

# The Quality of Engineering Education in the BRIC Countries

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## Abstract

*Background.* A huge increase in engineering graduates from the BRIC countries in recent decades potentially threatens the competitiveness of developed countries in producing high value-added products and services, while also holding great promise for substantially increasing the level of global basic and applied innovation. The key question is whether the quality of these new BRIC engineers will be high enough to actualize this potential. The objective of our study is to assess the evolving capacity of BRIC higher education systems to produce qualified engineering graduates. We compare developments in the quality of undergraduate engineering programs across elite and non-elite higher education tiers within and across each BRIC country. Our data suggests that in all four countries, a minority of engineering students receives high quality training in elite institutions while the majority of students receive low quality training in non-elite institutions. Given that the supply of graduates from elite programs in the BRICs is already substantial (and is still growing rapidly in India and Brazil) and that a proportion of non-elite programs in China and Russia have the potential to produce qualified graduates, the BRIC countries will soon be competitive with the world's developed countries in producing qualified engineering graduates.

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# THE QUALITY OF ENGINEERING EDUCATION IN THE BRIC COUNTRIES

## 1. Introduction

Three decades ago, developed countries such as the United States and Japan produced the majority of the world's engineers. Today, a high fraction of the world's new engineering graduates come from the four largest emerging economies: Brazil, Russia, India, and China (NSB, 2010)—collectively known as the BRIC countries. The massive increase of new engineering graduates in the BRIC countries has the potential to profoundly influence domestic and international high-skilled labor markets (NAS, 2010; Lynn and Salzman, 2009). The increase could threaten the competitiveness of developed countries in producing high value-added products and services, or could, to the contrary, increase innovation in developed countries by pushing down the wages of highly talented engineers (Freeman, 2010).

The ultimate impact of the shift in the world's supply of engineers will be determined less by the sheer *number* of engineering graduates emerging from the BRIC countries than by their *quality*. Unfortunately, previous attempts to measure the quality of engineering education in one or more BRIC countries have been limited. Gereffi et al. (2008) find that enrollment statistics exaggerate the competitiveness of China and India's engineering programs. Several studies also find that employers have negative views on the quality of engineering graduates in the BRICs (e.g. Blom and Saeki, 2011; Levin Institute, 2010; Gereffi et al. 2008; Bondarenko et al., 2005). The studies are limited, however, since they only examine quality from one or two angles (e.g. enrollment numbers, employer feedback) and at times draw on small, unrepresentative surveys.

The objective of our study is to provide a more complete and up-to-date assessment of the evolving capacity of BRICs to produce qualified engineering graduates. Specifically, we seek

to compare the quality of engineering programs across elite and non-elite higher education tiers within and across each BRIC country. To do this, we use multiple sources of primary and secondary data in combination with a production function approach. This production function approach focuses on the key input-, process- and outcome-based indicators widely associated with the quality of education programs (NAP, 2012).<sup>1</sup> By using richer data than previous studies, we provide a more comprehensive assessment of the quality of BRIC engineering education.

Our analysis suggests that only a minority of BRIC engineering students receives high quality training in elite institutions while the majority receives low quality training in non-elite institutions. However, because the past decade witnessed a great increase in the number of engineers trained in the BRIC countries and an improvement in the quality of BRIC elite institutions, we estimate that the “BRIC high quality minority” of engineering graduates has reached about 40 percent of the total output of high quality engineering graduates in developed countries. Our conclusions thus differ substantially from those of earlier studies, in part because our methodology is better able to assess educational quality and in part because the BRICs are increasing the number of graduates in high quality programs more rapidly than developed countries.

## **2. Data**

To assess the quality of engineering education, we rely on extensive data collected from each BRIC country between 2008 and 2011. We mainly utilize secondary data from national surveys, government statistics and databases, and third-party agencies on (i) engineering enrollments/graduates, (ii) financing, (iii) faculty qualifications, (iv) student achievement, and (v)

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<sup>1</sup> There have been attempts to define high quality engineering education for the 21st century (Sheppard et al, 2009) which could be used as an ideal against which to measure actual quality; however, such measurement is beyond the scope of this paper.

research productivity. We also assess quality using primary data we collected through interviews with university administrators/faculty and surveys of engineering students in China, India, and Russia and similar secondary data from Brazil.

Our primary data on administrators/faculty was collected using purposive sampling. We selected “representative” regions in China, India, and Russia and then selected both elite and non-elite institutions that represented the range of engineering institutions in each region. Specifically, we conducted interviews at 40 engineering colleges in four states in India, 36 engineering schools in universities in 4 provinces of China, and 25 technical universities in 7 regions of Russia. Although we did not conduct interviews in Brazil, we drew on representative findings from rich secondary-source surveys of public and private institutions.

Our primary data on students was collected through a combination of random and purposive sampling. In China, we surveyed a simple random sample of approximately 2,500 local final-year students from 41 institutions in Shaanxi and a representative sample of 5,000 students from 54 institutions in Beijing in 2008-2009. In Russia, we surveyed over 2,000 graduating engineering students in 2008-2009. In India, we surveyed approximately 7,000 final-year engineering students (mainly in electrical engineering and computer science) from 40 institutions in 2009. We asked students to fill out virtually identical survey questionnaires and were thus able to compare student responses across the three countries.

To facilitate the comparison of the quality of engineering programs across the BRIC countries and with the US, we take several steps to standardize the definitions of an engineering student and the types of institutions they attend. First, we extend the definition of engineering students to include computer science students (Gereffi et al., 2008). Second, we focus almost entirely on undergraduate (bachelor’s) engineering and computer science programs in each

country. Third, we define elite institutions according to existing definitions of elite institutions in each country (see Appendix A). We acknowledge from the outset that both our definitions and data are limited and subject to debate.

### **3. Analysis and Results**

#### *3.1 Input-based Indicators*

According to our input-based indicators, there are stark differences in the quality of engineering education across the BRIC countries and across elite and non-elite institutions. Differences in quality appear in three major sets of input-based indicators: (a) the quantity and quality of new engineering students; (b) the financing of undergraduate education; and (c) the availability of qualified faculty.

##### *3.1.1 The quantity and quality of new engineering students*

The number of engineering enrollments in elite versus non-elite institutions differs substantially across the BRIC countries. According to our estimates (Figure 1), by 2009, China had the most engineering students in non-elite institutions (~3 million), followed by India (~1.4 million), Russia (~700,000), and Brazil (~350,000). China also had the most engineering students in elite institutions (~640,000), followed by Russia (~140,000), Brazil (~116,000) and India (~90,000). The number of elite engineering enrollments in China was in fact greater than the aggregate number of freshman intending to study engineering in all US institutions from 2006-2010 (approximately 527,000 students, NSF, 2012).<sup>2</sup> This indicates that if the education received by engineering students in elite BRIC institutions were equal in quality to that of students in the average US institution, then China alone would be competitive with the US in

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<sup>2</sup> Similarly, in 2009, the number of undergraduate enrollments in engineering and engineering technology in the US (including fifth year students) was 577,538 (NSF, 2012).

producing quality engineers.

