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Abstract 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. To meet this objective, we compare developments in the quality of undergraduate engineering programs across elite and non-elite higher education tiers within and across each BRIC country. To assess and compare the quality of engineering education across the BRIC countries, we use multiple sources of primary and secondary data gathered from each BRIC country from 2008 to 2011. In combination with this, we utilize a production function approach that focuses on key input-, process- and outcome-based indicators associated with the quality of education programs. Our analysis 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

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training in non-elite institutions. Our analysis also shows how the BRIC countries vary in their capacity to improve the quality of engineering education.

Keywords BRIC · Engineering education · Quality · Elite · Emerging economies

Introduction

Three decades ago, developed countries such as the United States, the UK, Germany and Japan produced the majority of the world's engineers. Today, a high fraction of new engineering graduates come from the four largest emerging economies: Brazil, Russia, India, and China (National Science Board 2010)—collectively known as the BRIC countries. The massive increase in 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). It 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 view the quality of BRIC engineering graduates negatively (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 institutions within and across each BRIC country (see section "Appendix 1" for definitions of elite and non-elite institutions). To do this, we use multiple sources of primary and secondary data in combination with a production function approach (Hanushek 1986). An educational production function methodology models educational output—in this case, university trained engineers of varying quality—as a function of key educational inputs and processes widely associated with the quality of higher education programs (Massy 2013).[1] We do not strictly estimate a production function econometrically, but rather use data indirectly to fashion an empirical approach to the production of higher education output, including specifying various ways to measure that output. By using richer data than previous studies, we provide a more comprehensive assessment of the quality of BRIC engineering education.

[1] There have been attempts to define high quality engineering education for the twenty first 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.

Our analysis suggests that 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, given the great increase in engineers trained in the BRIC countries over the past decade, even if we assume no improvement in the quality of elite institutions, the number of graduates in the "high quality minority" has likely increased substantially as a proportion of total output of high quality engineering graduates in developed countries. Our conclusions thus differ from those of earlier studies, partly because we make a greater effort to assess the number of graduates coming from reasonably high quality institutions and partly because the BRICs are increasing the absolute number of graduates from elite institutions more rapidly than developed countries.

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 (1) engineering enrollments/graduates, (2) financing, (3) faculty qualifications, (4) student achievement, and (5) research productivity. We also assess quality using primary data collected through interviews with university administrators/faculty and surveys of engineering students in China, India, and Russia and similar secondary data from Brazil.

We collected primary data on administrators/faculty 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. We were unable to conduct interviews in Brazil due to limited funding, but instead drew on representative findings from rich secondary-source surveys of public and private institutions.

Our primary data on students were 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 (a northwest Province) 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 from seven regions 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 four states in 2009. We asked students to fill out virtually identical survey questionnaires and were thus able to compare student responses across the three countries (see "Appendix 2").

To facilitate the comparison of the quality of engineering programs across the BRIC countries and with developed countries, we take several steps to standardize the definition of engineering students and the types of institutions they attend. First, we extend the definition of engineering students to include those from a broad range of engineering disciplines (including aerospace, chemical, civil, electrical, mechanical, nuclear, and petroleum engineering) as well as computer science (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 1). We acknowledge from the outset that both our definitions and data are limited and subject to debate.

Analysis and results

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.

The quantity and quality of new engineering students

The number of engineering enrollments in elite versus non-elite institutions differs substantially across BRIC countries. According to our estimates (Fig. 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). The total number of engineering students from the BRICs in 2009 (~6.5 million) was, in fact, roughly 75 % more than the total from the United States, the European Union, Japan, Australia, and South Korea combined. However, the proportion of engineering enrollments to the total population was still relatively low in the BRIC countries. The proportion of engineering enrollments to the total population in China (0.28 %), Brazil (0.25 %), and especially India (0.13 %) were lower than those of South Korea (1.17 %), the European Union (0.45 %), and Japan (0.32 %). Two exceptions to this trend were Russia (0.61 %) at the high end of BRIC countries and the US (0.15 %) at the low end of developed countries.[2]

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 greater than the (total) number of engineering enrollments in the US, South Korea, or Japan (but still much less than Europe). This indicates that if engineering education in elite BRIC institutions were equal in quality to that of average institutions in developed countries, then China would be competitive with these countries in producing quality engineers.

Not only are engineering enrollments in the BRICs high, but in some cases they have increased rapidly (Fig. 1). In Brazil, engineering enrollments increased considerably faster in non-elite institutions from 1999 to 2003 and at an equally rapid pace (53 %) in non-elite and elite institutions from 2003 to 2009. In India, up until 2009 non-elite engineering programs expanded faster than 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 Fig. 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 to 2009, while non-elite engineering enrollments increased by 46 % over the same period. From 2006 to 2009 engineering enrollments in Russia increased slightly more in elite institutions (3 %) compared

[2] Engineering enrollment and the proportion of engineers among university graduates in Asian countries, such as Japan, South Korea and Taiwan has also been traditionally high (about 25 %). Asian countries have also sent large numbers of engineers to developed countries for graduate training. South Korea was extremely active in the 1970s, sending South Korean engineers to the United States for graduate training and requiring them to return to work in South Korean industry and universities. The large supply of engineers and government policies in South Korea, Japan, and Taiwan undoubtedly helped fuel industrial development and increased the quality of industrial exports in the 1970s and 1980s (Okimoto 1989; Amsden 1989, 2001).

