Getting the Numbers Right: International Engineering Education in the United States, China, and India

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ABSTRACT

This article challenges the commonly cited statistics for engineering graduates in the United States, China, and India. Our research shows that the gap between the number of engineers and related technology specialists produced in the United States versus those in India and China is smaller than previously reported, and the United States remains a leading source of high-quality global engineering talent. Furthermore, engineering graduates in China and India face the prospect of substantial unemployment, despite high corporate demand for their services; this raises questions about the quality of recent graduates. The United States, however, also confronts problems in its continued ability to attract and retain top engineering talent from abroad because of visa uncertainties and growing economic opportunities in their countries of origin. We argue that the key issue in engineering education should be the quality of graduates, not just the quantity, since quality factors have the biggest impact on innovation and entrepreneurship.

Keywords: dynamic and transactional engineers, engineering education, offshoring

I. THE GLOBAL TALENT POOL IN ENGINEERING

The global economy is undergoing a dynamic evolution. "Globalization" is the name of the game, and firm and industry leaders are rushing to capitalize on the advantages globalization can bring, including better access to suppliers and customers around the world. However, globalization also presents a series of major challenges to companies, their employees, and policymakers. Just as globalization has redefined the economic logic in traditional industries, it is now reshaping knowledge-intensive fields like electronics and information technology (IT).

While the offshoring of manufacturing jobs has been documented for decades, there is fresh debate over the relocation of service-related jobs in sectors like banking, IT, and engineering. Today, multinational corporations (MNCs) are reorganizing their global research and development (R&D) networks to lower costs and increase efficiency, while expanding their operations abroad—especially in the developing world (Goldbrunner, Doz, Wilson, and Veldhoen, 2006; Hart, 2006). These new business structures have required the coordination of research in different areas, bringing science and technology (S&T) workers in Silicon Valley in contact—and competition—with colleagues from Boston to Bangalore. In the process, they are catalyzing the emergence of global labor markets for knowledge workers, which is what the State University of New York's Levin Institute terms the "global talent pool" (Levin Institute, 2005).

The creation of a global talent pool and the relocation of U.S. research hubs abroad have raised serious questions about the continued competitiveness of the U.S. economy relative to emerging economic powers like China and India (Gereffi, 2006; Kenney and Dossani, 2005). Our paper aims to address these questions of relative competitiveness by examining one aspect of this global talent pool, namely, the competitiveness of engineers in the U.S., China, and India.

A. Why China and India?

A great deal of the debate over the globalization of knowledge economies has focused on China and India. One reason has been their rapid, sustained economic growth. The Chinese economy has averaged a growth rate of 9–10 percent for nearly two decades, and now ranks among the world's largest economies. India, too, has grown steadily. After years of plodding along at an average annual increase in its gross domestic product (GDP) of 3.5 percent, India has expanded by 6 percent per annum since 1980, and more than 7 percent since 1994 (Wilson and Purushothaman, 2003). Both countries are expected to maintain their dynamism, at least for the near future.

China and India also contain the world's two largest populations, but their per capita income remains low. The perceived potential of these two economies to surpass their Western counterparts is unmatched anywhere else in the world. While governments view these trends with caution, businesses are salivating over the potential opportunities. Both countries, indeed, have played a large role in recent offshoring trends, capturing large numbers of jobs that have relocated from other areas. It is no accident that China is called the "factory of the world," while India claims to be the "back office of the world."

In addition, China and India are not limiting their development plans to traditional manufacturing and service sectors. Both countries have sought to break into high-tech industries like computing, electronics, and nanotechnology, while maintaining their advantages in low-end manufacturing such as textiles and apparel. In both India and China, the dual magnets of low-cost, high-skill labor and access to their big domestic markets have driven MNCs to establish hundreds of new research parks and development centers in high-tech industries. Thus, even fields where American firms have typically held an advantage are now caught up in the great global scramble for jobs.

B. A Sharp Debate

The debate over engineering offshoring and the impact of globalization on science and engineering has raged fiercely in recent years, involving journalists, engineers, entrepreneurs, educators, and government officials, among others. A detailed analysis in the National Academies of Engineering report, *Rising Above the Gathering Storm*, has been central in this discussion. The list of key recommendations include a renewed U.S. commitment to education, research and innovation, with increased funding for teaching as well as basic research, and commitments not only from governments at the federal, state, and local levels, but also from individuals and families (National Academy of Engineering, 2006). Articles in sources ranging from *Fortune* to the U.S. Department of Education have also played a key role in this controversy (Bialik, August 2005, October 2005; Colvin, 2006; National Academy of Engineering, 2005; U.S. Department of Education, 2006).

Yet many aspects of the debate are murky, starting with the numbers themselves. A plethora of articles and speeches have recycled the same statistics on undergraduate engineers in the United States, India, and China. According to these reports, the United States produced roughly 70,000 undergraduate engineers in 2004, while China graduated 600,000 and India 350,000 (Colvin, 2006; National Academy of Engineering, 2005; U.S. Department of Education, 2006). While China and India have increased their engineering graduates, the U.S. number has fallen (Wulf, 2005).

Many Americans are worried about engineering education in the United States compared with other nations. *Rising Above the Gathering Storm* notes that the U.S. share of global degrees in science and engineering has dropped over the last several decades, as interest in these fields in the United States has waned. In addition, a large percentage of graduate degrees, especially Ph.D.s, are awarded to foreign nationals each year. As opportunities for career advancement grow abroad, these scientists may be more likely to return to their home countries, leaving fewer S&T workers here in the United States (Freeman, 2005; National Academy of Engineering, 2006).

We believe these issues deserve a closer look. Despite the wide circulation of these statistics for engineering graduates, multiple authors and articles have questioned their statistical validity (Bialik, October 2005; Gereffi, Wadhwa, and Rissing, 2005; Wadhwa, Gereffi, Rissing, and Ong, 2007; Wadhwa, 2006). There are also practical questions of strategy and policy, as analysts try to figure out how much of a challenge countries like China and India pose to the United States and the developed world, and in what ways these countries' engineers might be competing with their U.S. counterparts.

Our research on international engineering education at Duke University over the past few years shows that the engineering numbers for China and India are inaccurate and misleading. Each country collected its statistics using radically different methodologies and even distinct definitions for the term "engineer". Furthermore, we believe that one cannot assess the competitive positions of American, Chinese, and Indian engineers without a discussion of their relative quality. Our field research in China and India suggests that the increasing quantity of Chinese and Indian engineers has come at some cost to their quality.