[Figure 1 about here]

Not only are the numbers of engineering enrollments in the BRICs high, but they have been, in some cases, increasing rapidly (Figure 1). In Brazil, engineering enrollments increased considerably faster in non-elite institutions from 1999 to 2003 and at an equally rapid pace in non-elite and elite institutions (53%) from 2003 to 2009. In India up until 2009, elite engineering programs expanded more slowly than non-elite engineering programs. From 2009 to 2011, however, the number of new engineering places at elite Indian institutions increased by 55% (from 90,513 to 140,000 places—not shown in Figure 1), making the absolute number of elite engineering enrollments on par with that of Brazil and Russia. In China, elite engineering enrollments increased relatively slowly (8%) from 2005-2009, while non-elite engineering enrollments increased by 46% over the same period. Engineering enrollments in Russia increased only slightly from 2006-2009 and slightly more in elite institutions (3%) compared to non-elite institutions (1%).<sup>3</sup> Taken together, the changing numbers and proportions of students at elite and non-elite engineering institutions provide a baseline by which we can understand the quality of engineering education in each country.

Beyond numbers, the level of preparedness of the incoming engineers also differs by country. With the exception of Russia, it is the “cream” of each age cohort (in terms of innate ability, motivation, and social class) that is sorted into higher education through a competitive admissions process. In 2009, the gross enrollment rates among 18-22 year olds in Brazil (32%), India (roughly 14%) and China (13-14%) were low compared to Russia (75%) and the United

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<sup>3</sup> In the United States, the total number of engineering plus computer science enrollments has grown by about 12% over the last decade (NSF, 2012).

States (45%).<sup>4</sup> Furthermore, when we compare the academic skills of prospective engineering students, we find that Brazil and India are far behind China, Russia, and the US. Results from the Programme for International Student Assessment, for example, indicate that students in Russia and China's more developed regions score comparably to US students in math and science (at age 15). By contrast, students in Brazil and especially India tend to score much lower on international assessments (OECD 2010). Furthermore, once students in the BRIC countries enter high school, they take many more math and science courses than US high school students (see Carnoy et al., 2013, chapter 6). The combination of achievement results and high school coursework imply that students entering elite programs in all of the BRIC countries are well prepared in terms of basic math and science skills. Students entering non-elite institutions—especially in Brazil and India—are less prepared.

### *3.1.2 The financing of undergraduate education*

BRIC countries devote fewer financial resources than developed countries to train engineering students. Specifically, we estimate that the spending per student is relatively low.<sup>5</sup>

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<sup>4</sup> These statistics were either directly taken or estimated from various government statistical sources (i.e. NBS, 2010; MHRD, 2011; Brazil, INEP, various years; NCES, various years) and the World Bank (<http://data.worldbank.org/indicator/SE.TER.ENRR>, accessed November 13, 2012). The 45% rate for the US only uses enrollments at four-year institutions.

<sup>5</sup> Because of the lack of available data, spending per student is estimated for higher education students in general (and not just engineering students), except in India, where data are available separately for spending on technical higher education. Spending per student estimates (a) in the United States and OECD are based on public institution data only and include research costs; (b) in China, we use government estimates that do not include (unreported, but perhaps substantial) university debt; (c) in Russia, government budget data for “free” places is available from the State Statistical Committee of Russia (2010), but since about one-half of all students in universities pay fees, spending per student varies, according to different reports, on student fees. In the lower estimate, fees are standard fees reported on university websites; in the higher estimate, the fees are based on Ministry of Education reports of revenues per fee-paying student in various types of universities, which tend to be considerably higher than public spending per “free” place student; (d) in Brazil, spending per student in public institutions is available from the government (INEP, various years), and spending per private student is estimated from surveys by a private consulting firm (Hoper Educacional, 2009) of average tuition fees in private

According to our estimates (Figure 2), spending per student in higher education in recent years was approximately \$5,000 in Brazil; \$4,000-7,000 in Russia; \$4,300 in China; and \$1,300 in India. Spending per student was much lower than in the United States and other OECD countries.<sup>6</sup> This reflects either much lower salaries paid to faculty or more students per faculty, on average—both of which could negatively affect the quality of BRIC engineering education.<sup>7</sup>

Spending per student is much higher in the elite institutions. In China, elite institutions spend an average of \$6,000 per student while non-elite institutions spend about \$2,500 (NBS, 2010). From our surveys in India and secondary sources (Banarjee and Muley, 2009), we estimate that elite institutions spend about \$8,000 per student while non-elite institutions spend about \$1,560. In Russia and Brazil, spending per student in elite institutions is roughly double and triple that of non-elite institutions (INEP, various years; Hoper Educacional, 2009). Importantly, higher spending per student implies that elite institutions can hire more qualified faculty and/or have smaller class sizes, both of which can lead to higher quality engineering programs.

### *3.1.3 Availability of qualified faculty*

While spending per student can influence an institution's ability to hire qualified faculty and maintain smaller class sizes, the total supply of qualified faculty can also influence quality.

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universities; (e) in India, we used data from the MHRD (various years) and the UGC (2010) for public spending per university student and per technical higher education student. For private costs per engineering student, we use data from Indian states' websites reporting average tuition paid in public and private engineering colleges as well as tuition data from interviews in two dozen private engineering institutions in India.

<sup>6</sup> The estimate for spending per student in the United States (\$30,000) includes spending across undergraduate and graduate students (net of research costs). The estimate for spending per undergraduate student is therefore lower than \$30,000 (NCES, various years).

<sup>7</sup> The student-faculty ratio in higher education institutions in Brazil (15-16), Russia (13), and China (17-18) are fairly close to that of institutions in the OECD (15), whereas India's (24) is higher (OECD, 2011; NBS, various years; MHRD, 2011). The low levels of spending per student may thus indicate lower faculty salaries in the BRIC countries.



To understand the supply of qualified faculty, we first examine the number of engineering PhD graduates produced annually in the BRIC countries. In China, the annual number of engineering PhD graduates is high (~15,000) and has grown by approximately 5 times from 1998-2009 (Table 1). Russia also has a number of engineering PhD graduates each year (~7,500). The number of graduates is small in Brazil (~1,300) and India (~1,200). Yet, in marked contrast to Brazil where the number of graduates tripled over ten years, India's engineering PhDs only increased by 50%. Overall, the ratio of the number of undergraduate engineering enrollments to the number of engineering PhDs graduates (in 2009) is by far the highest in India (1324 to 1), followed by Brazil (370 to 1), China (239 to 1), Russia (114 to 1) and the US (roughly 75 to 1). Clearly then, BRIC countries' ability to find qualified faculty is considerably less than that of the US, with India lagging far behind the other BRICs.