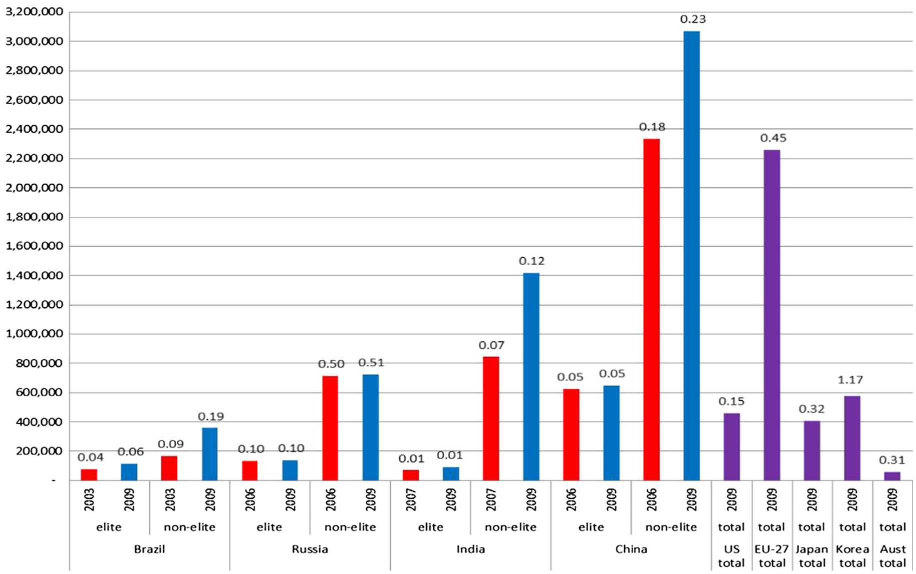

Fig. 1 Number of Bachelor's Engineering Enrollments in the BRICs (*Elite and Non-Elite*) versus Other Countries. *Notes*: the *numbers on top of the bars* are bachelor's engineering enrollments as a *percentage* of the total population. *Sources*: Authors' approximate estimates based on data from (a) China: NBS (1998–2010), (b) Russia: MOES (2011) and the State Research University Higher School of Economics, (c) India: UGC (2010), JEE (jee.iitm.ac.in) and AIEEE (www.aieee.nic.in), (d) Brazil: INEP (1998–2012), (e) United States: NCES (1998–2010), (f) European Union (27 countries): Eurostat (various years), (g) Japan: MEXT (1998–2010), (h) Australia: Kaspura (2013), (i) South Korea: KESS and KEDI (various years)

to non-elite institutions (1 %). Taken together, the changing numbers and proportions of students at elite and non-elite institutions provide a baseline by which to understand the priority given to 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 years olds in Brazil (32 %), India (roughly 14 %) and China (13–14 %) were low compared to Russia (75 %), the United States (45 %), and Europe (61 %).[3] Furthermore, when we compare the academic skills of prospective engineering students, we find that Brazil and India are far behind China and Russia. Results from the Programme for International Student Assessment, for example, indicate that students in Russia and China's more developed regions score comparably to (or higher than) US, European, Japanese, and South Korean 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 1998–2010). Furthermore, once students in the BRIC countries enter high school, they take many more math and science courses than high school students in the US and many European

[3] These statistics were either directly taken or estimated from various government statistical sources (i.e. National Science Board 2010; MHRD 2011; Brazil, INEP 1998–2012; NCES 1998–2010) 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 4-year institutions.

countries (for example, see Carnoy et al. 2013, chapter 6). The combination of achievement results and high school coursework imply that students entering elite programs in 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.

The financing of undergraduate education

BRIC countries devote fewer financial resources than developed countries to train engineering students. According to our estimates (Fig. 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.[4] BRIC spending per student was much lower than in the United States and Europe.[5] 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.[6]

Spending per student is much higher in elite institutions. In China, elite institutions spend an average of $6,000 per student while non-elite institutions spend about $2,500 (National Science Board 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 1998–2012; Hoper Educacional 2009). Importantly, higher spending per student implies that elite institutions can hire more qualified faculty and/or have smaller class sizes, which can lead to higher quality programs.

Availability of qualified faculty

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

[4] Because of the lack of available data, spending per student is estimated for higher education students in general, except in India, where data are available separately for spending on technical higher education. Spending per student estimates (a) in the United States and Europe 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 1998–2012), and spending per private student is estimated from surveys by a private consulting firm (Hoper Educacional 2009) of average tuition fees in private universities; (e) in India, we used data from the MHRD (2009–2012) 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.

[5] 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 1998–2010).

[6] 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 1998–2010; MHRD 2011). The low levels of spending per student may thus indicate lower faculty salaries in the BRIC countries.

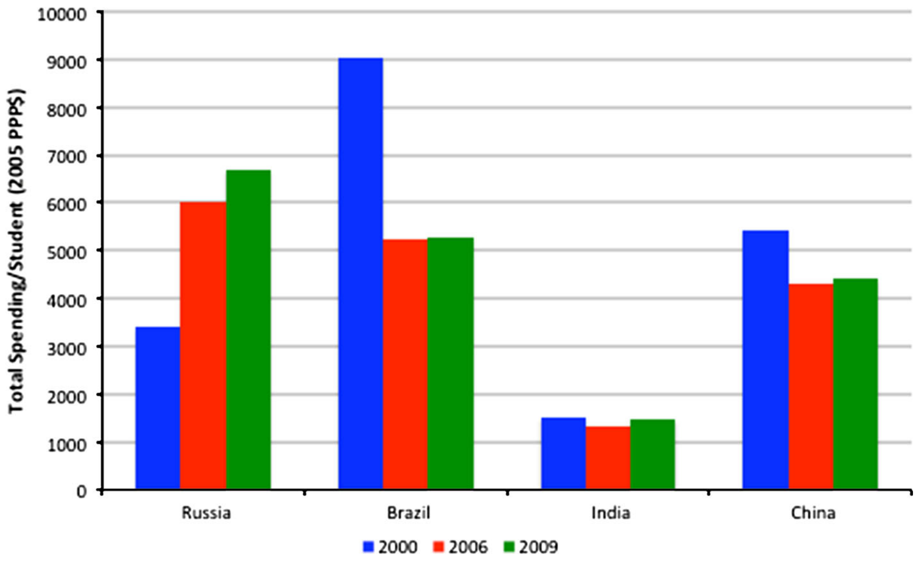

Fig. 2 BRIC Countries: Total of Private plus Public Spending in Higher Education per Student, by Country, 2000, 2006 and 2009 (in 2005 PPP dollars). *Source*: Authors' estimates based on OECD, *Education at a Glance* (1998–2010) and (a) China: (NBS 1998–2010), (b) India: *Analysis of Budget Expenditure on Education* (MHRD 2009–2012) and *Annual Reports* (UGC various years), (c) Brazil: Hoper Educacional (2009), and INEP (1998–2010); (d) Russia: State Statistical Committee of Russia (2010), and Bain (2001)

To understand the supply of qualified faculty, we first examine the number of engineering Ph.D. graduates produced annually in the BRIC countries. In China, the annual number of engineering Ph.D. graduates is high (~ 15,000) and has grown by approximately five times from 1998 to 2009 (see Table 1). Russia also graduates a large number of engineering Ph.Ds each year (~ 7,500). In contrast, the annual number of engineering Ph.Ds is small in Brazil (~ 1,300) and India (~ 1,200); furthermore, while the number of graduates tripled over 10 years in Brazil, it only increased by 50 % in India. Overall, the ratio of undergraduate engineering enrollments to engineering Ph.Ds (in 2009) is by far the highest in India (1324–1), followed by Brazil (370–1), China (239–1), Russia (114–1), Japan (106–1), Australia (102–1), the United States (roughly 75–1), South Korea (69–1), and the European Union (about 30–1). Clearly then, BRIC institutions have considerably less opportunity to find faculty with Ph.Ds than institutions in many developed countries.[7]

The supply of engineering Ph.Ds mirrors the proportion of faculty with Ph.Ds 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 developed countries such as the

[7] In addition, the supply of high quality Ph.Ds in these countries may be affected by emigration, although many of the engineers who emigrate do so by getting their Ph.D. abroad and not returning. The supply of high quality Russian engineers (many with Ph.Ds) available domestically was reduced substantially by a large emigration to Israel, the United States, and Western Europe in the 1990s. There is a concerted effort in China to bring back Chinese scientists and engineers with PhDs from developed countries to teach in China. Some of the Indian Institutes of Technology (Bombay, for example) fill teaching positions exclusively with Indian foreign Ph.Ds. As potentially important as this movement of professionals is, we were not able to get precise data on how it influences the supply of well-trained faculty available to BRIC universities.