II. Methodology

This study provides a comprehensive and detailed empirical comparison of engineering graduates in the United States, China, and India. We have assembled a cross-national dataset on the number of engineering, computer science, and information technology degrees granted from 1994 to 2006, including bachelor's, master's and doctoral degrees in each country. This statistical comparison is used to discuss the current production of engineers and technology specialists and their potential utilization by MNCs.

The Ministry of Education (MoE) in China and the National Association of Software and Service Companies (NASSCOM) in India are the main sources of engineering graduation data within their respective countries. The statistics released by these organizations include not only recipients of four-year degrees, but also holders of three-year degrees and other diplomas as well as a wide range of technicians. These numbers typically have been matched against accredited four-year engineering degrees in the United States, which generates fallacious comparisons.

To address these disparities, we performed a careful analysis of each of the major national sources of engineering graduation data in order to develop more valid conclusions. We also examined the educational policies of leading universities in China, India, and the United States to gain further insight into the quantity and quality of engineers being produced in each country.

A. What is an Engineer?

This debate originates with conflicting definitions of an "engineer." Varying conceptions of the engineering profession exist not only between countries, but even within them. In academic and professional settings, an engineer can be defined as a person capable of using scientific knowledge, especially math and science, to solve real-world problems. This conception, however, makes it difficult to count engineering populations. In the United States, various surveys and reports have used multiple definitions for an "engineer" including: an individual working in an engineering occupation, an individual whose most recent degree is in a traditional engineering discipline, and an individual working in a position that requires specific engineering knowledge (National Science Board, 2006; Pollak, 1999). Traditionally, engineering in the United States has been divided into specialties like civil engineering, mechanical engineering, electrical engineering, and so on.

In recent decades, fields such as computer science (CS) and IT have surged in popularity around the world, but U.S. academic institutions are divided as to whether or not these majors should be affiliated with engineering schools. IT degrees are rarely granted in schools of engineering, and CS degrees are only occasionally affiliated. During the 2005–06 academic year, computer engineering

degrees were awarded by 165 U.S. schools, while 48 schools granted electrical/computer engineering degrees and 148 schools offered computer science degrees within the engineering discipline (American Society for Engineering Education, 2007).

Although many prominent U.S. universities offer CS-related degrees through their engineering schools, hundreds of others offer CS degrees outside their engineering schools. At Duke University, for example, the computer science degree is offered through Trinity College (Arts and Sciences), rather than through the Pratt School of Engineering. These distinctions greatly increase the difficulty of counting engineering graduates in a systematic fashion.

In contrast, China and India both include CS and IT professionals in their tally of engineering graduates. In many locations, such as India, CS, and IT degrees dominate the output of engineering schools. In these countries, relevant computer training paired with an internet-enabled computer empower CS and IT graduates to compete in the global marketplace. In contrast, the equipment and infrastructure costs tied to a mechanical or civil engineering degree are quite high. India's IT boom has made this comparison even starker, and pushed record numbers of Indian students into the CS and IT sectors.

Some developing countries face another difficulty in determining who should be counted as an engineer. As we learned during our interviews in China, the Soviet development model led Chinese administrators to attach the term "engineering" to many institutions and programs that had science- and technology-related, but not necessarily pure engineering content. The legacy of this system means that some "engineering" programs may not utilize or even train actual engineers.

After carefully evaluating the educational landscapes in the United States, China, and India, we decided that the most objective means of comparing engineering graduates in these countries was to count engineering, computer science, and information technology degrees together. All three offerings involve fundamental problem-solving and quantitative skill sets. Additionally, skilled individuals with these degrees are at the very core of the current debate over engineering outsourcing. For the purposes of this paper, unless otherwise noted, the term engineer refers to this broader definition, and includes traditional engineers as well as holders of computer science and information technology degrees.

B. Sources of Engineering Graduation Statistics in the United States, China, and India

In this study, we investigated multiple statistical sources from the United States, China, and India to obtain graduation data on engineering, CS, and IT degrees. We provide a brief background below on these sources and the viability of their statistics.

1) United States: The U.S. Department of Education's National Center for Education Statistics (NCES) publishes comprehensive annual graduation figures for the United States in the fields of engineering, CS, and IT. As a result, these are the most appropriate data to use when comparing the United States to other nations with broader definitions of "engineering". The American Society for Engineering Education (ASEE) and the Engineering Workforce Commission (EWC) also publish detailed engineering graduation statistics, but they do not include full information for students graduating from CS or IT programs.

2) China: In China, the national government monitors engineering graduation statistics through the Ministry of Education.

However, this organization offers little information on how these data were collected, and a very limited explanation of which fields of engineering are covered. The MoE informed us that their aggregate numbers were obtained by adding all engineering graduates reported by each province. China's provinces, though, do not share a standard definition of engineering, and there are questions about what qualifies as an engineering program in China. Conversations with MoE representatives indicated that any bachelor's degree with "engineering" in its title is included in MoE statistics, regardless of the field or associated academic rigor. In essence, this means that the reported number of engineers produced in China may include not only traditional engineers, but also mechanics and industrial technicians.

Data released through the China Education and Research Network (CERN) provide another source of information on Chinese educational statistics in its *Education Report* (*Jiaoyu Bao*). The MoE data released by CERN are particularly valuable because the report gives information on specific engineering majors. However, one of the limitations of this source is that it includes only those specializations that enroll more than 10,000 students in China (56 specialties out of close to 500 in 2004), which leads to an undercount of total engineering undergraduates.

In April 2005, *Education Report* contained an article that, unlike earlier issues, included bachelor's degree graduation data broken down by major, with data for the 2002–03 and 2003–04 academic years. Utilizing the CERN statistics, we were able to identify the number of engineering graduates who received bachelor's degrees in 2003 and 2004 within engineering, CS, and IT fields.