[Table 1 about here]

The supply of engineering PhD graduates mirrors the proportion of faculty with PhD degrees in each country. Russia has a high proportion of faculty with doctoral degrees (63% in 2010, see Table 2). This proportion is even higher than that of the United States, where roughly two-thirds of professors in four-year doctoral granting institutions have a PhD (Cataldi et al., 2005). The proportions are much smaller in China (20%), Brazil (27%), and India (under 10%). Using data from our institutional surveys and secondary sources, we find that the percentage of faculty with PhDs at elite institutions in Brazil, India, and China (~50% in each country) is much higher than non-elite institutions.

[Table 2 about here]

We also rely on qualitative evidence to understand the quality of faculty in engineering programs in the BRICs. Our interviews in Russia reveal that faculty aging is an acute problem

and that academia is no longer attractive for young talents. In China, the quality of PhD programs is low as curricula are outdated and faculty-graduate student ratios are high. The quality of PhD programs in India is likely worse given the dearth of facilities and qualified faculty. By contrast, the Brazilian government's support of R&D and graduate programs has led to a steadily increasing proportion of faculty with a strong, research-based graduate education (Balbachevsky and Schwartzman, 2011). Still, the majority of non-elite institutions in the BRICs have trouble hiring faculty from elite graduate programs.

Overall, the variation in inputs among engineering programs across the BRIC countries has clear implications for their capacity to produce qualified graduates. Russia, with its enormous head start in university expansion and strong system of pre-tertiary schooling, has the highest level of inputs with which to produce the average quality of engineering graduates found in developed countries. China, Brazil and India's elite engineering programs similarly appear to have the inputs necessary to produce qualified graduates. On the other hand, the lack of inputs in China, Brazil and especially India's non-elite programs limits their ability to produce qualified graduates.

### *3.2 Process-based Indicators*

#### *3.2.1 Government Policies to Improve Quality*

Our interviews show that, beyond inputs, the BRIC governments create an institutional environment which favors elite programs. For example, each government uses competitive entrance exams to sort the highest ability students into elite programs. They further offer special incentives to elite institutions to become "world-class" universities. They also give elite institutions more autonomy than non-elite institutions.

By contrast, policymakers offer much less support to non-elite institutions. Our

interviews in India and studies from Brazil suggest that cost efficiency is far more crucial to non-elite institutions than quality improvements. The situation is similar in China, although the most selective non-elite institutions are incentivized to improve educational quality. In Russia, non-elite institutions have few incentives to improve quality or reduce costs.

Policymakers have at times legislated minimum standards of quality for non-elite higher education institutions. We frequently observed policymakers in China audit the quality of instruction at non-elite institutions and award outstanding instructors and classes. In Brazil, the government tries to increase competition among non-elites by making institutions publish their graduating students' test scores. A similar practice is followed in China and Russia. Engineering programs in China and Russia in fact use the average exam scores of incoming students as a proxy for institutional quality. The government of India, by contrast, grants greater autonomy (from supervising agencies) to a small number of non-elite institutions if they improve their standards.

Despite trying to ensure a minimum level of quality in non-elite institutions, our interviews reveal that BRIC governments are more focused on increasing enrollment than raising quality. As a result, non-elite institutions focus on delivering courses which maximize the number of students they can process “successfully” and yet still maintain demand. For most non-elite institutions, this means keeping costs per student low, lobbying governments to be less stringent in applying regulations, and competing for students with advertising that may have little to do with academic quality.

### *3.2.2 Students' Educational Experiences, Exposure to Practice and Non-Technical Courses*

Despite the large differences in inputs and government support, we find that students in both elite and non-elite institutions are positive about their educational experiences. More than

three-quarters of the students in our BRIC surveys claimed their technical knowledge and engineering skills improved during university. About three-fourths of students in China and Russia and about two-thirds in India felt they improved their oral communication, teamwork, and problem-solving skills. They further reported experiencing flexible instructional practices (e.g. by engaging in small group discussions and technical presentations). The survey findings are similar across elite and non-elite institutions and indicate that students at both types of institutions are satisfied with their education. Finally, in a secondary survey in Brazil nearly two-thirds of engineering students reported that instructional quality was adequate (INEP, 2005).

Although students seem satisfied with their education, they lack practical experience and exposure to non-technical courses. Only about one-sixth of students surveyed in India and China participated in a faculty research project compared to about one-third of students in Russia (table omitted for brevity). Few students reported having worked directly with enterprises. A minority of students participated in a leadership program or took an interdisciplinary course in the sciences. Few students in India and Russia had an engineering internship in college. Although most engineering students in China participated in an internship, the quality of internships is dubious (Cha, 2007). Finally, engineering students in all four countries took many fewer humanities and social science courses than their US counterparts.

### *3.3 Output-based Indicators*

#### *3.3.1 Value-Added Measures of Student Learning*

Although engineering students in the BRIC countries are satisfied with their educational experiences regardless of the type of institution they attend, given the lower inputs and support for non-elite institutions, we posit that students in non-elite institutions have lower levels of learning compared to students in elite institutions. To investigate this claim, we conducted a

“value-added” analysis to compare the learning gains of electrical engineering students in elite versus non-elite engineering programs in Brazil from their first to last year of study (see Carnoy and Carrasco, 2012). We find that while both elite and non-elite programs increase student learning, elite programs increase student learning more (by about 1.5 standard deviations or SDs compared to 1.25 SDs for the 2005-2008 cohort, see Table 3). We also find that final-year students in non-elite programs attain skill levels just below those of first-year students in elite programs. This suggests that the majority of engineering graduates from non-elite institutions in Brazil are only minimally prepared to work in technical jobs. Based on the input and process-based indicators discussed above, such a dramatic difference in the quality of engineering graduates from elite versus non-elite institutions may also exist in the other BRICs.

[Table 3 about here]

### *3.3.2 Graduates and Graduate Employment*

The value-added assessment above is useful, since unlike the United States, graduation rates tell us little about the quality of engineering education in the BRICs. While in the United States an estimated 56% of four-year higher education students graduate within six years (Symonds et al., 2011), graduation rates are much higher in China (~95%), Russia (~80%), and India (~79%) (NBS, various years; OECD, 2012; Banerjee and Muley, 2009).<sup>8,9</sup> Such high graduation rates imply that engineering programs in these countries may fail to “weed out” poorly performing students, creating a culture in which those accepted into university are easily able to graduate, regardless of their academic performance.

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<sup>8</sup> The graduation rates here are for all undergraduates (not just engineers). From our available primary and secondary data sources, we did not find that graduation rates in BRIC engineering programs differed substantially from those in non-engineering programs.

<sup>9</sup> In contrast, a full 45-50% of undergraduate students drop out in Brazil (INEP, various years, estimated by taking the difference between the number of students who entered university and the number of students who graduated 6 years later).

