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OBSERVATIONS ON INNOVATION AND TECHNOLOGY USE IN THE BRICS

*Keith E. Maskus**

I. INTRODUCTION

ONE of the primary questions of this conference, arising from both widely held concerns and hopes, is whether the BRICS—Brazil, Russia, India, China, and South Africa – along with other prominent emerging economies such as Mexico, Argentina, Malaysia, and Indonesia, can sustain their recent remarkable growth records. The concerns relate to continued prospects for offshoring US manufacturing and service jobs, with possibly negative consequences for lower-skilled and medium-skilled Americans. The hopes reflect the increasing recognition that Europe, Japan, and the United States face years of slow growth or economic stagnation, leaving to key emerging countries the critical role of driving increases in world demand for the medium-term.

Many important factors will determine whether the BRICS will continue to rack up significant growth gains. The most immediate forces are global and national macroeconomic elements, such as fiscal austerity, monetary expansion, energy and materials prices, and interest rate and exchange rate fluctuations. The large sizes of the BRICS economies, especially China's, have made economic conditions there increasingly important for world stability. Perhaps for the first time in recent history, analysts in the developed world must pay close attention to how these nations are faring in order to understand prospects for their own markets.

If macroeconomics dominates in the short run, structural microeconomic factors determine growth prospects over longer time horizons. Among the most important conditions are demographic trends, educational attainment, policy transparency, infrastructure, trade liberalization and deregulation, and the ability to innovate and adapt technologies. The various BRICS have registered different performance records on these basic factors in recent decades. Some have succeeded in moving underemployed labor and capital to more efficient uses (China, India, and South Africa). Others have taken advantage of increasing commodity prices (Brazil and Russia). Some have invested heavily in education

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and infrastructure (China) while others lag behind (Russia, Brazil, and India).

The prevailing story of the BRICS to date has been their seemingly rapid “catching up” of productivity, wages, and percapita incomes to levels in richer nations. These factors have been important in pushing these countries from being highly inefficient in resource allocation and investments toward a more productive frontier. With many of these gains now growing more difficult to achieve, the BRICS must turn to the next, and perhaps most significant, factor: how well situated are they to foster domestic innovation and the effective acquisition and transformation of foreign technologies? Its importance cannot easily be overstated; economic evidence finds that technical change is the key driver of productivity gains and long-term economic growth (Keller 2004; Maskus 2012).

In this paper I review the recent performance of some key emerging economies in terms of their innovativeness and use of technological improvements. The focus generally is on China, however, because it has taken perhaps the greatest strides in this regard and its sheer size makes the most difference for global structural transformation. After a discussion of performance and policy regimes, the paper turns to an assessment of potential roadblocks limiting future growth in this area. Overall, the view here is that these roadblocks are significant and, unless addressed effectively, could limit the prospects of substantial growth in innovation and ultimate convergence with more advanced countries, except in specific areas. Of course, there will continue to be considerable heterogeneity among the emerging economies in this regard, as there always has been, and the likelihood of long-run success for at least some of the BRICS seems high.

II. INNOVATION PROFILES

It is useful to set the stage by looking at recent indicators of innovation performance in the BRICS. Basic data on important factors are provided in Table 1. The top panels consider measures of technology inputs: R&D as a percentage of GDP and research personnel per million persons of population. In the decade from 1997 to 2007 virtually all of these countries saw increases in these ratios but there was marked variability among them. Russia’s share of R&D in GDP rose only 7.7%, in line with the proportionate increase in the United States, but it saw a decline in the skill ratio of its population. Brazil began from about the same level as Russia in terms of R&D but saw somewhat more rapid growth, with such investments now over 1% of output. Brazil’s ratio of research personnel nearly doubled in the period. India’s growth in the R&D performance measure was similar to Brazil’s but it retains a lower overall ratio. India saw modest growth in its share of technical researchers. South Africa experienced a rise of over 50% in the share of R&D in GDP and a doubling of research personnel, indicating a growing domestic investment in the sources of technological change. Finally, China registered by far the

greatest growth performances in these measures. By 2007 the country had reached an R&D to GDP ratio of 1.44%, around half that in the United States, and more than doubled the ratio of R&D researchers in the population.