Table 1 Ph.D. graduates (total and Engineering) from the BRIC countries and other countries, 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[a]	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
EU-27	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	509,058	525,809	n/a	n/a
Japan	10,974	12,192	12,375	13,179	13,642	14,512	15,160	15,286	15,973	16,801	16,281	16,463
Australia	n/a	3,664	n/a	3,884	4,291	4,728	4,900	5,244	5,519	5,721	5,786	5,796
South Korea	4,999	5,586	6,153	6,221	6,758	7,240	8,008	8,602	8,909	9,082	9,369	9,912
Engineers												
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[a]	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
EU-27	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	60,172	70,408	n/a	n/a
Japan[b]	n/a	n/a	3,964	3,955	3,921	4,077	3,915	4,195	4,177	4,073	3,954	3,758
Australia[b]	n/a	430	n/a	421	481	531	574	638	696	774	697	708
South Korea	n/a	n/a	n/a	n/a	n/a	1,758	1,971	2,138	2,201	2,104	2,078	2,112

Sources: China: National Science Board (2010), Russia: MOES (2011,), India: MHRD and UGC Reports (various years), Brazil: NBS and MOST (2010–2012), United States: National Science Board (2010; 2012), Europe (27 countries): Eurostat (2013a, b), Japan: MEXT (2013), Australia: Dobson (2012), Kaspura (2013, South Korea: KESS (2013) and KEDI (2013)

[a] University-only (including Ph.D. graduates from research institutes would add another 10–15 %)

[b] Only engineering Ph.D. graduates (no computer science Ph.D. graduates)

United States (where roughly two-thirds of professors in 4-year doctoral granting institutions have a Ph.D.—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 Ph.Ds in elite institutions in Brazil, India, and China (~50 % in each country) is much higher than in non-elite institutions.

We note here that questions can be raised about using an academic research degree such as the Ph.D. as a measure of the supply of qualified faculty in a field like engineering. In engineering, practical experience may well be an appropriate substitute for graduate academic training. That said, high quality engineering education also depends on a thorough grounding in advanced mathematics, high levels of preparation in the basic sciences, advanced skills in applying such knowledge to engineering problems, and an understanding of the social and environmental context of these applications (Sheppard et al. 2009). Furthermore, by analyzing student performance data on engineering knowledge tests for first and final year engineering students in Brazil (see subsection "Value-added measures of student learning" for more details), we, in fact, find that the proportion of faculty with Ph.Ds in a university engineering program is positively and significantly related to the "value-added" in each program. This is true even when controlling for a number of other variables including student socio-economic background (Carnoy and Carrasco 2012). This suggests that programs with more Ph.Ds among the faculty are associated with larger gains on a test of engineering knowledge.

Recognizing that the proportion of faculty with Ph.Ds is only one of several possible proxies for faculty quality, however, we also examine another indicator of faculty quality in the BRIC countries: the proportion of engineering faculty that has earned a professional license to practice engineering. Unfortunately, there are a multitude of associations (of widely varying quality, requirements, scope and significance) that license professional engineers both across and within countries (Kasuba and Vohra 2004). Because it is arguably much more difficult to compare licenses provided by domestic organizations across countries (than to compare Ph.Ds across countries, for example), we instead briefly focus on the degree to which engineering associations in the BRIC countries grant internationally-recognized professional engineering licenses.

Engineering associations in the BRIC countries have, in fact, only recently obtained the ability to grant internationally-recognized professional engineering licenses (to faculty or occupational engineers). For example, after becoming a member of the Engineers Mobility Forum in 2009, the Institution of Engineers in India (IEI) provided an "International Professional Engineer" license to a total of 29 engineers from 2009 to 2014 (IEI 2014). Likewise, after joining the APEC Engineer Register in 2008, the Russian Association for Engineering Education (RAEE) awarded the title of "APEC Engineer" to 27 Russian engineers from 2008 to 2010 (Chubik et al. 2010). Similarly, the China Association for Science and Technology has been working since 2007 to establish international licensing agreements with associations in the UK, US, Japan, South Korea, and Hong Kong. So far, these licensing agreements have been limited to specific fields such as mechanical engineering, automation, operations, instruments and electrical engineering. Finally, although engineers in Brazil are required to register with a federal association, there are few international licensing agreements between Brazilian associations and other countries. Taken together, it appears that engineering associations in the BRIC countries are beginning to use well-established, international licensing requirements to identify highly qualified engineers. At this early stage, however, only a handful of faculty in any BRIC country has earned international professional engineering licenses through these associations.

Table 2 Percentage of faculty with Ph.Ds in the BRICs

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 (1998–2010), (b) Russia: MOES 2011, (c) India: UGC 2010, (d) Brazil: INEP (1998–2012)

We also rely on qualitative evidence from our interviews in Russia, China and India (as well as secondary sources from Brazil) to better inform our understanding of 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, faculty and administrators frequently stated that the quality of Ph.D. graduates (and thus new faculty hires) is low, as Ph.D. curricula are outdated, entering Ph.D. students are of relatively low ability (compared to bachelors and masters degree graduates that enter industry or earn their advanced graduate degrees abroad), and only certain professors (that is, more traditional full professors as opposed to associate and assistant professors) are allowed to advise Ph.D. students. The quality of Ph.D. graduates in India also appears low. Interviewees from India frequently mentioned the lack of qualified advisers and adequate laboratory facilities for Ph.D. students. In contrast to the other three countries, the Brazilian government's support of graduate programs (in elite institutions) has apparently led to a steadily increasing proportion of faculty with a strong, research-based graduate education (Balbachevsky and Schwartzman 2011). Nonetheless, according to our interviews and secondary sources, the majority of non-elite institutions in all BRIC countries appear to have difficulties hiring faculty from elite graduate programs.[8]

[8] The BRIC governments have also promoted faculty development, primarily through support for short and longer-term international exchanges. In China, the government has funded a large number of students and faculty (through programs such as the Young Faculty Study Abroad Program) to study and conduct research abroad (National Bureau of Statistics 1998–2010). In Brazil, graduate courses have study abroad components that partially aim at developing a body of highly qualified faculty for university teaching and research. By contrast, the Russian government has provided a minimum of direct financial support for exchange programs (and even that only since 2010). Despite the lack of federal government support, however, leading Russian universities are supporting student and faculty international exchanges. For instance, in 2008, approximately forty Russian universities (<10 %) had joint-degree programs with foreign universities. In India, the Ministry of Education has also introduced some short-term opportunities for Indian scholars to participate in international exchanges with initiatives such as the Travel Grant, which provides teachers and staff involved in higher education to present papers at international conferences. The Ministry also promoted the Bilateral Exchange Programme, a scholar exchange program that (during the 2008–2009 academic year) deployed 90 Indian scholars abroad. On the whole, however, the number and size of India's programs to encourage international exchanges is quite small.