On the flip side, with such high graduation rates, the number of graduates emerging from elite and non-elite programs in each country is high (see Figure 4). Similar to enrollments (Figure 1), the number of engineering graduates from elite programs in China in 2009 (132,872) is higher than the total number of engineering graduates in the US (109,096).<sup>10</sup> By contrast, elite Russia and India graduated approximately one-fourth of the number of elite engineers (around 25,000) annually by 2012 (not shown in Figure 4), while Brazil graduated about half that amount.<sup>11</sup> In all of the BRIC countries, the number of graduates from non-elite institutions was 5-6 times higher.

[Figure 4 about here]

Although a large number of students graduate, they seem to have relatively little difficulty finding suitable employment. In China, although roughly 28% of all university graduates do not find a job within a year after graduation (Cai et al., 2008), most eventually find jobs (Park et al., 2010). In Russia, our survey results show that engineers have little difficulty obtaining work after graduation, although they often work outside their specialization. In Brazil, unemployment among recent college graduates is relatively low 6% in recent years (Menezes, 2009). Finally, in all four countries, the economic payoff to higher education, in general, and engineering education, in particular, is quite high (Carnoy et al., 2012). Although high employment rates and economic returns cannot tell us about the quality of engineering programs per se, they at least indicate that engineering graduates have skills demanded by the labor market.

### 3.3.3 *Research*

The final indicator of quality that we look at is research productivity. We summarize two

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<sup>10</sup>The number for China is a slight underestimate as we were only able to estimate the number of elite graduates in 30 out of 31 provinces.

<sup>11</sup> Our estimates assume that elite engineering students do not drop out. Accordingly, India should have about 45,000 elite engineering graduates by 2015.

major indicators concerning the state of research in higher education generally, and where our data allows, in engineering education specifically: (a) research expenditures in higher education<sup>12</sup> as well as (b) the number and quality of academic publications.

Overall, the BRIC countries are far behind the United States in total R&D spending in higher education (Figure 5). China and Brazil spend about as much as the UK and Germany, which have many fewer faculty and students. By comparison, Russia and India spend little on R&D in absolute terms.

BRIC countries are also behind the United States in terms of R&D spending in higher education per student (Figure 6). R&D spending per student is highest in Brazil (\$1,579 in 2010 in 2005 PPP\$ terms)—about 40% of the amount spent per student in the United States. China’s spending per student is approximately half that of Brazil, whereas Russia and India are far lower at \$279 and \$91. From these figures it appears that Brazilian faculty and students enjoy a more intensive research environment than their Chinese counterparts, while Russia and India lack research programs that contribute to the quality of engineering education.<sup>13</sup>

[Figure 5 about here]

[Figure 6 about here]

Policymakers in Brazil and China, and to a lesser extent in Russia and India, are increasing funding for engineering research, especially in elite institutions. In China, government research funding has grown more than 20% per year, and the State has created competition among elite institutions for research funding (Shi and Yi, 2010). The Russian government has

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<sup>12</sup> Although research expenditures are an input-based indicator, we discuss research expenditures and publications in the same subsection for convenience.

<sup>13</sup> National R&D expenditures are also much lower in BRIC countries compared to developed countries. In 2009, the United States’ R&D expenditures (\$398.02 billion) were more than three times that of China (\$84.9 billion), Brazil (\$19.5 billion), Russia (\$15.3 billion), and India (\$9.4 billion) combined (NBS and MOST, 2010; OECD, 2012; Brazil MOST, various years; UNESCO Institute for Statistics, various years).

elite institutions competing for substantial research funding with the goal of improving research and productivity and commercialization. Brazil's government similarly works closely with elite institutions to set research priorities. While elite engineering programs in India receive research funding, they receive far less than the other BRIC countries.

Mirroring the increases in research funding, the BRIC countries vary in the degree to which they produce academic publications. Table 4 shows the number of S&T papers in the Science Citation Index (SCI), the Engineering Index (EI), and the Index to Scientific & Technical Proceedings (ISPT), produced by researchers in each country.<sup>14</sup> In terms of the total number of scientific articles published per million of the population, China now ranks 2<sup>nd</sup> behind the United States (as of 2009) in S&T papers indexed by SCI or ISTP rankings and ranks 1<sup>st</sup> in the EI ranking. India, Brazil, and Russia rank 10<sup>th</sup>, 13<sup>th</sup>, and 15<sup>th</sup> respectively in SCI rankings and similarly in the other rankings. From 2004 to 2009, China more than doubled its output in all indices, and India's SCI-indexed publication output also nearly doubled in the last decade (King, 2008a). Although Russia's S&T paper output is comparable to other BRIC countries, it has actually seen a reduction in publications in recent years.

[Table 4 about here]

These statistics do not, however, reflect the overall quality of publications. Currently, the impacts of scientific publications from all four BRIC countries rank below the world average. Brazil has maintained the highest impact among BRIC nations at 63% in 2008 (King, 2009). China has made steady growth in the number of its high impact papers (defined as among the top 1% cited) from 73 in 1998 to 511 in 2007 (King, 2008b).<sup>15</sup> Even so, according to another

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<sup>14</sup> SCI (Science Citation Index) and EI (the Engineering Index) are popular indices managed by Thomson-Reuters and Elsevier respectively. ISPT (Index to Scientific & Technical Proceedings) is also a scholarly database that includes materials on international conferences.

<sup>15</sup> Brazil's impact is especially high in engineering (only 5% below the world average), with



indicator of publication quality—Elsevier’s Scopus citation database—China ranked lowest among the top 20 publishing countries (behind India and Brazil) on citations per article in 2009; citations per article in fact fell from 1.72 to 1.47 in China from 2005 to 2009.

Taken together, the quality of engineering research (again, an important indicator of the quality of engineering education) appears to vary more within than across the BRIC countries. With the possible exception of India, elite programs in the BRICs are receiving considerable and growing research support and are producing research of modest quality. By contrast, non-elite programs in the BRICS are receiving much less financial support and are producing research of low quality. For example, in China, non-elites are incentivized to produce research *en masse*, with little regard to quality. The lack of financial support for non-elites in Russia has resulted in a significant decline in research productivity in the last decade. The mass, private institutions in Brazil and India are seldom engaged in meaningful research activities.

#### **4. Discussion and Conclusions**

According to our findings, elite engineering programs in BRIC countries benefit from a combination of factors, including: a competitive process by which a select group of high-ability students are admitted, fairly high per student expenditures, and qualified faculty. Policymakers in each country not only play a large role in managing these factors, but also help elite institutions by providing substantial funding, mandating improvements in curricula and instruction, and encouraging faculty to concentrate more on research. The quality of elite versus non-elite engineering programs is also reflected in higher student learning gains and the greater

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China and India quickly improving their impact in this field as well. According to Thomson-Reuters, China is strong in material science, physics, and math. India is strong in multidisciplinary fields (5.47%), material science (5.45%) agricultural sciences (5.17%), chemistry (5.04%), physics (3.88%).

quantity/quality of their research publications. Among the BRIC countries, India's elite programs appear to lag the furthest behind in terms of inputs (e.g. qualified faculty) and outputs (e.g. research productivity).