A similar message of heterogeneity is delivered by the innovation output measure of patent grants issued by the US Patent and Trademark Office (USPTO). This is a useful comparative measure because the USPTO applies the same standards to applicants from all countries, while the need to pay associated fees implies that foreign firms generally register only inventive ideas. Listed in the bottom panel of Table 1 are the absolute numbers of grants and the shares of total patents approved by the USPTO for inventors from each nation. For example, despite the increase in its relative R&D share, South African inventors saw virtually no increase in patenting in the United States. Brazilian and Russian inventors were similarly unresponsive in this regard, with no increase in their shares of American patents. In contrast, the number of Indian patents went up by a factor of ten, with that country raising its share of US grants from 0.08% to 0.55%. China's growth was even more remarkable in this area. Its patent grants rose by a factor of almost thirty and its share of approvals increased from minimal to over 1.4%. This ability to capture a rising proportion of US patents during a period of mushrooming global growth in patenting is truly noteworthy.

Direct innovation measures are useful but do not capture the extent of technology transfer, a critical form of learning and structural change. Of course, these two concepts are closely related, for inward technology flows can precipitate domestic spillovers, imitation, and ultimately provide a basis for local innovation (Keller 2004; He and Maskus 2012). Put differently, countries that receive significant amounts of technology, and have enterprises that are capable of both deploying the technology effectively in domestic production and adapting it into localized uses, are generally capable of building on this information to develop competing innovations (Chen and Puttitanun 2005; Moran et al. 2005; Maskus 2004a). After some lag, these countries may become significant technology exporters as well as importers.

In this context, one reasonable measure of developing innovation capacity is the growth of two-way technology transfer flows, as detailed in Table 2. For example, in 1995 each of the BRICS had a significant share of high technology goods in manufacturing imports, ranging from 13.9% in India to 23.8% in South Africa.¹ With the exception of China, these shares were much lower in manufactured exports in 1995, indicating a largely one-way high technology flow in traded goods. All of these nations saw a rise in the high technology share of imports between 1995 and 2005, with the proportions in India and China doubling. But China was the only one with a similarly sharp rise on the export side (and, indeed,

1. For this purpose, high technology goods are defined as pharmaceuticals and medicines, electronic equipment, and aerospace products.

ran a trade surplus in these goods in the latter year), although Brazil increased its share of high technology exports by 4.1 percentage points. This share actually declined in Russia and was static in South Africa. On this simple measure, then, China stands out among the BRICS as a country that has seen its trade structure migrate heavily toward higher-technology goods, with substantial two-way exchange going on.

A second measure of technology flows is the inward and outward stocks of foreign direct investment (FDI). As economists note, multinational enterprises are properly thought of as more conduits of technical improvements across borders than as sources of financial capital (Markusen 2002). Thus, rapidly growing stocks, which are measures of cumulative FDI flows, should, in some degree, capture emerging two-way investments in technology transfer.² As noted in the bottom panel of Table 2, all the BRICS remained net recipients of FDI between 2000 and 2008 but there was remarkable growth in the outward direction in all cases. China's outward stock grew from \$28 billion to \$148 billion, while India's expanded by a factor of over thirty. Much of this outward expansion reflected investments in other developing countries. Indeed, the relatively new phenomenon of growing South-South FDI is attracting increased scrutiny by international economists. But a sizeable proportion of it, especially from China, Brazil, and India, has been aimed at takeovers and greenfield investments in the developed world (He and Maskus 2012).

A similar point may be made from the data on payments and receipts of royalties and licensing fees in the final panel. These figures, taken from balance-of-payments data, primarily account for net flows of licensed technologies, brand names, and copyrighted materials, such as software, and are the most direct measure of cross-border information transactions. As may be seen, the amount of payments made by the BRICS mushroomed between 1995 and 2008, growing from over \$500 million for China (in 2007) to \$10.3 billion. All of the BRICS remain significant net importers of technology by this measure. But, with the exception of South Africa, the BRICS' gross receipts of such technology fees also grew extremely rapidly.