Closely related to the issue of the supply of qualified faculty are the varying student-to-faculty ratios in elite and non-elite institutions across the BRIC higher education systems. Across all 4-year institutions in China, the student-faculty ratio has hovered around 17–18 to 1 since 2003 (NBS 2003-2010). The ratio was 15–16 to 1 in Brazil from 2002 to 2008 (MOE Brazil various years) and around 13–1 for all tertiary institutions in Russia in 2009 (OECD 2011). These ratios are quite similar to those in the United States and Europe (approximately 15:1) (OECD 2011). In India, although regulators require a ratio of 15:1, the reported student–teacher ratio is 24–1 (MHRD 2011). This short supply of professors in India may well have repercussions on the quality of instruction.

Overall, the variation in inputs among engineering programs across the BRIC countries has clear implications for their capacity to produce well 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 well 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 well qualified graduates.

Process-based indicators

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 and give them 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. In India, state/regional public universities assess learning levels among the non-elite institutions under their jurisdiction to ensure that graduates meet minimum ability requirements. Policymakers and university administrators in China and Russia, by contrast, use the average exam scores of incoming students as a proxy for institutional quality.

In addition, for several years the government of India has attempted to incentivize private, non-elite institutions with the carrot of greater autonomy (from supervising state or regional agencies) if they improve their standards. In essence, if a private, non-elite institution starts graduate programs, hires more instructors with Ph.Ds, and meets other quality criteria set by the central government, they can become "deemed" universities, a status which gives them control (autonomy) over their curriculum and student assessments. Nevertheless, these deemed universities would also come under the direct supervision of central government agencies (the AICTE/NBA). Requirements on affirmative action quotas (quotas for scheduled castes and scheduled tribes) would also not change. Because of these issues, administrators at several private institutions told us they preferred operating under state/regional supervision (through state public universities). They hence would not seek "deemed" status (Carnoy et al. 2013, chapter 5). In practice, the growth of deemed universities has been small, hence this incentive to improve quality has not been particularly successful.

Despite trying to ensure a minimum level of quality in non-elite institutions, our interviews in China, India, and Russia, survey data in Brazil, and the pattern of spending per student reveal that BRIC governments and university administrators are more focused on increasing (in Russia, maintaining) enrollment in the non-elites than raising quality. In China and Russia this focus is driven by funding and pressure either to absorb increasing numbers of students (China) or to maintain enrollment (or face closure) despite a declining youth population (Russia). In India and Brazil, the rapid expansion of engineering education has been led by private institutions, which are market-oriented and largely driven by the bottom line, regardless of whether they are officially non-profit or for-profit. They also need to operate under the constraints, in India, of government tuition control, and, in Brazil, by the need to attract new waves of lower-income students by keeping tuition low. This may make them more cost-efficient than public institutions but predictably less oriented toward staffing with higher-priced, more qualified professors (for details on the interviews with private college and university administrators, see Carnoy et al. 2013; Balbachevsky and Schwartzman 2011). 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.

Students' educational experiences, exposure to practice and non-technical courses

We find large differences in inputs and government support between elite and non-elite institutions, but we also 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) that have been shown to increase student learning (Fairweather 2008; Pascarella and Terenzini 2005). The survey findings are similar across elite and non-elite institutions. Although much of this self-reported information is subjective (and therefore limited because students may be inclined to speak more or less positively about their own institution), it seems to 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 1998–2012).

Although students seem satisfied with their education, they lack practical experience and exposure to non-technical courses—both of which are believed to be important elements of a successful engineering education program (Fairweather 2008; Pascarella and Terenzini 2005; ABET 1997). 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 science course. Few students in India and Russia had an engineering internship during college (with “internship” referring to a short-term experience in an engineering-related occupation outside of college). Although most engineering students in China participated in an internship, the quality of these internships is dubious (Cha 2007). Finally, engineering students in all four countries typically take fewer humanities and social science courses than their counterparts in developed countries.

Quality assurance and program accreditation

In the last two decades, accreditation agencies have played an increasingly important role in monitoring the quality of engineering programs in developed countries. A recent development among accreditation agencies in developed countries (for example, ABET in the United States and the Engineering Council in the UK) is the increased focus on outputs-based assessment as opposed to inputs-based assessment (Augusti 2007; Volkwein et al. 2004). Another recent development is the increased focus on building professional skills such as problem solving, effective communication, and teamwork (in addition to more traditional math, science, and engineering skills). In general, researchers have perceived these developments as effective in improving the quality of engineering education in developed countries (Prados et al. 2005; Volkwein et al. 2004).

In a break from their traditional arrangements, the BRIC countries have also begun emphasizing accreditation schemes based on these new developments. A major impetus to emphasize new accreditation schemes is the desire of engineering program administrators and national policymakers to establish the equivalency of degrees/graduates from their engineering programs with those of other countries. Thus, as part of the effort to justify the equivalency of their engineering programs, the BRIC countries have sought, to varying degrees, to become members of international accreditation agreements.

Given its association with the European Higher Education Area and in accordance with the Berlin Communiqué, Russia is taking an active part in such international accreditation agreements.[9] The Association for Engineering Education in Russia (AEER), for example, has recently signed the Washington Accords, the APEC Engineer agreement, and has joined the European Network for Accreditation of Engineering Education (EUR-ACE). The federal government (which in the past was mainly responsible for accrediting higher education programs) is also now working with the AEER to develop a national system for accrediting engineering programs. To date, AEER has accredited about 30 programs.

Although accreditation for a few engineering programs existed in China in the early 1990s (Bi 2009), serious efforts to promote accreditation (in alignment with international standards) started less than a decade ago. Specifically, the China Association for Science and Technology (CAST), the Chinese Academy of Engineering and associated government ministries jointly piloted an engineering accreditation program for computer, chemical, electrical, and mechanical engineering in 2006.[10] Since the pilot project, there has been an expansion in the number of disciplines included in the pilot program and greater international cooperation (most notably with the UK, Hong Kong, South Korea, and Japan). As recently as June of 2013, CAST gained provisional status in the Washington Accords. Furthermore, at the start of 2014, CAST accredited a first batch of 86 engineering programs (most from elite institutions).