3) India: In India, the most prominent source for information on the government's yearly allocation of engineering bachelor's seats is the All India Council for Technical Education (AICTE). This allocation refers to the maximum number of engineering students permitted to *enroll* in a given year. To estimate the number of engineering and technology degrees awarded in a specific year, NASSCOM combines AICTE intake figures for the year 2000 with statistics on historical graduation trends (and drop-out rates), as reported by the Indian government's Institute of Applied Manpower Research (IAMR). However, NASSCOM only performs this analysis for bachelor's and select master's degrees. Our group collected raw AICTE trend data and did an analysis that mirrors NASSCOM's for master's level engineering degrees, in order to give us complete information across all degree categories. Doctoral data were obtained though the Indian Ministry of Education

C. Interviews and Field Research

In addition to our statistical calculations, we sought to confirm and refine our data through interviews and field research in each country. In the initial stages of our project during the fall of 2005, a team of student researchers from the Master of Engineering Management Program at Duke University, including Chinese and Indian nationals, contacted relevant organizations in our three key countries. We held detailed telephone conversations with representatives of NASSCOM, MoE, the U.S. Department of Education, and ASEE. Our team also contacted over 100 universities in India, 200 universities in China, and selected engineering school deans in the United States to validate the graduation statistics. These phone calls sought data on the number of engineering degrees awarded from these schools and affiliated colleges.

While some university registrars in India were able to provide full data, many were unable to tell our researchers how many engineering students they graduated or enrolled, or were uncertain how many colleges were affiliated with their university system. In China, government policy often prevented universities from disclosing any graduation data. This initial round of phone calls, however, seemed to support the engineering graduation totals issued by the national reporting agencies in China and India.

During our second round of research, we traveled to China and India in August and October of 2006, respectively, to conduct further data searches and interviews. In China, we spoke with both government and university officials, including individuals from Tsinghua, Fudan, and Shanghai Jiao Tong Universities. During our time in India, we visited Bangalore and New Delhi, and met with individuals from the AICTE and from several key universities, including the Indian Institute of Technology (IIT) in Delhi and the Indian Institute of Information Technology (IIIT) in Bangalore. In both countries, we conducted interviews in prominent MNCs that were hiring China's and India's top engineering graduates, and we toured R&D centers. This research allowed us to complete our datasets, especially on the post-baccalaureate side, and to learn more about the quantity and quality issues that shape global engineering.

III. Quantitative Findings

A. Cross-National Comparisons of Engineering, CS, and IT Degrees in the United States, China, and India

In this section we present data on engineering, CS, and IT degrees in the United States, China, and India over the past decade. Separate trend analyses will depict the changes in bachelor's, master's, and doctoral degree production within these countries. Although we still do not have perfectly comparable statistics, these datasets represent to the best of our knowledge the most accurate set of quantitative data that can be assembled using publicly available information from the aforementioned countries.

1) Bachelor's Degrees: As Figure 1 shows, all three countries experienced growth in their output of engineering degrees at the bachelor's level since the mid-1990s, with China's being the most rapid. Since the late 1990s, the United States had a modest increase in bachelor's degree output, from just over 103,000 in 1998–99 to more than 137,000 in 2003–04 before declining slightly to about 129,000 in 2005–06, a growth of nearly 25 percent since 1998–99. India's expansion at the bachelor's level was more rapid, with four-year degree holders in engineering, CS, and IT more than tripling in the last seven years, from just over 68,000 in 1998–99 to nearly 220,000 in 2005–06. The fastest growth in bachelor's degrees, however, appears
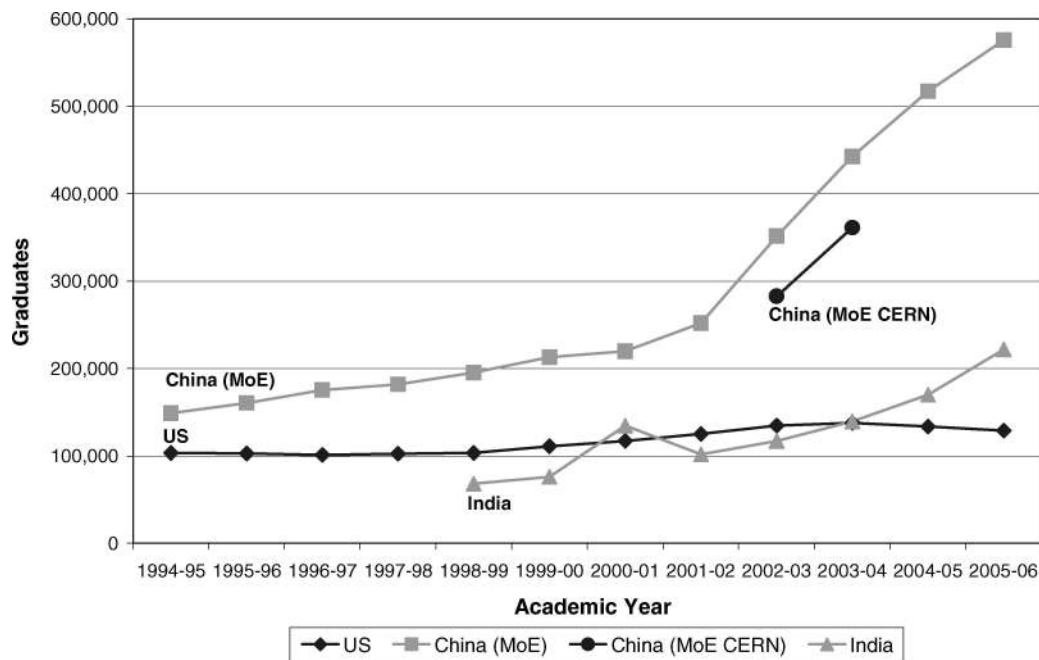
Notes:
- Sources (All India Council for Technical Education, various years; China Educational and Research Network, 2005; National Bureau of Labor Statistics, various years, 2007, U.S. Department of Education, 2007).
- The data provided by the Chinese MoE may include additional engineering and technology degrees outside traditional engineering fields, CS majors and IT specializations.
- The MoE's CERN data omit "small majors," defined as any major (engineering or otherwise) with a 2004 enrollment of less than 10,000 students.
- The statistics for India are estimates based on government-approved intake capacity as reported by the AICTE. These estimates do not account for graduates from India's IITs and IIIT Bangalore. As a benchmark, 2,274 undergraduate students received bachelor's degrees from all of the IITs during the 2002-3 academic year (Natarajan, 2005).