To summarize, all of the BRICS remain significant net recipients of formal technology flows, whether through trade, FDI, or licensing of intellectual property. This is true whether measured as absolute dollar values or relative to some activity benchmark, such as GDP or manufacturing trade. In virtually all cases, these countries have increased their relative investments in innovation inputs and now receive more patent grants at the USPTO. But there are considerable differences across countries in these measures and only China stands out as a major growth locus in all these dimensions. That is particularly true with our measures

2. It should be noted that the UNCTAD data from which these stocks were taken refer to total stocks, not just manufacturing.

of two-way technology trade, which anticipate the emergence of China as a significant international competitor in new products and technologies.

The data suggest that a process of technological catch-up is underway in the BRICS. This is especially the case in China, but there are clear hints of it in Brazil and India as well. The following section will offer further perspective on this question with regards to China. It is worth pointing out that any conclusions drawn from such figures should be treated cautiously as statistical measures may capture quite different factors across countries. For example, the definition of what constitutes a researcher, and the nature of her credentials, varies widely. China's educational system produces a great many scientists and engineers, but, at least to this point in time, their productivity in research lags that of most developed countries.

Similarly, a significant amount of what is considered R&D spending in China occurs in either public laboratories or state-owned enterprises (SOEs), which may limit the productivity of that spending in innovation. Further, the statistics on growth in patents granted reflect many factors, including most importantly the sectors in which economies tend to specialize. In the case of China, for example, these USPTO patents are overwhelmingly in software and microelectronics, industries where it is common for firms to register patents on small slivers of innovation (Hu and Jefferson 2009). Indeed, the bulk of these patents were granted to just six Chinese enterprises, such as Huawei and Hong Fu Jin Precision Industries—a major assembler of the iPhone³—and Microsoft, which actively engages in software development in China. Finally, the prominence of consumer electronics assembly in China's production structure itself explains much of the growth in China's high technology imports and exports. These goods are counted in trade on the basis of gross value, rather than value added. As has been well documented, the value added contributed by Chinese enterprises in such sectors remains small, though it is growing as a share of exports (Koopman et al 2008). China's exports in other high technology industries, such as pharmaceuticals, precision machinery, and aerospace equipment, remain relatively small (OECD 2007).

With this kind of uncertainty from basic data it may be more informative to consider independent measures of each country's overall engagement with innovation, research, and knowledge. Thus, Table 3 lists the World Bank's Knowledge Economy Index (KEI) for each of the BRICS plus the United States in 2000 and 2012. The KEI is designed to measure "whether the environment is conducive for knowledge to be effectively used for economic development."⁴ It is the average score of four "pil-

3. See http://www.uspto.gov/web/offices/ac/ido/oeip/taf/asgstc/cnx_ror.htm. More perspective may be found in Maskus (2012).

4. KI and KEI Indexes, World Bank, <http://web.worldbank.org/WBSITE/EXTERNAL/WBI/WBIPROGRAMS/KFDLP/EXTUNIKAM/0,,contentMDK:20584278~menuPK:1433216~pagePK:64168445~piPK:64168309~theSitePK:1414721,00.html> (last visited Jan. 19, 2013).

lars” of the knowledge economy: economic incentives and institutional regime, education, innovation, and activities in information and communication technology (ICT).

This index offers a rather different picture than the transactions data above. Specifically, nearly all of these countries have been relatively stagnant in their rankings in the early years of the twenty-first century, according to the World Bank. India saw its index level decline and it lost three spots in the global rankings, with similar results in Brazil. South Africa’s performance was the least attractive of the group, falling fourteen places in the rankings. Russia experienced a small improvement in its index, with associated gains in the rankings. Again, the largest improvement was in China, with its index rising over 11% and a rise of ten spots relative to other countries. Nonetheless, its absolute index still lags behind those in Brazil and South Africa, while barely reaching half that in the (declining) United States. Put briefly, China’s economy may be catching up to the West, but it has a long way to go. Innovation and technical change are still in their initial phases in both China and India. Other national innovation measures are available but would tell a similar story (Maskus 2012).