[9] Much of the information in this paragraph can be found at http://www.ac-raee.ru/eng/accreditation.php.

[10] Much of the information in this paragraph can be found at http://www.cast.org.cn.

Having recently obtained provisional status in the Washington Accords, India is also starting to place greater weight on internationally accepted accreditation practices. Specifically, the National Board of Accreditation (NBA) in India has introduced new criteria for accreditation that focus on outputs-based assessment and broader definitions of student learning.[11] Because of India's large number of technical institutions, however, the NBA has also introduced a two-tier system of accreditation. The first tier (which is more stringent, and more aligned with international standards) is for university departments and autonomous institutions (including elite institutions). The second tier (which is less stringent and less aligned with international standards) is for non-autonomous institutions (mostly non-elite, private institutions affiliated with universities).

Because they are relatively new, the degree to which internationally accepted accreditation practices will aid in improving engineering education in Russia, India and China remains to be seen. The NBA in India has already recognized, for example, that it may be extremely difficult for non-elite institutions to meet such accreditation requirements. Because non-elite programs in the other BRIC countries have similar levels of inputs as non-elite programs in India (low ability students, less qualified faculty, low funding), non-elite programs in the other BRIC countries may also find it difficult to meet accreditation requirements (at least for the foreseeable future).

In contrast to the other BRIC countries, policymakers in Brazil place less weight on international accreditation. Rather, they rely on their own (national) system for evaluating higher education (Sinaes). Specifically, all higher education institutions in Brazil are evaluated by the National Institute of Studies and Research and Education (INEP). INEP commissions external evaluations using an approved, national list of evaluators. The external evaluators assess the pedagogy of new and existing courses of study, the quality of faculty instructors, physical facilities, and administrative support. Furthermore, INEP requires students in all engineering programs in Brazil to take part in general knowledge and major (engineering) knowledge exams. These exams are intended to measure students' knowledge at the beginning and end of their studies and identify which programs are failing to educate students. The results of these exams are not used for accreditation/accountability purposes, however.

Output-based indicators

Value-added measures of student learning

Given the lower levels of inputs and lack of processes to support quality in non-elite versus 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 draw on research in Brazil that conducted a "value-added" analysis. The value-added analysis compares the learning gains of electrical engineering and computer science students in different engineering programs in Brazil from their first to last year of study. Brazil is unique internationally in that, as part of its higher education evaluation/credentialing system, the Ministry of Education tests first and final year students in a variety of majors across all higher education institutions. The tests, called the Exame Nacional de Desempenho de Estudantes (ENADE) consist of a short general knowledge test and a test designed for the particular program of study. It is difficult to match first-year students with final-year students, but we were able to make upper and lower bound estimates of ENADE

[11] See http://www.nbaind.org/views/Home.aspx#sthash.4vPD0xCU.dpuf.

test gain on the engineering and computer science tests for student cohorts in the same university who took the initial test in 2008 and the final test in 2011.

When we compare the scores on the ENADE test for elite and non-elite programs, we find that both types of programs increase student learning. Specifically, we observe that elite engineering programs increase student learning by about 1.7 standard deviations or SDs (0.64–2.34 SDs) compared to 1.25 SDs (−0.16 to 1.09 SDs) for non-elite programs (Table 3). We also find that final-year students in non-elite engineering programs attain skill levels only slightly above those of first-year students in elite programs.[12] This suggests that the majority of engineering graduates from non-elite institutions in Brazil may be only minimally prepared to work in technical jobs.

The value-added results are much starker for the computer science programs. Elite computer science programs increase student learning by about 2.52 standard deviations or SDs (1.45–3.97 SDs) compared to 1.31 SDs (−0.13 to 1.18 SDs) for non-elite programs (Table 3). We also find that final-year students in non-elite computer science programs attain skill levels below those of first-year students in elite programs.

Taken together, these results for Brazil suggest that students who attend engineering and computer science programs in the elite institutions are very different in their level of subject matter knowledge than are students in non-elite programs. It is important to note, however, that although the wide differences in inputs and process-based indicators between Brazil's elite and non-elite institutions are mirrored in the other BRIC countries, the differences in value-added between more selective and less selective institutions in Brazil may or may not generalize to the other BRIC countries.

Graduates and graduate employment

The value-added assessment above is useful, since unlike developed countries and, to some extent, Brazil, graduation rates tell us little about the quality of engineering education in the BRICs. In the United States, for example, an estimated 56 % of 4-year higher education students graduate within 6 years (Symonds et al. 2011). In Brazil, the total of graduates in 2010 represented roughly 60 % of the entering students in 2004 (INEP 2010). Graduation rates are much higher in China (∼95 %), Russia (∼80 %), and India (∼79 %), however (NBS 1998–2010; OECD 2012; Banerjee and Muley 2009).[13] Such high graduation rates may imply that engineering programs in these countries fail to "weed out" poorly performing students, creating a culture in which those accepted into university can easily graduate, regardless of academic performance. Graduation rates could also be high, however, because the quality of incoming college students is high. As stated previously, the greater emphasis on math and science courses in high school in combination with the competitive admissions processes in each country, may weed out poorly performing students before they get to college.

On the flip side, with such high graduation rates in China, India, and Russia, the number of graduates emerging from elite and non-elite programs in each country is high (see Fig. 3). Similar to enrollments (Fig. 1), the number of engineering graduates from elite

[12] We moreover find that the proportion of faculty with Ph.Ds in a program is positively and significantly related to value-added [inter-cohort (2008–2011) value-added on the ENADE].

[13] 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. In Brazil, for example, the number of graduates in 2010 represented about 60 % of the cohort of entrants into engineering programs in 2004—the same percentage as for all undergraduates.

Table 3 Estimated inter-cohort and intra-cohort test score gains in computer science and electrical engineering, 2005 and 2008, for students entering elite and non elite programs (standard deviations from mean = 0)

	Computer Science					
	Non-Elite universities			*Elite Universities*		
Year	*No.of Programs*	*Initial Year Test Score*	*Final Year Test Score*	*No. of Programs*	*Initial Year Test Score*	*Final Year Test Score*
2005	207	-0.13	2.26	29	1.45	4.64
		(0.86)	(1.60)		(1.20)	(1.46)
2008	207	-0.19	1.18	29	1.19	3.97
		(0.85)	(1.10)		(1.26)	(1.86)
	Electrical Engineering					
	Non-Elite universities			*Elite Universities*		
	No. of Programs	*Initial Year Test Score*	*Final Year Test Score*	*No. of Programs*	*Initial Year Test Score*	*Final Year Test Score*
2005	173	-0.16	1.37	63	0.64	2.66
		(0.85)	(1.47)		(0.95)	(1.61)
2008	173	-0.10	1.09	63	0.82	2.34
		(0.83)	(1.07)		(0.85)	(1.09)

The decline in initial year and final year test scores between cohorts from 2005 to 2008 is difficult to interpret since the tests used in each year are not equated (i.e. vertically scaled) across years

Source: Estimates from INEP, ENADE database, provided by Carnoy and Carrasco (2012)

programs in China in 2009 (132,872) is higher than the total number of engineering graduates in the United States (109,096), Japan (95,216), or South Korea (74,126), and about one-third that of the entire European Union (369,367).[14] In contrast, by 2012 Russia had approximately one-fourth of the number of elite engineering graduates (around 25,000), India had approximately one-fifth the number (around 20,000), and Brazil graduated about 12,500 (not shown in Fig. 3).[15] In all of the BRIC countries, the number of graduates from non-elite institutions was 5–6 times higher.