Figure 1. Production of engineering and technology Bachelor's Degrees in the United States, China, and India.
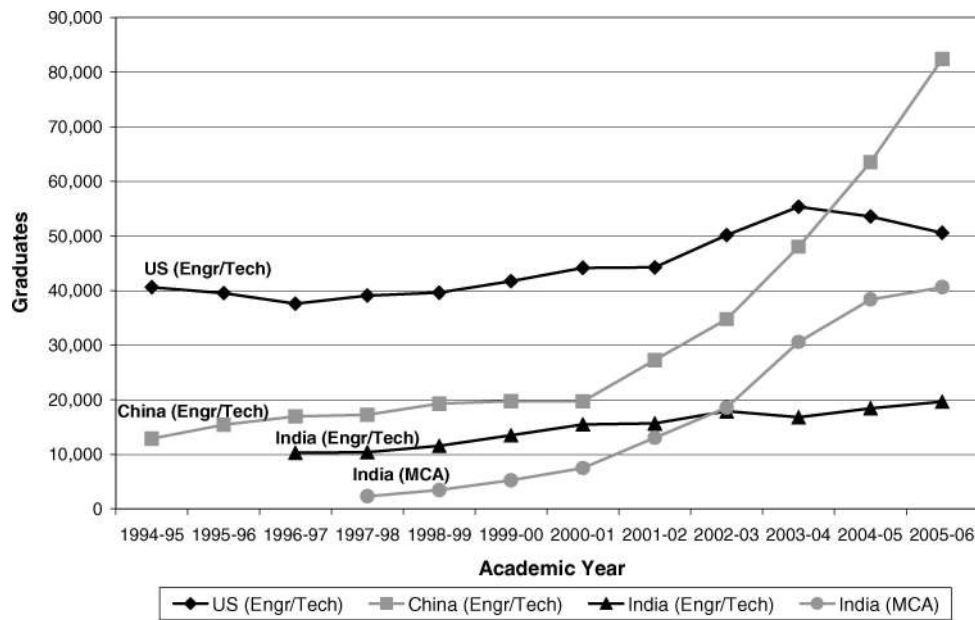
Notes:
- Sources (All India Council for Technical Education, various years; National Bureau of Statistics, various years, 2007, U.S. Department of Education, 2007).
- The data provided by the Chinese MoE may include additional engineering and technology degrees outside traditional engineering fields, CS majors and IT specializations.
- The statistics for India are estimates based on government-approved intake capacity as reported by the AICTE. These estimates do not account for graduates from India's IITs and IIIT Bangalore. As a benchmark, 3,675 postgraduate students (excluding PhDs) received degrees from all of the IITs during the 2002-3 academic year (Natarajan, 2005).

Figure 2. Production of engineering and selected CS and IT Master's Degrees in the United States, China, and India.

to be occurring in China. According to the Chinese MoE, the number of bachelor's degrees awarded has more than doubled in the last four years, from 252,000 in 2001–02 to 575,000 in 2005–06. Data from CERN, which is more detailed but only available for a limited number of years, parallels this growth rate, indicating a sharp surge in the number of Chinese engineering graduates.

2) Master's Degrees: The growth in engineering, CS, and IT master's production in these three countries paints an interesting picture, as seen in Figure 2. In the last decade, the number of U.S. master's degrees awarded in these three fields grew from 39,525 to 50,585, an increase of 28 percent. During this same period, Chinese master's production increased by a factor of five, from 15,391 to 82,386. Whereas in 1994–95, China produced only one-third as many master's degrees as the United States, by 2005–06, China produced nearly 40 percent more master's degrees than the United States

The Indian situation is more complex, due to the existence of two distinct master's-level engineering degree offerings. The first is a traditional technical master's degree, meant for students who have completed engineering education at the undergraduate level. The second degree, a Master's of Computer Applications (MCA) degree, is a one- to three-year certificate that offers a foundation in CS to individuals who had previously received a bachelor's degree in a different field. Thus, while most MCA entrants have little knowledge of CS, their knowledge base at graduation is roughly equivalent to that of an individual with a bachelor's degree in CS.

Individuals with an MCA hold a graduate degree by definition, but do not possess a graduate-level education by customary standards. As a result, we have separated out MCA degrees from tradi-

tional master's degrees, and show them as a separate trend line. Over the past decade, these two trend lines show very different trajectories. Technical engineering master's degrees in India have enjoyed a moderate growth in the last ten years, expanding by 90 percent since 1996–97. In contrast, interest in MCA degrees has exploded, rising at an average of 44 percent per year. This is probably due to the growing opportunities and strong popularity that are tied to CS and IT positions in India.

3) Ph.D. Degrees: The trends in doctoral engineering, CS, and IT degree production in the United States, China, and India shown in Figure 3 offer a striking portrait of the educational environments in these countries. In the United States, the number of Ph.D. degrees awarded in technical engineering, CS, and IT fields has averaged around 7,000 degrees for the past decade, with a slight upswing in the last four years to reach 8,887 in 2005–06. In contrast, Chinese Ph.D. production increased nearly sevenfold during the same time period, from 1,784 in 1994–95 to 12,130 in 2005–06, tracking the growth rates at other degree levels. This steady and significant increase can be attributed to the Chinese government's educational reforms, which will be discussed later in this paper.

However, in India, the growth in undergraduate and master's degrees in engineering has not translated to the doctoral level. Over the last decade, Indian Ph.D. production has averaged in the high 700's each year, and shown very little movement. This lower degree output is attributable to the lack of higher education institutions in India equipped to offer doctoral programs. While most public and private schools in India can offer bachelor's and MCA degrees, very few institutions have the funding, facilities, and faculty to offer
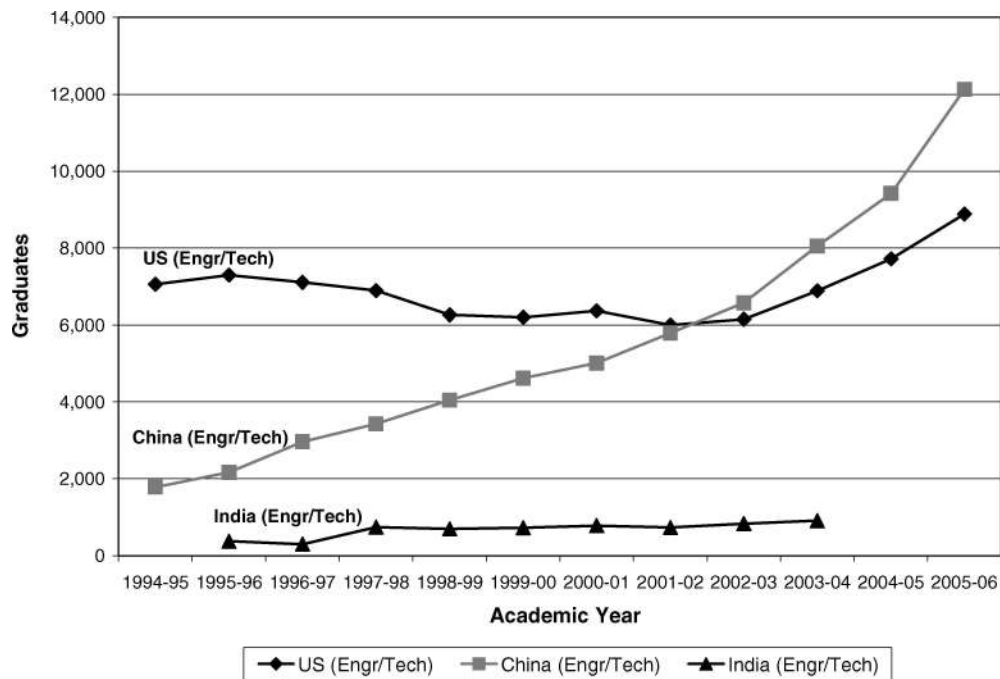
Figure 3. Production of engineering and technology Ph.D. Degrees in the United States, China, and India.