III. MEDIUM-TERM INNOVATION PREPAREDNESS

The relatively low positioning of the BRICS in these KEI indexes, and the apparent recent stagnation of some of these countries in this context, raise two important questions. Specifically, what essential national factors determine the capability of enterprises to become more engaged over time in creativity, innovation, and the use of science and technology? And how well positioned are these BRICS to build and take advantage of a robust system of innovation over the next ten years or so? The discussion here will focus on China, the country that Western observers seem most worried or optimistic about, with additional commentary offered for other BRICS where relevant.

A. BASIC CONDITIONS

For purposes of describing pro-innovation national characteristics it is useful to follow the categorization set out by the OECD in its periodic surveys (OECD 2007). As that organization notes, the strongest determinants of innovation capabilities come from the country’s framework conditions or economic environment. The first framework condition is the pervasiveness and quality of the educational system and the opportunities it gives students to think creatively. Here, China has made considerable strides, seeing its secondary enrollment rate (secondary enrollment as a percentage of associated age group) rise from 58% in 1997 to 81% in 2010. In contrast, India’s rate was 47% in 1997 and rose to just 63% in

2010.⁵ The other BRICS already had high secondary enrollment rates in 1997, including 99% in Brazil (unchanged by 2010), 92% in Russia (down to 89% in 2010), and 90% in South Africa (up to 94% in 2010). At the tertiary level, enrollment rates reached 26% in 2010 in China, with corresponding figures of 27% in Brazil, 18% in India, and 76% in Russia (data unavailable for South Africa). For comparison, the tertiary enrollment rate in 2010 for the United States was 95%.

On these simple indicators, China is rapidly gaining on the other BRICS nations, if not the major developed economies, in achieving universal secondary education. University enrollments, which remain limited to successful performers on standardized examinations, lag well behind in China, while India faces structural problems in expanding such access for students from rural and impoverished backgrounds. Of course, rising enrollments do not necessarily imply improving quality. It is common to argue that China's focus on rote learning and standardized examinations diminishes the ability of its students to think creatively and, ultimately, to contribute to national innovation (OECD 2007). Still, China's students have registered unmistakable gains in global academic performance measures. For example, in 2009, high school students from Shanghai finished first on all three key PISA assessments.⁶ In comparison, Russian students were thirty-eighth in mathematics and thirty-ninth in science and Brazilian students were fifty-seventh in mathematics and fifty-third in science. Again, for comparison it is worth noting that US students finished thirty-first in mathematics and twenty-third in science.

It is also important to note that when it comes to building a human capital stock from which scientific and engineering skills may be deployed, absolute scale matters considerably. In this context, while China has seen a rise in most of its proportionate measures of education and science, the sheer size of its investments dominates the other BRICS. For example, China is engaged in an ambitious program to build a large number of research-oriented universities, while expanding its science and engineering (S&E) enrollments at existing institutions (Maskus 2012). Perhaps the best measurement of China's large scale ambitions is simply the fact that China is easily the largest source of international doctoral students in American S&E programs (Stuen et al. 2012). It is also significant that a rapidly increasing share of Chinese students earning a technical Ph.D. abroad return home to work in enterprises, public research institutes, or universities, in part because the opportunities in science and innovation have improved (Kerr 2008).

Thus, while the overall picture is mixed, it is reasonable to expect that China will achieve a human capital base within the next generation that will be the foundation for significant global competition in innovative industries, even if they amount to a small share of the total economy. The

5. World Bank, *World Development Indicators*, <http://data.worldbank.org/indicator/SE.SEC.ENRR> (last visited Jan. 19, 2013).

6. <http://ourtimes.wordpress.com/2008/04/10/oecd-education-rankings/>.

outlook for the other BRICS appears to foretell stasis or limited growth in this context.