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-Filho 2009). Finally, in all four countries, the economic payoff to higher education (that is, the economic or Mincer returns to graduating from a higher education institution as opposed to not attending a higher education institution), in general, and engineering education, in particular, is quite high (Carnoy et al. 2013). 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 are in relatively high demand in the labor market. The high demand may indicate that graduates possess the skills demanded by the labor market or, in turn, may imply that the graduates are the best human resources available to employers (and that employers are willing to train the graduates up to suitable skill levels during employment).

[14] 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.

[15] Our estimates (perhaps conservatively) assume that 20 % of entering elite engineering students drop out before graduation. Accordingly, India should have about 36,000 elite engineering graduates by 2015.

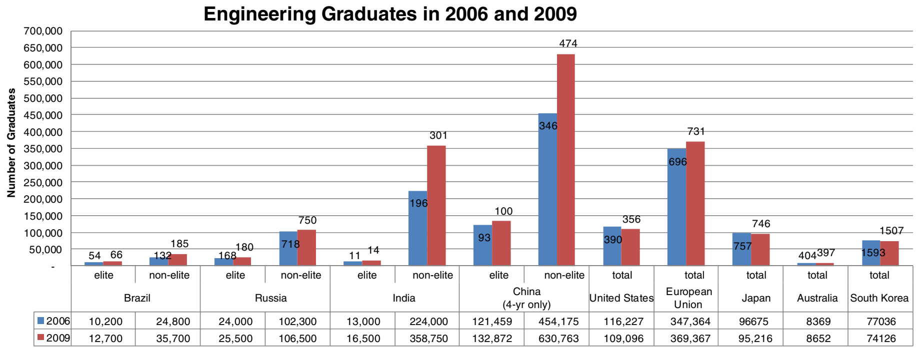

Fig. 3 Engineering graduates from the BRICs (*Elite and Non-Elite*) versus Other Countries, 2006 and 2009. *Note*: The *numbers* located near the *top of the bars* are graduates per million population. *Sources*: Authors' approximate estimates based on data from (a) China: NBS (1998–2010), (b) Russia: MOES (various years) and the National Research University Higher School of Economics, (c) India: UGC (2010), and JEE (jee.iitm.ac.in) and AIEEE (www.aieee.nic.in), (d) Brazil: INEP (1998–2012), (e) United States: NCES (1998–2010), (f) European Union (27 countries): Eurostat (various years), (g) Japan: MEXT (2013), (h) Australia: Kaspura (2013), (i) South Korea: KESS and KEDI (various years)

Research

The final indicator of quality we look at is research productivity. We summarize two 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 as well as (b) the number and quality of academic publications.[16] We note that high levels of research funding and high publication rates, by themselves, are not necessarily correlated with learning gains among undergraduate students (Astin 1994). At the same time, integrating research and teaching (such as by incentivizing faculty to bring research into the classroom through inductive teaching practices and exposing undergraduates to research projects) has the potential to improve undergraduate engineering education (Prince et al. 2007). That is, while statistics on publication rates and research funding per student do not necessarily reflect the current quality of engineering education, they reflect the potential of higher education institutions to improve the quality of engineering education through the successful integration of research and teaching.

Overall, the BRIC countries are behind in total R&D spending in higher education (Fig. 4). Although they lag far behind the US, China and Brazil spend about as much as the UK and Germany, which have many fewer faculty and students. Russia and India spend even less on R&D.

BRIC countries are also behind the United States, Europe, and South Korea in terms of R&D spending in higher education per student (Fig. 5). R&D spending per student is highest in Brazil ($1,579 in 2010 in 2005 PPP$ terms)—about 72 % of the amount spent in South Korea, 40 % of the amount spent per student in the United States, and only 25–30 % of the amount spent in the UK and Germany. 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 can potentially contribute to the quality of engineering education.

[16] Although research expenditures are an input-based indicator, we discuss research expenditures and publications in the same subsection for convenience.

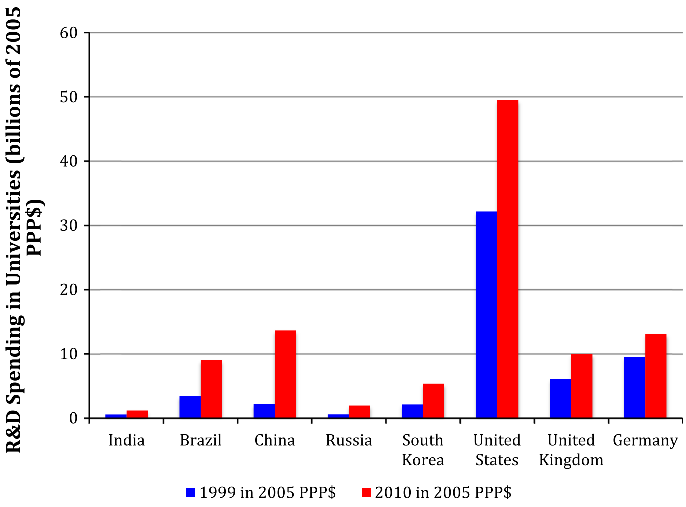

Fig. 4 Total R&D Spending in Higher Education in the BRICs and Other Countries. *Sources*: OECD *Main Science and Technology Indicators* (1998–2010), UNESCO Institute for Statistics (2012). *Notes*: India's statistics are for 1999 and 2007; Brazil's statistics are for 2000 and 2008. U.S. statistics are for 1999 and 2009

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 elite institutions compete for substantial research funding with the goal of improving research 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 and Technical Proceedings (ISPT), produced by researchers in each country.[17] In terms of the total number of scientific articles published per million of the population, China now ranks 2nd behind the United States and ahead of the UK (3rd), Germany (4th), Japan (5th), and France (6th) (as of 2009) in S&T papers indexed by SCI or ISTP rankings and ranks 1st in the EI ranking. India, Brazil, and Russia rank 10th, 13th, and 15th respectively in SCI rankings (compared to South Korea and Australia which rank 11th and 12th). 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.