Ph.D. programs to Indian students, and this number has not expanded much in recent years. As a result, many Indian engineers and technology specialists who are interested in pursuing a doctoral education travel abroad.

B. The Role of Foreign Nationals in Engineering in U.S. Universities

In the United States, concern has been raised over the large proportion of graduate-level science and engineering degrees that are earned by foreign nationals. This preoccupation has been exacerbated in recent years because of the perception of an increased likelihood that these engineers may return to their home countries in response to new incentives to develop high-technology fields there. This "export" of the fruits of their American-earned education abroad for the benefit of other economies marks a reversal of the traditional international "brain drain" from which the U.S. high-technology community has long benefited (Pollak, 1999).

While engineering, CS, and IT degree production in the United States has been stable or increasing at all degree levels over the past ten years, a sizable percentage of these degrees are indeed being awarded to foreign nationals. Statistics collected by the ASEE on bachelor's, master's and Ph.D. degrees in engineering indicate that during the 2005–06 academic year, 7.2 percent, 39.8 percent and 61.7 percent of these degrees, respectively, were awarded to foreign nationals (Figure 4). As these figures indicate, the percentage of foreign nationals is significantly higher at the graduate level, especially for Ph.D. degrees.

The high percentage of U.S. engineering degrees earned by foreign nationals becomes an even greater concern, however, if these individuals do not remain in the United States after they graduate. How many of these foreign degree-earners actually return to their home countries? According to research by Michael Finn from the Oak Ridge Institute for Science and Education, the number of Chinese and Indian nationals who received science and engineering doctorates from U.S. universities who were still in the United States five years after receiving these degrees was quite high—90 percent for Chinese and 86 percent for Indian graduates in 2003.

By field, most of those areas with the longest five-year stay rates were all engineering-related: computer science (70 percent), computer/EE engineering (70 percent), and other engineering (67 percent) (Finn, 2005). These numbers, however, contain a significant time lag, since the 2003 statistics chart the stay rates of individuals who received their doctoral degrees in 1998. Given the changes in the U.S. visa system since 2001 and the rapid ascent of the Chinese and Indian economies, there are serious concerns that the U.S. visa landscape is greatly limiting the country's capacity to retain exceptional individuals once they graduate (Wadhwa, Jasso, Rissing, Gereffi and Freeman, 2007).

IV. Qualitative Findings

A. The Supply and Demand for University-Trained Engineers in China and India

The rapid increase in the number of engineers graduating from institutions in China and India is caused by the interaction between two variables: the supply of engineers graduating from universities and a rapid increase in the demand for engineers in these economies. For China and India, the supply and the demand for engineers have
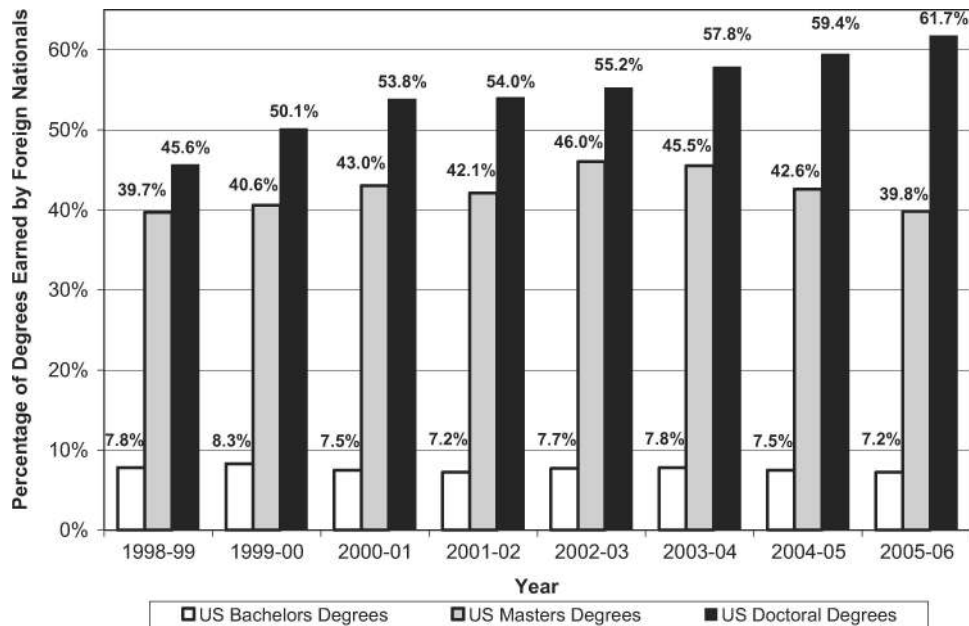
Figure 4. Percentage of U.S. engineering degrees earned by foreign nationals (American Society for Engineering Education, 2006, p. 13, 21, 25).

both increased dramatically in recent years. Yet each of these factors has different dynamics and requires a separate discussion.

1) Supply of Engineers—Changes in Educational Policy and Education Systems: In China and India, an increase in the supply of engineers with postgraduate degrees has been the result of market forces and explicit policy decisions. Both countries have large populations, 1.32 million for China and 1.13 million for India as of July 2007, and thus the sheer number of engineers in each country could be correspondingly large. Citizens in these countries have long viewed engineers as a critical input to their national development, and interest in engineering fields runs high among students, government officials and technology leaders alike. China and India have each taken concrete steps to increase the engineering enrollments of their universities.