A second major determinant of national innovation capacity is the competitiveness of product and capital markets (OECD 2007). The BRICS all have undergone significant liberalization of trade and investment barriers in recent years, with China now perhaps the most open of all the BRICS in the wake of its entry into the WTO in 2001 (Maskus 2012). One simple measure of this openness is the weighted-average tariff rate across all industrial sectors, which in China fell from 12.3% in 2001 to 3.7% in 2009.⁷ Comparable tariff rates for Brazil were 10.4% (2001) and 9.9% (2009), for India 21.0% (2004) and 7.2% (2009), for Russia 8.9% (2001) and 6.6% (2009), and for South Africa 4.9% (2001) and 4.6% (2009). Thus, by 2009 China had the lowest average tariff rate and had cut its import taxes by a far larger proportion than the other BRICS, though all five had achieved relatively low industrial tariffs by the end of last decade. Similarly, according to expert opinion at the World Economic Forum, China reduced its protection against imports and restrictions against FDI between 1995 and 2008 by considerably more than did India, Brazil, and numerous other emerging economies (Maskus 2012). All of this liberalization has expanded external competition in these markets, while bringing in significantly larger amounts of international technology, ultimately stimulating more innovation.

Still, while trade and investment openness are important, they may have little impact if not accompanied by strongly competitive forces in internal markets. Here, the BRICS have made considerably less progress, including China (OECD 2007). China retains significant internal distortions in labor and capital markets, experiences extensive market intervention by federal and provincial authorities, protects inefficient SOEs, and has little tradition or experience with anti-monopoly regulation. So far, at least, its universities, public research institutions, and enterprises have been ineffective at commercializing new knowledge to create and introduce innovative goods. Brazil and India have fared somewhat better in this regard, at least in particular sectors, though entry of new firms in India remains a daunting prospect. These difficulties may be seen by the “ease of doing business” indicators published by the World Bank.⁸ On this score, in 2011, Singapore ranked first, Hong Kong second, and New Zealand third. In contrast, China was ninety-first, Brazil 126th, India 132nd, Russia 120th, and South Africa thirty-fifth. Thus, with the possible exception of South Africa, dealing with corruption, red tape, and other barriers to entry continues to restrain competition in the BRICS.

Moreover, in China, significant problems remain with corporate governance regarding innovation (OECD 2007). For example, the cautious and political orientation of SOEs offers few incentives for long-term in-

7. Data from World Bank, WITS data source, at <http://wits.worldbank.org/wits/>.

8. World Bank, *World Development Indicators*, <http://data.worldbank.org/indicator/IC.BUS.EASE.XQ> (last visited Jan. 19, 2013).

vestments in risky R&D projects, especially aimed at foreign markets or meeting rapid changes in consumer demand. Additionally, China suffers from limited development of private financial markets for funding innovation and there is only a fledgling venture capital market. These two problems – uncompetitive domestic markets and poorly structured innovation incentives and supports – remain the primary medium-term blockage to the development of domestic innovation societies, especially in China and India.

A final major framework condition is the structure of intellectual property rights (IPRs). Innovative economies strive to ensure effective protection for new inventions, technical secrets, creative ideas, and brand names, while striking a balance between the needs of firms to profit from their creative investments and users to access new knowledge. The period from 1995 to 2010 saw remarkable increases in the scope of legal protections for patents, trademarks, and copyrights in all emerging economies, especially the BRICS (Maskus 2012). Brazil, India, and China all adopted significantly updated patent laws in this period, partly in response to the need to meet WTO obligations. China, in particular, enacted major changes in all forms of intellectual property in the wake of its entry into the WTO in 2001 and now has a legal framework for protection that is not much different from that in the United States. Brazil revamped its patent laws in the late 1990s, also adopting significant new protective norms. India enacted its latest patent law in 2005, clarifying that pharmaceutical products and agricultural chemicals are eligible for protection. Each country also has extensive copyright regimes, though both patents and copyrights are subject to important limitations and exceptions. For example, all three nations assert an active role for compulsory licensing of critical patented goods, especially new essential medicines. Brazil and India implicitly require domestic production to sustain a patent in force, and India offers broad scope for educational use of copyrighted materials.

