its high-end, high-quality engineers. In 2005, China attracted $72.4 billion in FDI, while India attracted $6.6 billion (UNCTAD 2006).

Much of this FDI has gone to building factories and facilities grouped on the low end of their industries’ respective global value chain, but the high-tech component of FDI in both China and India is growing sharply, as more and more firms seek to take advantage
of the two countries’ low-cost, high-skill talent pool. This is clearly evidenced by the rate at which MNC R&D centers are popping up in both countries.

While these R&D centers are performing a range of activities, centers like Microsoft Research Asia (based in Beijing) and Oracle’s India Development Centre (based in Bangalore) are showing that R&D in the developing world does not have to be limited to product adaptation, but can be global and innovative in scope. At Microsoft Research Asia, for instance, scientists are working on cutting-edge graphics and multimedia research, from speech recognition to video download technology to facial recognition (Huang 2004). These industry-oriented research labs are demanding higher levels of human capital to operate, but also higher levels of knowledge input to innovate. Nor is this landscape purely operated by foreign MNCs; in both India and China, a new round of domestic technology-driven companies has emerged, from Infosys and Wipro in India to Lenovo and Huawei in China.

3) Supply is attempting to respond to demand, but generally with increased quantity instead of increased quality. The results, however, have shown that quality matters.

As the demand for science and technology work has increased, the supply of inputs, of both human and intellectual capital, has sought to respond. As discussed previously, this increase in demand has spurred a sharp rise in the number of engineering graduates from both China and India, with China and India’s numbers each doubling in the last five to six years. In China, this increase can be tied to government changes in policy dating from 1999; in India, much of this increase can be tied to the market-led growth of the private sector. In both cases, this jump marks the first attempt to reply to changes in demand, and have generally focused on increasing the quantity of engineers to meet burgeoning demand. Many analysts in these two countries – and many in the US – pointed to this increase to indicate that these countries’ engineering workforce was more globally competitive, since they now had the supply to meet an increased level of demand.

The actual labor market that exists for these engineers, however, calls into question the long-term validity of this strategy. The labor market reveals an apparent paradox: despite the fact that ever-increasing numbers of engineers are graduating from Chinese and Indian institutions, many of them are going unemployed; at the same time, representatives from multinationals are complaining of a deficit of qualified engineers. The key to this paradox is the assertion that quality matters. While China and India may be producing more and more engineers, these engineers do not meet the quality requirements they need to compete globally. In fact, as India’s faculty shortage would indicate, the drive to increase quantity of graduates may have even eroded the quality of the education those very graduates are receiving.

4) China and India both seek to upgrade their knowledge economy, but the approaches and the strategies that they have taken differ greatly, due largely to their contrasting political and cultural systems.
China and India have both tackled this issue of knowledge-intensive upgrading, and both have sought to jump ahead of the development curve by investing and cultivating new areas of the knowledge economy. Yet the two have taken very different approaches, and have used very different sets of tools to address this problem. China has taken a fairly top-down approach to this issue. In looking at engineering education, for example, the government played a primary role, launching a national effort to promote mass education. It plays a similar role in promoting nanotechnology research; in contrast to the US or even Europe, where private and venture capital play a large role in promoting start-ups and advancing new lines of research, the majority of nanotechnology funding in China comes from government sources. It is important to note, however, that this top-down model is not absolute. In speaking to administrators from several top-end universities, we found that China’s top tier of schools was largely able to resist the major expansion that began in 1999, both due to their political connections and because they successfully argued that they needed to maintain quality. Private education is still small in scope, but has grown in recent years. In R&D funding, China’s private capital markets are growing, and Hong Kong capital also does play a role. In large part, however, China’s response to this upgrading challenge reveals a more centralized, top-down approach.

In India, where some claim that the economy has succeeded “in spite of the government,” has taken a bottom-up, market-led approach. In terms of education, India’s state-run institutions are only part of a larger education system that includes a significant number of private colleges. These private colleges represent a significant portion of the increase, both because enrollment has increased in existing colleges and, more importantly, because new colleges have sprung up to meet demand. In addition, new institutions like NIIT have appeared to address this skills gap between college graduates and company hires. The government has played a role in this process, enacting policy on the state and federal levels. This role, however, has been more facilitative, and less directive, than has been the case in China.

5) Both India and China still face major bottlenecks and barriers they must overcome.