China

In China, the surge in engineering degree production can be traced to a series of 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 university enrollment. The Chinese leadership had several reasons for this shift, including long-term development needs for more domestically trained engineers, medium-term goals to help China upgrade by building a competitive position in knowledge-intensive industries, and short-term causes like the Asian financial crisis in the late 1990s and the ascension of Zhu Rongji to the position of Premier in 1998 (Bai, 2006; Kang, 2000; Li, 2004; Ni and Wang, 2005; Yang, 2004). The reduction of engineering salaries has been a clear consequence of these policies, intended or not, as we learned during our conversations with executives. According to several industry executives, they can now hire master's level graduates for the same salaries as they used to pay engineers with bachelor's degrees.

As part of their development plan, the central and provincial governments put pressure on universities to increase the number of students enrolled in their engineering programs. In a country where

the vast majority of universities are public, not private, most universities complied, despite serious concerns that extra students would strain resources and lower quality. This enrollment surge was focused mainly on the undergraduate levels, but also spilled over into the graduate programs, due both to the response of university officials to educational imperatives as well as to the employment woes of many baccalaureate degree holders. By 2005, overall enrollment in higher education institutions (HEIs) had reached 23 million students, giving China the highest HEI student enrollment in absolute terms of any country in the world (Fladrich, 2006).

Although the MoE announced in June 2006 that it would begin to curb enrollment growth, enrollment (and by extension graduates) are expected to increase for several more years, as the expanded classes continue to work their way through the system (*Xinhua*, 2006). These growth rates are likely to slow, however, both because of conscious government policy and because the ballooning supply of graduates has led to increased rates of unemployment among university-trained engineers (Fladrich, 2006). This is especially true for those graduating from universities that are not in the top tier.

China's National Development and Reform Commission, a major economic planning body, reported in early 2007 that job openings for new graduates across all disciplines had fallen over the previous year by 22 percent, to a level of only 1.6 million. At the same time, university graduates had increased substantially, meaning that 60 percent of China's 2006 university graduates would be unable to find work (Chan, 2006). In one interview with an engineering professor from the mid-level Beijing Institute of Technology, he indicated that up to 30 percent of students in his specialization would be unable to find full employment after graduation.

India

India has shown much more modest growth in its graduate education. In contrast to China, India's growth has been more market-driven than policy-driven, and more bottom-up than top-down. These characteristics reflect the less centralized nature of India's

economic and educational systems. Government policy has taken some steps to reform university engineering and increase enrollment. For example, the Indian government announced an expansion of higher education with the creation of 500,000 new university seats in September 2006 (Verma, 2006). The AICTE, the Indian government body charged with regulating technical higher education, also conducts periodic reviews of its graduate education systems, which have resulted in the adoption of a series of recommendations to improve and expand the engineering education system. The Rama Rao Committee, which convened from 1995 to 1999, produced a list of suggestions about postgraduate engineering education, ranging from changing program length for master's degree programs to altering the financing and geographic distribution of programs. While some of these recommendations have been carried out, others are still not fully implemented (Natarajan, 2005).

In addition to the growth of state-run education, India has experienced an explosion in its private education. By 2004, India boasted 974 private engineering colleges across the country, compared with only 291 public and government institutions (Somaiya, 2005). Many of these private institutions are unrecognized and unregulated by AICTE, since the federal government has yet to pass a legal framework governing private colleges. State governments, especially those in Maharashtra and South India, have been more proactive, with many passing legislation that defines and regulates the role of private universities in their territory (Altbach, 2005; Das, 2006; Gupta, 2005). In this environment, new colleges and training centers have sprung up to address skill gaps between traditional college graduates and company hires. NIIT (formerly the National Institute of Information Technology) is perhaps the largest of these, and it 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.

Like China, India is also facing unemployment for some of its engineers. While the expanded hiring practices of employers, combined with the emergence of private sector training programs, have helped to combat these unemployment trends, India still faces a serious unemployment problem. According to articles published in the *Chronicle of Higher Education*, India has nearly one million unemployed engineers (Mooney and Neelakantan, 2006).

2) Demand for Engineers—The Motor of Economic Growth: In both China and India, the increase in the supply of engineering graduates is partly a response to a corresponding increase in demand. China's burgeoning science and technology workforce has been fueled not only by its dominance in traditional industries like textiles/apparel and footwear, but also by growth in medium and high-tech products, from air conditioners and washing machines to construction equipment and mobile telephones (Appelbaum, Gereffi, Parker, and Ong, 2006). India has been led by the economic explosion in its software and business process outsourcing (BPO) sectors. Today, India exports US$20 billion worth of software and BPO services, and this figure is forecast to reach US$35 billion by 2008 (Mooney and Neelakantan, 2006).

Multinational firms, however, have also played a large, although by no means solitary, role in stoking demand. The growth of R&D centers, of foreign direct investment (FDI), and of local firms in knowledge-intensive industries are providing the pull factors for the S&T labor market, especially for its high-quality engineers. In 2005, China attracted US$72.4 billion in FDI, while India attracted US$6.6 billion (United Nations Conference on Trade and Development, 2006). Much of this FDI has gone to building factories and facilities grouped on the low end of their respective global value chains, but the high-tech component of FDI in both China and India is growing sharply too, as more and more firms seek to take advantage of both countries' low-cost, high-skill talent pools. Although estimates vary, most agree that China now boasts nearly 1,000 MNC R&D centers, mostly clustered in Beijing and Shanghai (Economic Daily, 2006). In India, an estimated 150 of U.S. Fortune 500 firms had established R&D centers as of 2005 (Lane, 2005).

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 and facial recognition to new forms of video download technology (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 populated by foreign MNCs; in both India and China, a cohort of domestic technology-driven companies has emerged, from Infosys and Wipro in India to Lenovo and Huawei in China.

Despite this growth in demand, China and India are still facing a significant level of unemployment among their engineers. Both countries confront a vexing paradox: while statistics show high levels of unemployment among engineers, many large companies complain of difficulty in finding qualified candidates. This paradox can be explained in terms of quality differentials among engineers: there is an oversupply of all engineers, while an undersupply of globally competitive engineers. A 2005 McKinsey Global Institute survey of corporate human resource managers supports this idea, concluding that 80.7 percent of U.S. engineers were globally employable, while only 10 percent of Chinese engineers and 25 percent of Indian engineers were similarly employable (more detail on this survey is provided in section B.2 below) (Farrell, Laboissière, Rosenfeld, Stürze, and Umezawa, 2005).