Of course, while legal reforms are important, they are not very meaningful if the laws are enforced poorly or on a discriminatory basis. In this context, China still faces considerable obstacles in achieving a transparent and effective IPRs regime (Suttmeier and Yao 2011). Beyond the obvious problems of endemic trademark counterfeiting, widespread copying of digital products, and websites posting copyrighted goods are several structural difficulties. Among the more important problems are inadequate investments in enforcement, especially of infringing exports, regional differences in levels of protection, administrative mismanagement, and insufficient provision of judicial procedures, which may seem tilted against international companies (Mertha 2005; Maskus 2012). Such problems plague both foreign firms and innovative domestic enterprises, which react in strategic ways that limit China's ability to benefit from access to new technologies. Survey results find that the situation makes innovative firms more reluctant to transfer their frontier technologies to

domestic partners or licensees, reduces the willingness of domestic innovators to commercialize their knowledge, damages the quality reputation of Chinese enterprises, and limits investments in global quality (OECD 2007; Maskus 2004b). China is now investing more resources in enforcement, which should reduce these problems, but infringement of patents and loss of trade secrets remain a severe challenge for international enterprises.

B. INNOVATION POLICIES

Where China clearly outstrips the other BRICS is in the clear strategic priority it places on building a modern national innovation system (NIS) and facilitating the emergence of a globally competitive, technology-based economy. All emerging economies recognize that, in order to support competition and growth, it is important to create a system of institutions, markets, enterprises, and consumers that turn knowledge into innovation and effectively absorb technologies into production processes. Only a few, however, such as Singapore, South Korea, Taiwan, and, most recently, China, have elevated this objective into a national policy obsession, albeit with different models.

Thus, in the mid-1990s, the government of China stated the development of domestic science and technology as a major economic priority. Several initiatives were launched to build innovation capacity in such high technology sectors as biotechnology, advanced materials, and ICT (Xue and Liang 2010). Central to this effort was a major and ongoing investment in establishing high-level research universities and facilitating commercialization of their research through linkages to SOEs and creation of spinoff companies. Similarly, there are extensive public supports for domestic R&D centers, with over 2300 existing in SOEs today. Related incentives for multinational enterprises to establish R&D facilities in China have borne fruit, with over 1000 of them in key cities.

Correspondingly, Chinese enterprises and public authorities have increased investments in research, with the R&D/GDP ratio rising from 0.6% in 1995 to nearly 1.5% in 2007, as noted earlier. Such major enterprises as Haier, Lenovo, and Huawei grew larger and more focused on technological change and innovation in this period. Still, these figures should be kept in perspective. A large portion of the increase in R&D came from public investments in science and the establishment of research centers owned by foreign concerns (Xue and Liang 2010). Relatively little investment has emerged in SOEs or small Chinese firms. Further, even large firms, such as Lenovo and Huawei, disproportionately bought or licensed technologies and production rights rather than invested in new global technologies. In China's high technology sectors, domestic enterprises still lag significantly behind their competitors in the advanced economies. As the OECD (2007) puts it, there is far more "D" than "R" in the country's R&D investment, with little evidence of much shift to date. For such reasons, Chinese authorities remain concerned

that even larger domestic enterprises are well below the frontiers of technology competitiveness. Despite solid gains in productivity, many—especially among Chinese thought leaders—still think of the country as a location for assembly factories rather than a source of new technology.

Recognizing such problems, in February 2006 the State Council published a document setting out guidelines and principles for developing scientific and technological capacity in the Chinese economy. These principles run the gamut of government actions that could support, or even mandate, the development of a full national innovation system. Additional incentives were offered for supporting university research, technology transfer of research results to private and public enterprises, and even filing patent applications.

The central element of the new policy was the requirement that promoting “indigenous innovation” would become the most important element of S&T policy at all levels of government. Such encouragement had long been a policy objective but never elevated to this level. Government procurement programs at the national and provincial levels were targeted as a primary instrument for supporting innovation by Chinese enterprises (Ernst 2010; Suttmeier and Yao 2011). Thus, in November 2009 the Ministry of Science and Technology (MOST) and two other agencies defined terms under which products could be certified as developed by indigenous innovators in six industries: software, telecommunication products, office equipment, computer and application devices, alternative energy technologies, and high-efficiency energy-saving products. The policy defined criteria under which a Chinese enterprise could have a certified product put into a public catalogue of goods approved for government procurement.