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).

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

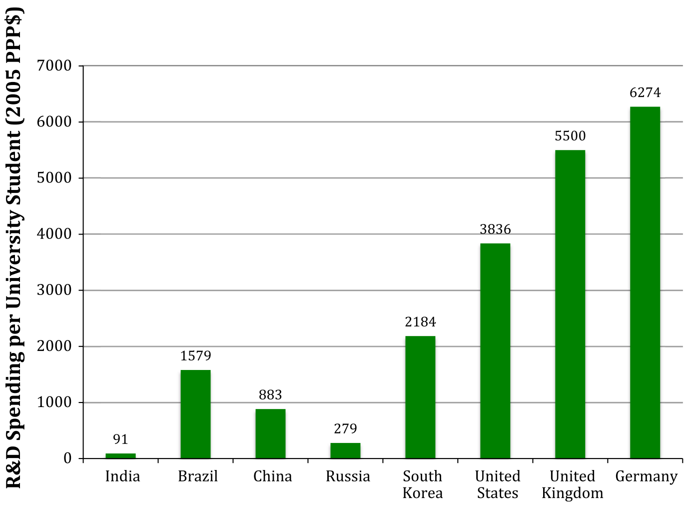

Fig. 5 Total R&D Spending per Student in 2010 (2005 PPP$). *Source*: OECD *Main Science and Technology Indicators* (1998-2010). UNESCO Institute of Statistics (2012). *Notes*: India's statistics are for 2007; U.S. statistics are for 2009

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).[18] Even so, according to another 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, a potential 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, faculty in non-elite programs are incentivized to produce research *en masse*, with little regard to quality. A large number of low quality publications are also produced by Ph.D. students in both elite and non-elite programs in China (since publishing papers is often a requirement for graduation). The lack of financial support for non-elites in Russia has resulted in a significant decline in research productivity in the last decade. Faculty at the mass, private institutions in Brazil and India are seldom engaged in meaningful research activities.

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-

[18] Brazil's impact is especially high in engineering (only 5 % below the world average), with 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 %).

Table 4 Number of science and technology papers indexed by SCI, EI and ISTP in the BRICs and other countries, 2009

Country	SCI			EI			ISTP		
	Papers (10,000)	Rank	Papers per million	Papers (10,000)	Rank	Papers per million	Papers (10,000)	Rank	Papers per million
World total	144.2			40.9			42.8		
Brazil	3.5	13	180.9	0.6	17	31.0	0.7	12	36.2
Russia	3.2	15	225.5	1.1	13	77.5	0.7	14	49.3
India	4.5	10	37.8	1.6	8	13.4	0.8	10	6.7
China	12	2	90.1	9.3	1	69.9	5.2	2	39
USA	39.8	1	1297.4	6.9	2	224.9	10.5	1	342.3
UK	11.4	3	1761.9	2.2	5	340.0	2.6	4	401.8
Germany	10.7	4	1306.4	2.5	4	305.2	1.9	5	232.0
France	7.5	6	1246.0	2.1	6	348.9	1.9	6	315.7
Italy	6.4	7	1035.4	1.4	10	226.5	1.4	7	226.5
Japan	9.2	5	721.2	2.9	3	227.3	2.7	3	211.7
Australia	3.9	12	793.0	n/a	n/a	n/a	n/a	n/a	n/a
South Korea	4.3	11	2271.5	1.6	7	845.2	0.7	13	369.8

Paper per million = (papers/total population)*1,000,000

Source: NBS and MOST (2010–2012)

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 on research. The quality of elite versus non-elite engineering programs is also reflected in higher student learning gains and the greater 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 mass of 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, given the data we have been able to assemble, we conclude that 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 do not possess comparable skills to the average engineering graduate in developed countries.

Our data on engineering students and programs in elite universities tentatively suggest that engineering graduates from the relatively small fraction of elite institutions in the BRICs are prepared at a level that is comparable with average engineering graduates in the developed countries. Since the number of engineering graduates coming out of even this relatively small group of institutions in the BRICs (particularly China) is so large, the probable comparability of preparation and skill of these elite BRIC graduates implies that the large and increasing supply of qualified engineering graduates from the BRIC countries likely will have an important impact on high technology production in the coming years. This could mean that high tech production would be further stimulated in the developed countries by a relatively cheap supply of highly skilled engineering labor, or it could mean that, increasingly high tech production shifts to the BRIC countries.

Appendix 1: 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 elite (highly selective, high quality) and non-elite (less selective, lower quality) institutions in these two countries will likely be the same across the range of viable definitions.

Appendix 2: Student (Final Year of Bachelor Degree) Questionnaire

1. Your name: _________________________

2. Your student ID#: ____________________

3. Your birth date: ____ Year ____ Month ____ Day

4. Your gender: ☐ male ☐ female

5. Your ethnicity: ________________

6. Where were you born?

7. How many siblings do you have?
☐ none ☐ 1 ☐ 2 ☐ 3 ☐ 4 ☐ 5 or more

8. What is the highest level of education obtained by your parents? (Mark one in each column)

	Father	Mother
Some primary school or less	☐	☐
Primary school graduate	☐	☐
Middle school graduate	☐	☐
Upper secondary vocational school grad	☐	☐
Upper secondary academic school grad	☐	☐
Vocational college graduate	☐	☐
University graduate (bachelor's degree)	☐	☐
Graduate level degree (masters/PhD)	☐	☐
Don't know	☐	☐

9. Which of the following assets does your family own (please check all that apply)?
   a. Color television
   b. Refrigerator
   c. Phone/mobile
   d. Motorbike
   e. Bicycle
   f. Microwave
   g. Camera
   h. Computer (desktop)
   i. Computer (laptop)
   j. Air Conditioning
   k. Car
   l. Washing Machine

10. What is your primary major? _______

11. Do you have a second major? Yes/No; If so, please specify___________

12. Which high school did you graduate from?
   a. Full name: _________________
   b. City/Region: _________/_________
   d. Were you in a specially designated science or humanities track class?_____

13. What was your score on the national college entrance exam (the year you entered this college)? _____

14. Which type of national college entrance exam did you take?
(Please indicate: ______________________)

15. What city/region did you take the national college entrance exam in?
City/Region____________________

16. Did you also take the national college entrance exam in a previous year also? ☐ yes ☐ no

17. Upon entering the university, did you receive your first choice of major? Y/N

18. Entry date into this university: _____Year ______Month

19. Expected date of graduation: _____Year ______ Month

20. What is your current ranking in your department? _____

21. How many hours do you spend during a typical week doing the following?

a. Attending classes / labs	______hours
b. Studying / homework	______hours
c. Student clubs/groups/volunteer work	______hours
d. Leisure (movies, exercise, socializing entertainment,, etc.)	______hours