Although BRIC policymakers appear to be most concerned with the quality of elite engineering programs, the quality of non-elite engineering programs may be of even greater importance. After all, as we noted, the number of non-elite enrollments exceeds the number of elite enrollments by at least six times in every BRIC country. Yet, according to the various input, process, and output measures we observed, the quality of non-elite engineering education appears to be at best modest in China and Russia and low in Brazil and India.

How well positioned are the BRICs to improve the quality of non-elite engineering education? Russia, with its high gross enrollment rate in both academic high schools and higher education, its relatively strong performance in international assessments, reputable math/science preparation in high school, and long history of engineering education with a qualified professoriate, is perhaps best positioned to extend quality improvements to non-elite programs. However, certain historically-based institutional factors, such as disconnects between non-elite institutions and the needs of industry, as well as lack of clear incentives for non-elite institutions to make improvements, has resulted in considerable inertia. In China, the top layer of non-elite engineering programs seems capable of producing quality graduates. The remaining mass of China's non-elite programs still lags behind in a number of areas (e.g. low spending per student, fewer qualified faculty, low quality research, and so on). In Brazil, part of the reason that non-elite institutions may struggle is the low quality of prospective engineering students (who, according to international assessments, have much lower achievement levels than students in China and Russia). A second reason is that, despite government regulations, non-elite institutions

have few incentives to improve student learning. Of the four BRIC countries, India seems least equipped to improve the quality of engineering education on a broad scale. India's non-elite engineering programs on average admit students with low math and science skills, spend little per student, lack access to qualified faculty, have few incentives to improve student learning, and barely engage in research.

What does our analysis of the quality of engineering education imply for the capacity of the BRIC countries to produce qualified engineering graduates? In sheer numbers of engineers produced, the BRIC countries have already become world leaders. However, a high percentage of these graduates are simply not trained to the same level as engineers in the United States, Europe, or Japan. In particular, the low quality of engineering education in most non-elite institutions indicates that a high percentage of BRIC engineering graduates are not comparable in skill levels to the average engineer graduating from programs in developed countries.

On the other hand, given the resources and attention that governments have lavished on elite institutions in recent years, we speculate that the top half of engineering graduates from elite institutions in the BRICs are as well-prepared technically as the top half of all engineering graduates in developed countries. More specifically, of the nearly 200,000 engineers emerging from elite programs in BRIC countries each year (as of 2009—by 2013, the number is much larger), the top 100,000 are comparable to the top 50,000 engineers receiving bachelor's degrees from U.S. colleges and universities, the top 150,000 engineering graduates annually in the European Union, and the top 50,000 engineering graduates annually in Japan. If this approximation has merit, it implies that the large and increasing supply of qualified engineering graduates from the BRIC countries will have important implications for shifts in the global production of and innovation in high technology products and services in the coming years.

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**Table 1: PhD Graduates (Total and Engineering) from the BRIC countries and the US, 1998 to 2009**

		1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009
Total	Brazil	3,949	4,853	5,344	6,040	6,894	8,094	8,109	8,991	9,366	9,919	10,718	11,368
	Russia	18,274	n/a	24,828	n/a	n/a	n/a	29,850	33,561	35,530	35,747	33,670	34,235
	India	10,408	11,066	10,951	11,296	11,544	11,974	13,733	17,853	17,898	12,773	13,237	10,781
	China*	7,535	8,749	9,409	11,065	12,849	16,401	20,607	24,035	31,653	36,270	38,111	48,658
	US	42,638	41,098	41,366	40,737	40,025	40,759	42,118	43,381	45,617	48,130	48,763	49,562
Engineer	Brazil	n/a	492	705	765	819	1,023	1,055	114	1,123	1,178	1,222	1,284
	Russia	n/a	n/a	6,208	n/a	n/a	n/a	n/a	7,431	7,743	7,902	7,528	7,570
	India	744	696	723	778	734	779	882	968	844	1,079	1,427	1,141
	China*	3,095	3,642	4,225	4,534	5,252	6,573	7,262	8,377	10,879	12,852	13,593	15,524
	US	5,922	5,330	5,323	5,510	5,081	5,281	5,777	6,427	7,185	7,744	7,862	7,634

**Sources:** China: NBS (2010); Russia: MOES (2011); India: MHRD and UGC Reports (various years); Brazil: MOST (2012); United States: NSF (2010, 2012).

**Notes:** \*University-only (Including Ph.D. graduates from research institutes would add another 10–15%)



**Table 2: Percentage of Faculty with PhDs**

Year	China	Russia	India	Brazil
2001	n/a	57.6%	n/a	n/a
2002	9.4%	n/a	n/a	21.4%
2003	10.2%	n/a	n/a	21.0%
2004	11.4%	n/a	n/a	21.6%
2005	12.7%	n/a	n/a	22.4%
2006	n/a	60.0%	n/a	23.0%
2007	16.1%	61.2%	n/a	24.0%
2008	17.7%	62.4%	n/a	24.0%
2009	19.5%	63.3%	n/a	26.3%
2010	n/a	63.5%	~9%	28.4%

**Sources:** (a) China: NBS (various years); (b) Russia: MOES, 2011; (c) India: UGC, 2010; (d) Brazil: INEP, various years.

**Table 3: Estimated Inter-cohort and Intra-cohort Test Score Gains in Computer Science and Electrical Engineering, 2005 and 2008, for Students Entering Least and Most Selective Programs (standard deviations from mean = 0)**

<b>Computer Science</b>						
<i>Year</i>	<i>50% Least Selective Programs</i>			<i>50% Most Selective Programs</i>		
	<i>No. of Programs</i>	<i>Initial Year Test Score</i>	<i>Final Year Test Score</i>	<i>No. of Programs</i>	<i>Initial Year Test Score</i>	<i>Final Year Test Score</i>
2005	119	-0.70 (0.50)	1.62* (1.40)	117	0.85 (0.86)	3.51 (1.58)
2008	118	-0.76 (0.64)	0.84** (1.19)	118	0.71 (0.75)	2.21 (1.52)
<b>Electrical Engineering</b>						
	<i>50% Least Selective Programs</i>			<i>50% Most Selective Programs</i>		
	<i>No. of Programs</i>	<i>Initial Year Test Score</i>	<i>Final Year Test Score</i>	<i>No. of Programs</i>	<i>Initial Year Test Score</i>	<i>Final Year Test Score</i>
2005	118	-0.66 (0.37)	0.69 (1.06)	118	0.76 (0.81)	2.74 (1.40)
2008	118	-0.57 (0.42)	0.60 (0.72)	118	0.86 (0.72)	2.24 (1.03)

**Source:** Authors' estimates from INEP, ENADE database

**Notes:** \*In 2005, the average score on final year test for students in the 50% least selective programs was equal to approximately the *initial year score* of the top 20 percent of students in the most selective programs.