It should be noted that the original guidelines amounted to a particularly discriminatory policy biased against international technology developers. Of greatest concern were the draft rules regarding IPRs. There were requirements that qualifying enterprises must own or acquire IPRs developed in China and that trademarks must be originally registered there. This rule in essence tied procurement-market access to intellectual property ownership. Foreign IPRs holders would have to transfer those rights, or even the R&D done under their protection, to a domestic enterprise. Under the guidelines, the certified technologies had to achieve recognized levels of global standards, meaning that the associated IPRs would be valuable. A further condition stated that use or improvement of intellectual property could not be restricted by foreign firms. This policy would prevent original IPRs owners from issuing standard contract terms regarding local sales, ownership of follow-on technologies, or licensing of local rights.

Obviously, these procurement rules, especially in connection with complementary policies encouraging or requiring the surrender of Chinese patent rights to domestic business partners within a given period of time, were controversial for technology developers. Many foreign businesses

and, interestingly, larger Chinese enterprises objected strongly to the procurement policy and its implications for IPRs ownership. Under this pressure, in 2010, MOST issued a new document that considerably softened the procurement conditions, essentially abandoning the Chinese-origin IPRs requirement and the limitations on contract terms. Still, the basics remain in place, and time will tell whether this heavy-handed bit of industrial policy will be implemented.

Whether it will be effective in promoting domestic innovation also remains unclear, based on recent history. For example, China's efforts to develop domestic—and inherently discriminatory—ITC standards have met with mixed success (Ernst 2010). The government has successfully promoted a domestic 3G standard that is commonly used in cell phones sold in China, an example of using the large market to foster a home technology. But at this time there are no Chinese-developed standards that have made successful international inroads.

To summarize, China continues to target innovation and S&T policy as a high priority for public policy. Undoubtedly, the country will continue to make large public and private investments in education and research infrastructure and will pursue incentives for encouraging domestic innovation, while working within its rules and international obligations to foster rapid acquisition of international technologies. Already it is possible to see signs of increasing innovation, both in terms of quantity and quality, in such sectors as solar panels, biofuels, automobile parts, appliances, and biotechnology. Still, structural problems remain that will take some time to overcome, suggesting that China's emergence as a full global competitor in the knowledge arena is perhaps a generation away.

The other BRICS certainly have innovation policies in place, but they are not as extensive or centrally directed as China's strategy. India invests heavily in public research institutes, but the ability of those entities to transfer new technologies seems limited by numerous factors (Maskus 2012). Brazil has strong technology orientations in a few industries, such as sugar, biofuels, and small aircraft. Its government has also taken several recent steps to build a stronger national innovation system, including incentives for commercialization of research done in universities and public research laboratories. So far, however, the country has largely failed to establish an overall culture of innovation (Mazzoleni and Povoia 2010).

IV. SUMMARY AND CONCLUSIONS

The discussion to this point suggests that, while there are clear signs of growing innovation and technology use in the BRICS, there remain significant structural difficulties that must be addressed to establish fully competitive cultures of innovation and creativity. China has proceeded furthest in terms of policy reforms, investments in research infrastructure, and incentive systems, but continues to be plagued by problems of weakly enforced IPRs, corruption, favoritism, and misallocated capital for R&D. India has made considerable strides in software and ITC services and has

spawned some major private global corporations, such as Tata Industries and Dr. Reddy's (Jonsson 2008). But few of these originate globally competitive innovation, while much of India's economy has barely touched the modern technological sector. Brazil, Russia, and South Africa all feature the existence of technologically oriented companies in specific sectors, but do not score very highly on global innovation scales. Each of those economies is dominated by development and exports of primary commodities, which are less likely to spawn rapid technological increases, contrasted with the microelectronics industry in China.

In brief, the BRICS all share some features and successes in their technological catch-up processes, but their experiences have been quite varied in terms of industry mix, capital markets, R&D, and public policy. None of them is currently a consistent contributor to global technical advances, and only China (and possibly Brazil) seems poised at this time to enter that competition anytime soon. Put differently, catch-up is a real phenomenon, which ultimately will make most or all of today's BRICS a significant source of innovation, but that emergence remains more a long-term than a medium-term prospect.