Both countries, however, still have a number of issues that they must deal with in order to fully implement this knowledge-based upgrading strategy. In terms of the workforce, both countries share a set of issues: cultural issues, language issues, questionable (or at least inconsistent) technical skills, and a lack of “soft skills.” Engineers in India and China may receive solid technical training, but it is a host of other “soft skills” and leadership skills – nearly identical to those of a “dynamic engineer” – that firms repeatedly told us were underdeveloped in many of their new hires. Language skills are far less of an issue in India, due to the widespread use of English, but are a major concern in China. Cultural issues were also an issue in both. For example, hiring officials in both labor markets discussed the more hierarchical nature of social interactions between employees as a concern, as it can dampen the free flow of ideas and suggestions throughout the company. In addition, both countries are facing questions about their facilities and faculty to continue turning out increasing number of engineers.
Both countries also face concerns about the long-term durability of these clusters, based on questions about the sustainability of their high-skilled, low-cost labor pools. In the immediate future, we expect that the number of R&D centers operating in India and China should continue to grow, as more and more companies jump on the bandwagon and move abroad to take advantage of high-skill, low-cost labor and access to growing markets. Already, however, some are concerned that current hubs of MNCs activity – Beijing and Shanghai, Bangalore and Hyderabad – may eventually become less competitive. One major factor behind this is labor costs; in Bangalore, MNCs have already had to increase salaries and restructure benefits to attract and retain qualified engineers. The labor market currently is fairly flexible, with high attrition and turnover, which dampens wage rigidities that could keep wages low. Though we encountered this concern less often while interviewing in China, a similar set of labor market dynamics would indicate that China faces the same puzzle. While the current discussion on this generally concludes that this business may go to other domestic locations – Bangalore to Chennai, for example – the long-term issues of durability remain for policymakers in both India and China to address.

Each country also faces a separate set of unique concerns. India faces major concerns about its infrastructure, especially that related to transportation. Many R&D facilities in India can partially handle concerns about the electric grid by building duplicate facilities on site, and have less need for clean water than other types of R&D facilities might have. Roads and transportation, however, remain major issues for IT firms, and came up time and time again in our discussions with industry leaders. In China, IP protection remains a concern for some S&T firms. Financial resources are a potential bottleneck for both countries, although with the funds that China is pouring into research and the R&D centers popping up in both countries, one might think differently.
Table 1: A Breakdown of the Commonly Cited Statistics on Engineering Graduates

<table>
<thead>
<tr>
<th>Country</th>
<th>Reported Graduates</th>
<th>What is Included in these Numbers:</th>
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<tbody>
<tr>
<td>The United States</td>
<td>70,000</td>
<td>Four-year engineering bachelors degrees.</td>
</tr>
<tr>
<td>China</td>
<td>600,000</td>
<td>Three- and four-year engineering degrees under a broad definition of &quot;engineer&quot;. Additionally, computer science and information technology three- and four-year degrees are included.</td>
</tr>
<tr>
<td>India</td>
<td>350,000</td>
<td>Three- and four-year engineering, computer science and information technology degrees.</td>
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</tbody>
</table>

Source: Gereffi, Wadhwa and Rissing (2006a)

Table 2: Four-Year Bachelors in Engineering, Computer Science and Information Technology Awarded from 1999-2004 in the United States, China and India

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</thead>
<tbody>
<tr>
<td>United States 1</td>
<td>101,249</td>
<td>108,750</td>
<td>114,241</td>
<td>121,263</td>
<td>134,406</td>
<td>137,437</td>
</tr>
<tr>
<td>India 2</td>
<td>82,107</td>
<td>109,376</td>
<td>129,000</td>
<td>139,000</td>
<td></td>
<td></td>
</tr>
<tr>
<td>China (MoE CERN) 3</td>
<td></td>
<td></td>
<td>293,125</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>China (MoE Yearbook) 4 *</td>
<td>195,354</td>
<td>212,905</td>
<td>219,563</td>
<td>252,024</td>
<td>351,537</td>
<td>442,463</td>
</tr>
</tbody>
</table>

*Data highlighted in gray may constitute overestimated figures.
Source: Gereffi, Wadhwa and Rissing (2006a)

3 There are some minor questions with this data. For Chinese data, we believe that data provided by the Chinese Ministry of Education may include additional engineering and technology degrees outside traditional engineering, computer science majors and IT majors (for example, auto mechanics). In addition, it should be noted in the US statistics that the National Center for Education Statistics reports the total US engineering bachelors degrees granted in 2004 to be 63,558, while the American Society of Engineering Education's (ASEE) 2004 statistic of 72,893. This variation is due to the way that each of these organizations classifies and categorizes engineering graduates. Primary sources for this data: United States Department of Education National Center for Educational Statistics (NCES), (Assorted years), Current Tables 249 and 253; National Association of Software and Service Companies (NASSCOM), “NASSCOM Strategic Review: The IT Industry in India” (Assorted Years); China Education and Research Network (2005) “The Ministry of Education announced in the last two years of ordinary professional enrollment data,” (April), Last Accessed 6 November 2006 <http://www.edu.cn/20050430/3136324.shtml>; Chinese Ministry of Education (MoE) “Number of Students in Regular HEIs by Field of Study,” Chinese Statistical Yearbook (Assorted Years).
Figure 1: Engineering, Computer Science and Information Technology Graduates in the US, China and India

Source: Gereffi, Wadhwa and Rissing (2006a)

Figure 2: Subbaccalaureate Engineering, Computer Science and Information Technology Graduates in the US, China and India

Source: Gereffi, Wadhwa and Rissing (2006a)
Figure 3: Bachelors Degrees in Engineering, Computer Science and Information Technology per Million Citizens, 2000-2004

Source: Gereffi, Wadhwa and Rissing (2006a)

Figure 4: Nanotechnology Value Chain

Bibliography

Primary Sources

In addition to the secondary references mentioned below, we also relied heavily on interviews conducted in both China and India with a number of firms and institutions. For further information on these interviews, contact Ryan Ong (ryan.ong@duke.edu).

Secondary Sources