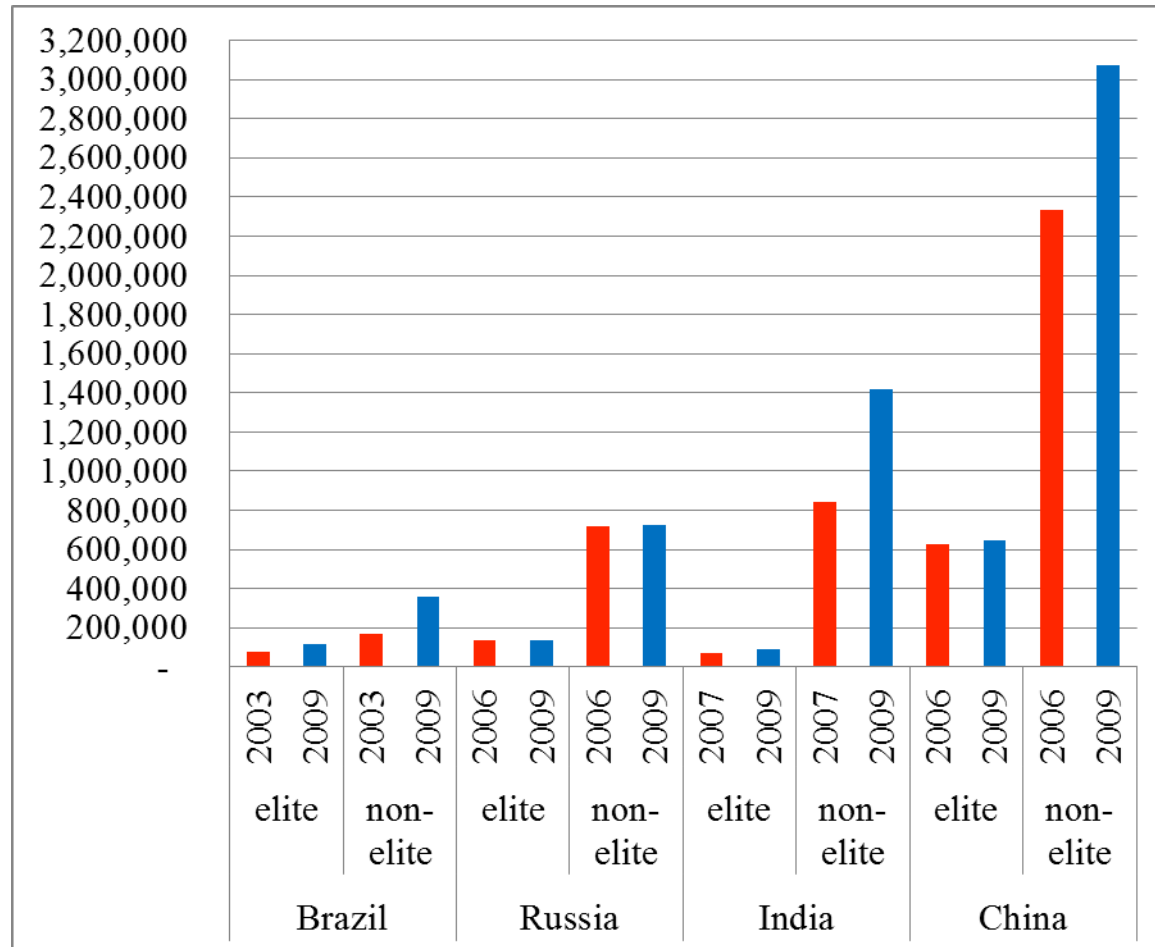
\*\* In 2008, the average score on final year test for students in the 50% least selective programs was equal to approximately the *initial year score* of the top 40 percent of students in the most selective programs.

**Table 4: S&T papers indexed by SCI, EI and ISTP in the BRICs and US, 2009**

<i>Country</i>	SCI		EI		ISTP	
	<i>Papers (10,000)</i>	<i>Rank</i>	<i>Papers (10,000)</i>	<i>Rank</i>	<i>Papers (10,000)</i>	<i>Rank</i>
World Total	144.2		40.9		42.8	
China	12	2	9.3	1	5.2	2
USA	39.8	1	6.9	2	10.5	1
Russia	3.2	15	1.1	13	0.7	14
India	4.5	10	1.6	8	0.8	10
Brazil	3.5	13	0.6	17	0.7	12

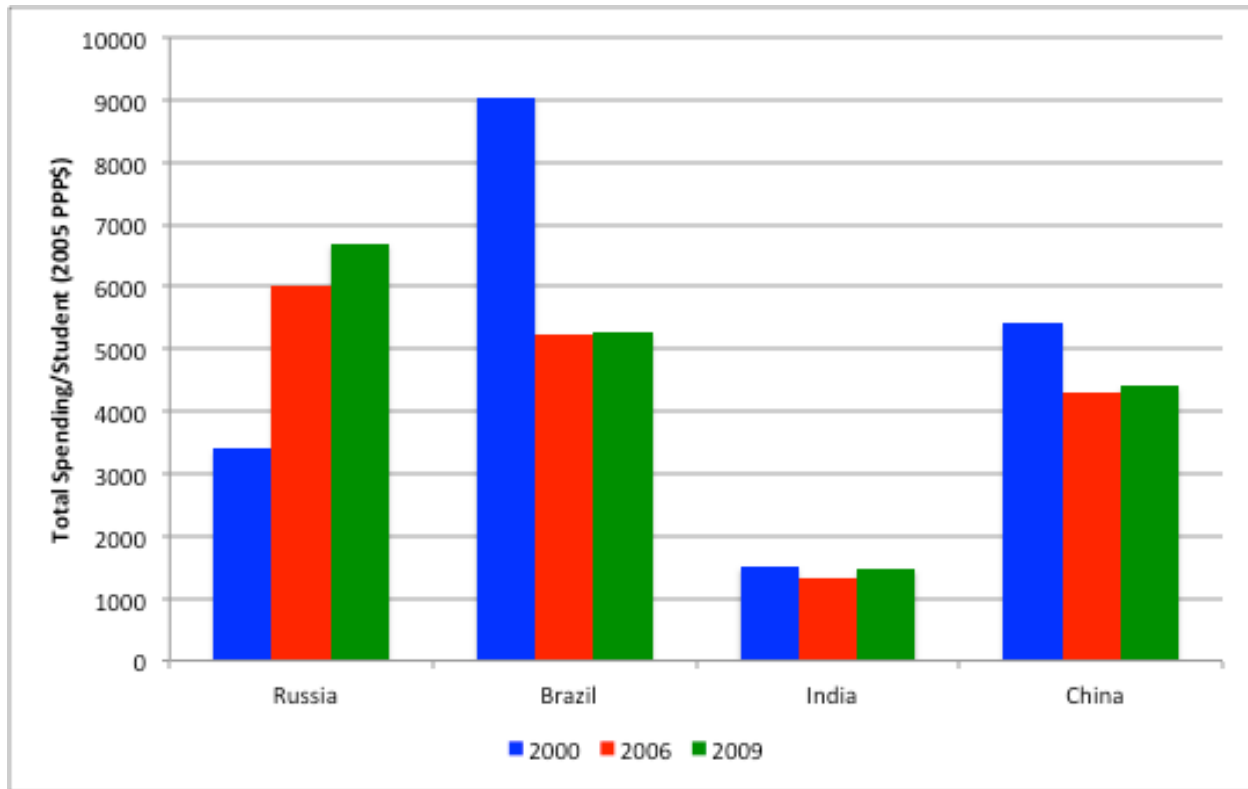
**Source:** NBS and MOST (2010).