In sum, top-level graduates in India and China are in high demand, resulting in a severe shortage and high turnover among leading MNCs and domestic firms. Conversely, an engineering graduate from a lower-level institution faces grim employment prospects. While the domestic economy absorbs large numbers of engineers from these less highly ranked institutions, unemployment remains an issue for this supply of engineers, and the problem grew significantly during China and India's enrollment surge after 2000.

B. Quality Issues: Are All Engineers the Same?

This debate is not simply about statistics, although these are central to the discussion. An understanding merely of the number of engineers being produced by the United States, China, and India omits the more important question: how many high-quality, appropriately trained engineers capable of meeting current domestic and global market demands are being produced in each country? In other words, how many Chinese and Indian engineers are capable of competing with each other and with their counterparts in the United States?

1) Types of Engineers – Dynamic versus Transactional: Defining and measuring these quality issues is quite difficult, both for conceptual and empirical reasons. A debate within the engineering profession is leading universities and businesses to redefine those skills that characterize a high-quality engineering education and to discuss how to inculcate students with those skills. In our research, we communicated with a number of industry analysts and academics to develop a working typology of engineers that could help us frame this issue. We have identified two ideal types of engineering graduates that represent the poles of this skills spectrum: dynamic engineers and transactional engineers.

Dynamic engineers are individuals capable of abstract thinking and high-level problem solving using scientific knowledge, and are most likely to lead innovation. These engineers thrive in teams, work well across international borders, have strong interpersonal skills, and are capable of translating technical engineering jargon into common language. In the United States, most dynamic engineers have a minimum of a four-year engineering degree from nationally accredited institutions. These engineers tend to be globally competitive, and are in high demand regardless of their location.

In contrast, *transactional engineers* possess solid technical training, but not the experience or expertise to apply this knowledge to larger domains. These individuals are typically responsible for routine tasks in the workplace. In the United States, transactional engineers often receive associate, technician or diploma awards, although they may also have a bachelor's degree. In other countries, these engineers are produced by lower-tier universities, with thinner curricula and a weaker emphasis on research, group work, applied engineering, and interdisciplinary thinking.

Empirically, it is difficult to separate dynamic engineers from transactional engineers on an individual level because these distinctions are largely skills-based. While the graduates of top-level universities are more likely to be dynamic, this is not a rigid distinction; graduates from top schools may be dynamic or transactional, while graduates from lower-tier institutions may possess (or quickly learn) the skills necessary to compete on a global level. The same applies to countries; no country has a monopoly on good engineering schools or superb engineering graduates. In addition, corporations may hire both transactional and dynamic engineers to fulfill different kinds of jobs. Thus, while this typology does not afford a foolproof statistical breakdown of engineers by quality or employability, we feel it is useful in understanding the innovation issues with which companies in all three countries are grappling.

There is growing evidence that this dichotomy between dynamic and transactional engineers is shaping how businesses think and how universities seek to train their graduates. To explore this topic, our team surveyed 78 division representatives at 58 U.S.-based companies that are involved in engineering offshore. We asked executives to compare the productivity and quality of work performed domestically with that performed overseas, and to describe the strengths and weaknesses of their international engineering workforces. From their responses we derived insights into the characteristics of dynamic and transactional engineers.

Dynamic engineers tended to have good technical training but also a background in non-technical fields. They were often more creative and had better business skills, but in turn, they demanded higher wages for their abilities and they looked for challenges to prove they were capable of higher-level work. Transactional engineers, on the other hand, were able to master fundamental engineering concepts, manage projects, and bridge functional disciplines. Such individuals, however, are less likely to generate out-of-the-box solutions or innovative results. The demand for engineers that have a broad combination of skills, knowledge, and education that go beyond traditional engineering and science training is also highlighted in recent empirical studies of engineers that focus on the offshoring of technology and product development in various emerging economies, such as China, India, Brazil, and Mexico (Lynn and Salzman, July/August 2007, 2007).

On the supply side, faculty and administrators in U.S. engineering schools are also calling for new kinds of engineers as they seek to respond to the challenges of an increasingly globalized engineering workforce. For example, the Masters in Engineering Management Program at Duke University attempts to integrate fields like business and law with the core principles of engineering in order to help foster more advanced skills in innovation, entrepreneurship and high-technology management (see Pratt School of Engineering, 2007). At the Milwaukee School of Engineering, faculty in the Electrical Engineering Department have been active in promoting these ideas, stating that "preparing the next generation of engineers to enter this world with a competitive advantage requires inventive, resourceful, and continuously evolving methods to instill parallel intercultural communication, global resource management, and interpersonal professional training alongside the requisite and non-negotiable technically related subjects of the discipline" (Lee and Dion, 2006; Mossbrucker, Petersen, Scheibler, Williams, and Wrate, 2006).

2) Competitiveness of Engineers in India, China, and the United States in Relation to the Global Economy: To further assess the quality issue, we sought measures that would allow a balanced comparison of engineers across regions and countries. However, this comparison is no easy task. As noted above, the definition of a "quality engineer" is a matter of debate even within the United States; an international consensus on the characteristics of a high quality, globally competitive engineer is even more difficult. Second, the role of engineers in the U.S. economy is vastly different than their role in the Chinese and Indian economies, due to the varying levels of development in each country. The qualities that would make an engineer employable in India or China might not be enough to land a job in the United States. All of these issues make transnational comparisons difficult.

Nonetheless, we can address this question with the results of a 2005 survey by the McKinsey Global Institute, which seeks to measure the employability, and thus the competitiveness in global labor markets, of engineers from a variety of countries. McKinsey surveyed human resource (HR) professionals from 83 companies operating all over the world, and asked them the following question: "Of 100 [engineering] graduates with the correct degree, how many could you employ if you had demand for all?" Because those surveyed were using similar employment criteria (that is, consistent for each company to evaluate engineers from a variety of countries), we felt that this allowed McKinsey to make a fair comparison across countries of the global competitiveness (and thus to some degree the "quality") of American, Chinese, and Indian engineers.