Nor should we lose sight of further potential roadblocks for technological growth in the BRICS. For example, there are already signs of diminishing returns to R&D investments in China, as the easily attainable gains from imitation and acquisition of technologies give way to the hard work of original invention (Maskus 2012). Further, to some degree, China and Brazil seem caught in an emerging "middle income trap," which means that wages and costs have risen in labor-intensive manufacturing, but the shift of activity into higher-skilled and innovative sectors is insufficient to absorb these costs. It will be interesting to see if China in particular can manage this transition effectively before its ongoing demographic problem of rapid aging inevitably diverts resources from R&D to social programs. Finally, endemic problems of corruption and concentrated political power continue, which tends to channel resources in directed and inefficient ways rather than through channels that respond to market demands. Each of the BRICS, but especially China and Russia, must come to grips with this fundamental problem.

These are significant roadblocks to further development of innovative societies, but they must be kept in perspective. Other, now developed, economies, including South Korea, Singapore, Japan, and even the United States, have been described in similar terms at various points in history. Each of the BRICS faces strong challenges which can be overcome with a firm vision and appropriate policies. Betting on technological failure in the long run, especially for China, seems unwise at this point.

Table 1. Broad Technology Indicators in the BRICS and United States

Country	R&D as a share of GDP			Researchers in R&D per million population		
	1997	2007	% change	1997	2007	% change
Brazil	0.96	1.10	14.6	340	657	93.2
China	0.64	1.44	125.0	477	1,071	124.5
India	0.69	0.80	15.9	110	145	31.8
Russia	1.04	1.12	7.7	3,598	3,305	-8.1
S. Africa	0.60	0.92	53.3	199	396	99.0
USA	2.58	2.72	5.4	4,179	4,745	13.5
<i>Patent grants at USPTO</i>						
Country	2000 (%)		2011 (%)			
Brazil	98 (0.06)		215 (0.09)			
China	119 (0.08)		3,174 (1.41)			
India	131 (0.08)		1,234 (0.55)			
Russia	183 (0.12)		298 (0.13)			
S. Africa	111 (0.07)		123 (0.06)			
USA	85,068 (54.0)		108,626 (48.4)			

Sources: World Bank, *World Development Indicators* and United States Patent and Trademark Office.

Table 2. Measures of Two-Way Technology Transfer in the BRICS

Country	High technology Imports				High technology Exports			
	1995		2005		1995		2005	
	\$billion	% of mfg.	\$billion	% of mfg.	\$billion	% of mfg.	\$billion	% of mfg.
Brazil	8.7	22.3	16.3	29.0	2.4	9.0	8.4	13.1
China	22.0	20.7	209.4	41.0	24.4	19.2	284.8	40.0
India	2.9	13.9	20.1	26.8	1.5	6.5	5.5	7.4
Russia	5.2	19.3	17.3	24.2	1.3	4.3	1.9	3.3
S. Africa	5.0	23.8	10.8	28.2	0.7	5.1	1.7	5.1

Country	Inward FDI Stock		Outward FDI Stock		Royalties and License Fees			
	2000	2008	2000	2008	1995	1995	2008	2008
	\$billion	\$billion	\$billion	\$billion	Payments(\$m)	Receipts(\$m)	Payments(\$m)	Receipts(\$m)
Brazil	122.3	287.7	51.9	155.7	529	32	2,697	465
China	193.3	378.1	27.8	147.9	543*	55*	10,319	571
India	16.3	125.2	1.7	63.3	90	1	1,529	148
Russia	32.2	215.8	20.1	205.5	34	4	4,595	453
S. Africa	43.4	68.0	32.3	50.0	293	45	1,676	54

Sources: UN Comtrade database, UNCTAD STAT database, and World Bank, *World Development Indicators*. * Data are for 1997.

Table 3. World Bank Knowledge Economy Index for the BRICS

<i>Country</i>	<i>Knowledge Economy Index</i>	
	<i>2000 (rank)</i>	<i>2012 (rank)</i>
<i>Brazil</i>	5.55 (58)	5.56 (60)
<i>China</i>	3.92 (94)	4.37 (84)
<i>India</i>	3.17 (107)	3.06 (110)
<i>Russia</i>	5.41 (64)	5.78 (55)
<i>South Africa</i>	5.73 (53)	5.21 (67)
<i>USA</i>	9.32 (6)	8.77 (12)

Source: http://info.worldbank.org/etools/kam2/KAM_page5.asp