**Figure 1: Number of Bachelor's Degree Level Engineering Enrollments in the BRICs: Elite vs. Non-Elite Universities**



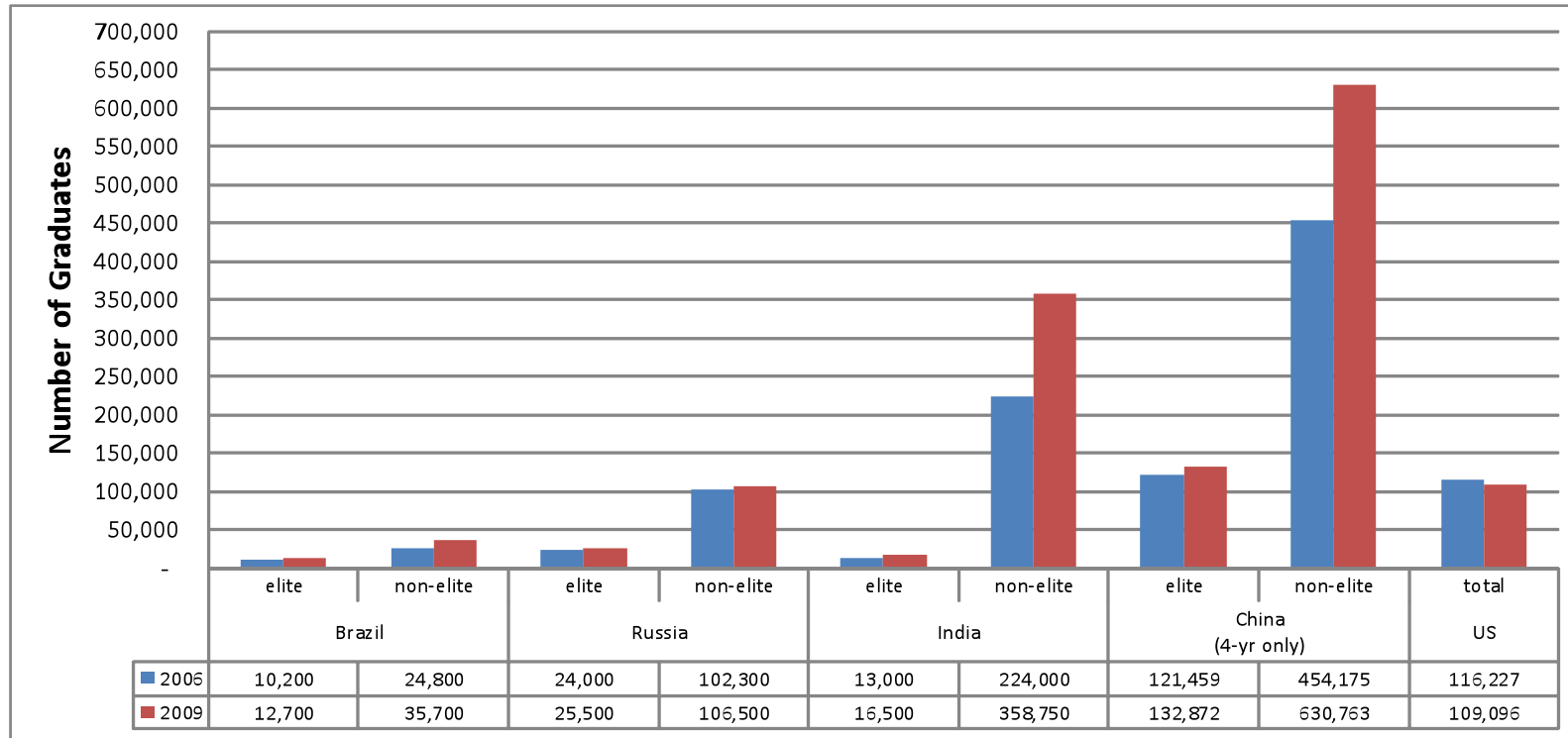
**Sources:** Authors' approximate estimates based on data from (a) China: NBS (various years); (b) Russia: MOES, 2011 and the State Research University Higher School of Economics; (c) India: UGC, 2010, JEE ([jee.iitm.ac.in](http://jee.iitm.ac.in)) and AIEEE ([www.aieee.nic.in](http://www.aieee.nic.in)); (d) Brazil: INEP, (various years).

**Figure 2: BRIC Countries: Total of Private plus Public Spending in Higher Education per Student, by Country, 2000, 2006 and 2009 (in 2005 PPP dollars)**



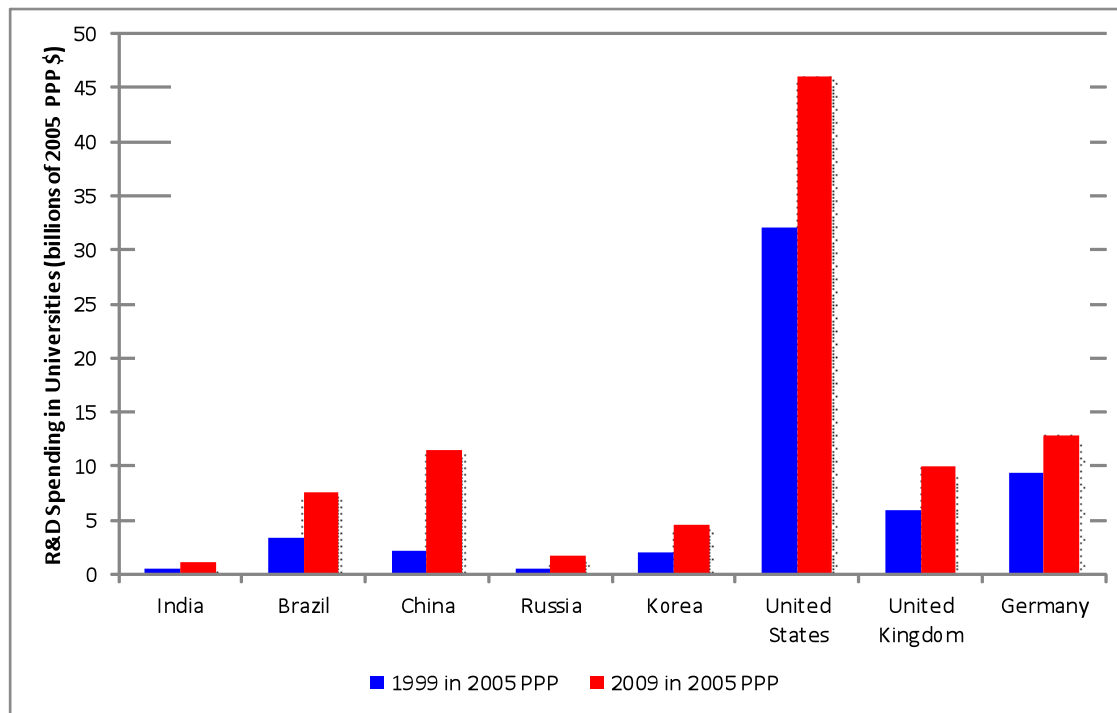
**Source:** Authors' estimates based on OECD, *Education at a Glance* (various years) and (a) China: (NBS, various years); (b) India: *Analysis of Budget Expenditure on Education* (MHRD, various years) and *Annual Reports* (UGC, various years); (c) Brazil: Hoper Educacional, 2009, and INEP (various years); (d) Russia: State Statistical Committee of Russia, 2010, and Bain, 2001.