Respondents stated that 80.7 percent of U.S. engineers were employable, while only 10 percent of Chinese engineers and 25 percent of Indian engineers were similarly employable. Employment barriers for these foreign engineers included education quality, cultural issues, and often a lack of accessibility to major urban centers.

English-language ability was a concern for both countries, but while it was only minor concern for Indian engineers, it remains a major concern for Chinese engineers (Farrell, Laboissière, Rosenfeld, Stürze, and Umezawa, 2005).

Multinational corporations like those surveyed by McKinsey represent a small percentage of the overall employment opportunities for engineers in India and China, nor are they the only players in the market for globally competitive engineers. Hundreds of thousands of Chinese and Indian engineers will find gainful employment working for domestic firms. Yet in looking at the challenges facing engineers in the U.S. economy, it is the globally competitive engineers that China and India are producing that should be of primary concern, since it is these engineers that will compete directly with American engineers for jobs. In order to utilize this talent, the crème de la crème of their respective countries' engineers, MNCs are building R&D centers abroad and shifting operations. Thus, while the McKinsey study represents only a portion of the overall employment picture, we believe that our focus on this segment of engineers is valid in examining the quality issue.

3) Is There a Quantity-Quality Tradeoff?: Quality and quantity are closely linked issues in all three of the countries under consideration. Indeed, improving the quality of education and increasing the quantity of those educated are often divergent strategies. Improving quality means devoting more resources per student or enhancing the efficiency of those resources, while increasing quantity means that one should increase the number of students (and, under fixed resources, decreasing resources per student). Degree quality cannot easily be maintained in the face of expanding student populations, unless academic staff and facilities grow accordingly. In many countries, both developing and developed, private institutions are called upon to bridge this gap. Unfortunately, variations in infrastructure, funding, and teaching quality result in an inconsistent private education system in many developing countries (Appelbaum, Gereffi, Parker, and Ong, 2006). China and India are no exceptions to this rule.

In India, much of the surge in engineering graduates has been absorbed by the country's growing private education system. In 2005, 1,355 Indian universities and colleges offered engineering, CS, and IT degrees, with more than 75 percent of these private (All India Council for Technical Education, 2005). This is partly due to India's open regulatory environment, in which private institutions are loosely controlled, and partly due to the over-burdened status of India's public education system. Only a small number of students can attend India's IITs and other public institutions, due to the limited number of seats. As a result, hundreds of thousands of students seek private educations annually.

Unfortunately, the quality of private institutions of higher education in India varies significantly. Funding, facilities, faculty, and recruitment of quality students are all major concerns. For example, private institutions struggle to retain faculty in the face of the allure of alternate Indian engineering business prospects and the relatively low number of individuals holding graduate engineering degrees. In our interviews with educational officials, we learned that some institutions end an academic year with fewer instructors than they began due to defections to the business world. Consequently, degree quality suffers at many of India's colleges and universities.

Despite China's recent surge in engineering graduates, only a fraction of the country's top institutions have maintained their commitment to the quality of the education they deliver. As we learned in our interviews in China, during the enrollment surge that began in 1998 administrators from top-tier institutions like Tsinghua and Fudan Universities lobbied hard to be able to maintain their low enrollment profiles. In doing so, they argued that they needed to limit enrollment increases in order to continue building world-class educational programs. Through lobbying and university connections, these schools were successful. The educational quality at these premier universities is likely a deciding factor for MNCs looking to hire Chinese engineering graduates.

We spoke with executives and recruiters from 10 different multinational engineering firms in China. During these meetings we were told that the majority of MNCs in China target a listing of about 10 to 15 Chinese universities, which varies only slightly from company to company. Beyond this list, recruiters stated, the quality of engineering education drops off drastically. Demand for engineers from China's top-tier universities is high, but the supply is limited, making it difficult for global firms to recruit and retain talent.

Presently the higher education systems of China and India are experiencing great strain. The pressure on these organizations to deliver a quality education is extreme. In years to come, the enrollment in these countries' education systems may stabilize, allowing a greater focus on quality of education—a focus that is badly needed in both countries. While the United States cannot compete with China and India in terms of numbers of engineers, the United States can retain its edge by continuing to be a global hub for world-class engineering education and research, and by focusing on the quality of the education that it provides its citizens.

V. CONCLUSION

There has been great interest in the comparison of engineering graduates in the United States, India, and China. This paper has demonstrated that the statistics commonly cited to compare the number of engineering undergraduates in these three countries are inaccurate indicators of the size of the newly minted engineering workforce and the skills that it possesses.

Improving our engineering statistics is important for national debates on international competitiveness and innovation policy. We have a long way to go, however, in order to have adequate comparative data on either the quantity or quality of engineers produced in these countries. Engineers are still defined differently across national borders; engineering specializations or subfields are often obscured or unreported, and reliable longitudinal data on engineering graduates are extremely difficult to obtain. In our study, recent field research in China and India at the level of national education ministries, industry associations, and leading engineering universities failed to resolve many of these statistical inconsistencies, and indeed revealed ongoing debates within each country over how to count engineers, how to train them, and how many to produce.

The United States, China, and India each believe that educating the engineering and scientific workforce is an essential ingredient for economic development and technological competitiveness. Regardless of the exact numbers, India and China are increasing their engineering graduates at a more accelerated pace than the United States. The debate among U.S. engineering educators is increasingly focused on how to improve the quality of its engineering graduates, since innovation is based on leadership, communication skills, and business acumen, as well as technical prowess. In this respect, a

new generation of dynamic engineers is needed, but there is still no consensus on how best to attain this goal.

Future research on this topic should probe more deeply into the quality of engineers produced in the United States and its leading international competitors. We need to look at what engineers learn in the factories and research labs where they are employed, and not just in the classroom. We also need to extend this research to higher levels of education, including graduate programs. A topic of particular importance to the United States is whether the prominent role played by foreign-born engineers, especially in U.S. master's and doctoral degree programs, will diminish, and whether the incentives provided to undergraduate engineering students are sufficient to attract enough talented individuals from other more lucrative professions.

In engineering, as in all other arenas, the challenge of global competition cannot be avoided. The United States is well-positioned to reap the benefits from growing international competition, but other countries are catching up fast in the global talent race. This is evident in the rapidly growing number of R&D centers in China, India, and other overseas locations. The United States must continue to be a pacesetter not only in how it educates engineering and scientific talent, but also in designing ways to deploy this workforce effectively to tap new innovative frontiers.

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