22. University fees/costs (2007-2008 school year only)

a. Standard tuition rate for current major(s)	________$
b. Dorm/Housing	________$
c. Food	________$
d. Textbooks, all other class materials	________$
e. Extra miscellaneous fees	________$

23. University Subsidies/Aid (2007-2008 school year only)

a1. Received a tuition waiver(s)?	☐ Yes ☐ No
a2.Total Amount 2007-08:	________$
b1. Received merit scholarship(s)?	☐ Yes ☐ No
b2. Total Amount 2007-08:	________$
c1. Received need scholarship(s)?	☐ Yes ☐ No
c2. Total Amount 2007-08:	________$
d1. Room/board/other allowances/waivers?	☐ Yes ☐ No
d2. Total Amount 2007-08:	________$
e1. Work Study opportunity provided?	☐ Yes ☐ No
e2. Total Amount 2007-08:	________$

24. Loans (2007-2008 school year only)

a1. Received government loan(s)?	☐ Yes ☐ No
a2.Total Amount 2007-08:	________$
b1. Received bank/commercial loan(s)?	☐ Yes ☐ No
b2. Total Amount 2007-08:	________$
c1. Received university/department loan(s)?	☐ Yes ☐ No
c2. Total Amount 2007-08:	________$
d1. Received loans from family/friends?	☐ Yes ☐ No
d2. Total Amount 2007-08:	________$
e1. Other, explain _____________	
e2. Total Amount 2007-08:	________$

25. Additional Expenditures (Total for 2007-2008 school year)

a1. Outside classes (English, computers, etc)?	_______$
a2. Total amount paid to attend such classes:	_______$
b. Electronics (cell phone, computer, etc.)	_______$
c. Internet Fees	_______$
d. Telephone or cell phone fees	_______$
e. Necessary life expenses	_______$
f. Entertainment expenses	_______$

26. Did you work part-time or full-time during any of your years of university study?
☐ Yes ☐ No
If yes:
a. how many hours per week on average? _______hrs/week
b. how much did you earn per hour on average? ______(currency unit)/hr

27. Have you already signed a contract for a full-time job upon graduation?
☐ Yes ☐ No
If yes:
a. Estimated start date ___ Month ____ Year
b. *Occupation_____________________
c. City/province____________/__________
d. Type of company ☐ foreign ☐ joint-venture ☐ domestic
e. Total annual salary in first year (with bonuses) __________$

If no, then realistically:
a. When do you expect to start working full-time? __Month __Year
b. Where do you think you will work? _____City _______Region
c. What will your occupation be? ________
d. What type of company do you think you will work for?
☐ foreign ☐ joint-venture ☐ domestic
e. What do realistically estimate your total annual salary (including bonuses) to be in your first year? ________$

28. How much do you realistically expect your annual salary to be in:
5 years ______________ $ 15 years _____________$

29. Will you attend graduate school in fall 2008?
☐ No, didn't apply ☐Yes
☐ Don't know (e.g. on a waiting-list or haven't found out yet)

If yes:
i. Is the university domestic or abroad? ☐ Domestic ☐ Abroad
ii. Which university? _____________ Which major? ___________

If "no" or "don't know":
iii. Do you ever plan on going to grad school? (Y/N)_____
iv. If so, which university? _________ Which major? __________

30. What do you plan to be doing in the fall of 2008?
(mark all that apply):
☐ working in industry
☐ working in the government sector
☐ working full-time in another area
☐ working abroad
☐ studying to apply for graduate school in fall 2009

- ☐ serving in the military
- ☐ traveling
- ☐ staying at home to take care of my family

31. In your Engineering courses, how often were the following used in class? (mark frequently, occasionally, or never)

a. lecture	☐..........☐..........☐
b. technical demonstrations by instructor	☐..........☐..........☐
c. small group discussion	☐..........☐..........☐
d. small group work	☐..........☐..........☐
e. student presentations	☐..........☐..........☐

32. In your Engineering courses, how often were the following used for evaluation? (mark frequently, occasionally, or never)

a. multiple choice tests	☐..........☐..........☐
b. tests with problem solving	☐..........☐..........☐
c. end of course exams	☐..........☐..........☐
d. student oral presentations	☐..........☐..........☐

34. Since entering college, have you?

a. Had an internship?	☐ Yes ☐ No
b. Worked on a professor's research project?	☐ Yes ☐ No
c. Participated in a study abroad program?	☐ Yes ☐ No
d. Participated in a leadership program/class?	☐ Yes ☐ No
e. Been active in a student organization	☐ Yes ☐ No
f. Studied a foreign language?	☐ Yes ☐ No
g. Taken an interdisciplinary course in the sciences	☐ Yes ☐ No

35. In your Engineering courses, how often did you do any of the following? (mark frequently, occasionally, or never)

a. Write technical/laboratory reports	☐..........☐..........☐
b. Develop original technical designs	☐..........☐..........☐
c. Work on group projects	☐..........☐..........☐
d. Orally present technical reports	☐..........☐..........☐
e. Discuss the global economy	☐..........☐..........☐
f. Discuss the nature of your profession	☐..........☐..........☐
g. Work on projects with firms	☐..........☐..........☐

36. Compared with when you entered college, how would you now describe your (1= much weaker; 2 = weaker, 3 = same; 4 = stronger; 5 = much stronger):

a. Technical knowledge: __________
b. Knowledge of engineering practice: __________
c. Foreign language ability: __________
d. Leadership abilities: __________
e. Writing skills: __________
f. Confidence in your academic abilities: __________
g. Knowledge of new technologies: __________
h. Knowledge of global markets/economies: __________
i. Oral communication skills: __________
j. Problem solving abilities: __________
k. Ability to collaborate with others: __________
l. Interest in lifelong learning: __________
m. Intercultural skills: __________
n. Entrepreneurial skills: __________

37. What is the highest level of education you plan to attain? (mark one):
 a. Bachelor's b. Master's c. Doctorate d. Law degree e. Medical degree

38. Please indicate your level of agreement with the following (1 = strongly disagree; 2 = disagree; 3 = neutral; 4 = agree, 5 = strongly agree

a. I am well prepared for a career in engineering: _________
b. If I could pick all over again, I'd study engineering: _________
c. My engineering career will include working abroad: _________
d. My career goals include managerial positions: _________
e. Technical abilities are the most important skill for engineers: _________
f. There will always be jobs available for engineers in my lifetime: _________

39. Did you take any courses outside your primary and secondary department majors? If so what were they? ____

40. Did you take any courses that covered issues of economic globalization? If so what were they?
____

41. Do you have plans to keep in touch with friends/alumni?

42. Are there any formal mechanisms already set up by the school to keep in contact with classmates and alumni?
____

43. Did you participate in any career counseling services from the university? Y/N

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