**Figure 3: Engineering Graduates from the BRICs, 2006 and 2009, Elite vs. Non-elite Institutions**



**Sources:** Authors' approximate estimates based on data from (a) China: NBS (various years); (b) Russia: MOES (various years) and the National Research University Higher School of Economics; (c) India: UGC, 2010, and JEE ([jee.iitm.ac.in](http://jee.iitm.ac.in)) and AIEEE ([www.aieee.nic.in](http://www.aieee.nic.in)); (d) Brazil: INEP (various years). (e) United States: NCES (various years).

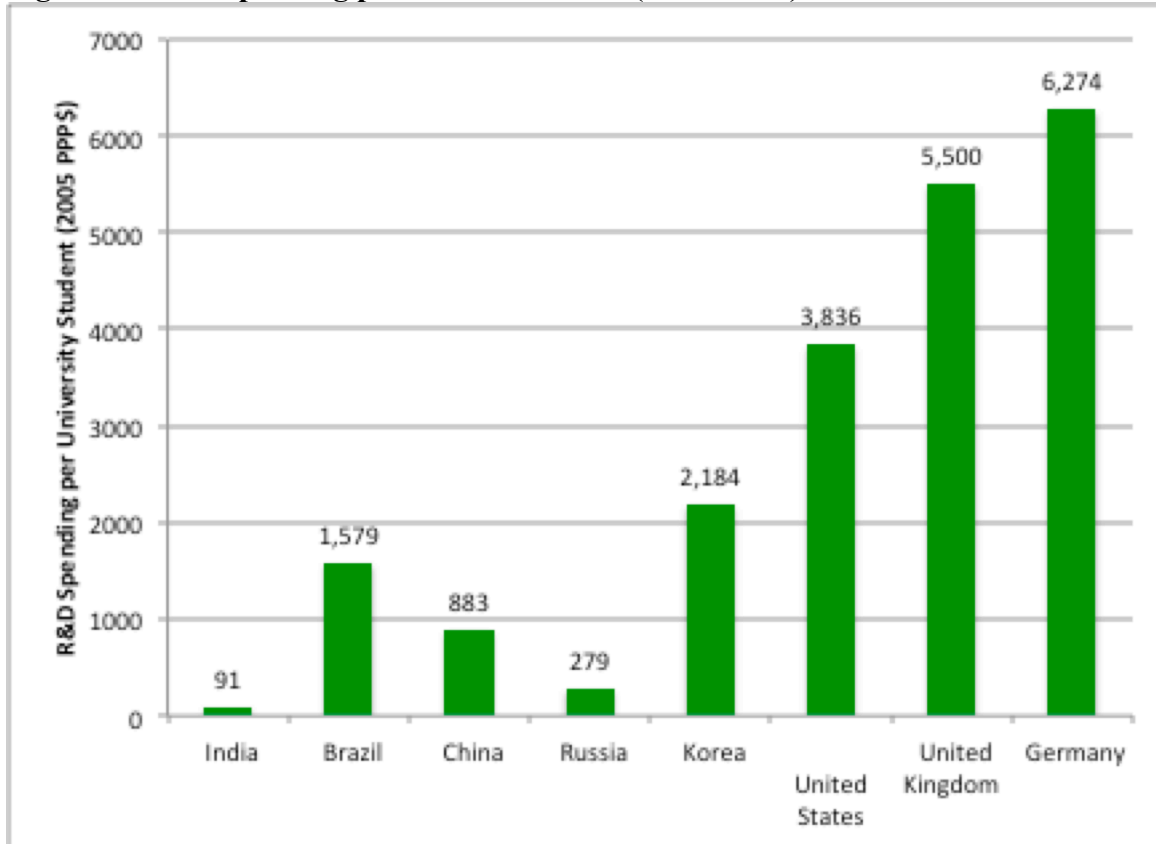
**Figure 4: BRIC and Other Developed Countries: Total R&D Spending in Higher Education**



**Sources:** OECD, *Main Science and Technology Indicators* (various years); UNESCO Institute for Statistics (various years).

**Notes:** India's statistics are for 1999 and 2007; Brazil's statistics are for 2000 and 2008. U.S. statistics are for 1999 and 2009.

**Figure 5: R&D Spending per Student in 2010 (2005 PPP\$)**



**Source:** OECD, *Main Science and Technology Indicators* (various years). UNESCO Institute of Statistics (various years).

**Notes:** India's statistics are for 2007; U.S. statistics are for 2009.



## **Appendix A: Definitions of Elite Institutions Applied to each BRIC Country**

The definitions of an elite institution in Russia and China are standard and widely accepted. Specifically, we defined Russian elite institutions as the 38 Category A institutions (including Moscow State and St. Petersburg State, a number of Federal Universities, and National Research Universities), which receive much more State funding than other universities. We defined Chinese elite institutions as 985 and 211 institutions (largely those institutions that are under the jurisdiction of the central government).

The definitions of an elite institution in Brazil and India are less standard than in Russia and China. We define Brazil elite institutions as federal universities, elite private Catholic universities (PUC Sao Paulo, PUC Rio Grande do Sul, and PUC Belo Horizonte), the University of Sao Paulo and the State University of Campinas. However, because not all federal universities are necessarily “elite”, in estimating enrollments and graduates from elite programs we only include 80% of students in federal universities. For India, we define elite engineering institutions as those institutions that take students through the JEE and AIEEE exams. While the specifics of the definitions for Brazil and India may be debatable, the overall picture of highly selective, high quality and less selective, lower quality institutions in these two countries will likely be the same across the range of viable definitions.