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The Changing Geography of Innovation: The Rise of the BICs—Challenges and Opportunities

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The last two decades have seen a change in the geography of innovation toward developing countries in three areas.1 First, on the input side, there has been a significant increase in the share of total world research and development (R&D) expenditures by developing countries. There has also been an increase in the share of students in higher education, as well as of the number researchers. Second, developing countries have increased their share of intermediate outputs in the form of scientific publications and the number of patents. Third, on the output side, the growth of GDP in developing countries has been greater than that of developed countries, largely because it is easier to grow by using technology that already exists (technological catch-up) than by pushing the world technological frontier forward. At the same time, and accelerated by the financial and economic crisis of 2008–09, there has been a significant shift in the share of total world economic activity accounted for by developing countries, which also has implications for the direction of innovation, as will be argued below.

Much of this changing geography of innovation and growth is the result of the emergence of the BICs—Brazil, India, and China.[2, 3] This policy note focuses on the changing geography of innovation in these three countries, particularly China, and provides a quick overview of innovation efforts and performance. As China is already well on its way to becoming a major global player in innovation, this note will summarize some of the lessons from the county's success, as well as its challenges. This note then will more broadly summarize the challenges and opportunities for advanced countries as well as for other developing countries. Finally, it will describe some challenges and opportunities for the global system.

China

China's authoritarian government has focused on science and technology since the 1960s. Science and technology was one of the four modernizations proclaimed by Cho

1. Although not geographic, another important shift has been that of the relative importance of the main agents of innovation. The shift has been from government to the productive sector, and to the university.

2. The Republic of Korea has also become a major player on the global innovation stage in inputs, outputs, and growth over the last two decades, but is not considered here. Korea is already ranked as a developed country and this note focuses on developing countries.

3. Russia has lost relative share in world totals on all the above indicators in the last two decades. However, in recent years it has been recovering some lost ground as it focuses on strengthening its innovation system.

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En Lai in 1963. In addition, after Deng, most Chinese leaders have been engineers rather than lawyers or social scientists as in most Western countries, and they have focused on science and technology.

China already has the largest number of researchers in the world; is the second largest spender on R&D in the world in purchasing power parity (PPP) terms (after the United States, and having surpassed Japan in 2010); and is the second-largest producer of scientific publications. In 2011 it also registered the largest number of patents by domestic residents in the world. In China the productive sector already accounts for more than 65 percent of R&D, which is close to the average for advanced countries. In 1995 China's spending on R&D was just 0.5 percent of GDP. Currently it is 1.6 percent of GDP, but China aims to be spending 2 percent of GDP on R&D by 2020, which is the average for EU countries, and 2.5 percent of GDP by 2025, the average for the United States.

Some of China's major innovation accomplishments include its own green revolution, space technology, and the nuclear bomb. Some of the country's state-owned enterprises are demonstrating growing technological capability; they include the China Ocean Shipping Company (COSCO); the State Construction and Engineering Company, China National Petroleum, China Offshore Oil, China Communications Construction, China Railways Construction Co., Sinochem, Sinosteel, Shanghai Baosteel, the China International Trust and Investment Corporation (CITIC); and Beijing Enterprise Holdings (diversified conglomerates). Private firms are evolving too; they include Shanghai Automotive Industries, Huawei and ZTE (makers of telecommunications equipment), Lenovo (which bought IBM's personal computer division), Haier (electrical appliances), Goldwind (windmills), and Suntech Power (the world's largest producer of solar panels).

At the most macro level, a gross measure of a country's innovation performance is the annual rate of economic growth. In the stylized economist's framework, growth is the result of increases in capital and labor as well as technology. China's growth performance has been extraordinary, averaging 9 to 10 percent per year for the last 30 years. This is due in part to high rates of investment and the growth of labor and education. Another large driver of growth has been due improvements in productivity and other technical changes, which are the result of successful technological catch-up and innovation with the developed world.

Brazil

Brazil started focusing on innovation during the military period from the mid-1960s to the late 1970s. Spending on R&D reached one percent of GDP in the 1970s, the bulk of it by the government. Most researchers work for the government. The government has been trying to increase spending on R&D for several decades now but has not managed much of an increase. It also has failed to get the private sector to spend more on R&D, which remains at barely half a percent of GDP. However, Brazil has increased its share of scientific publications from less than one percent of the world's total to almost three percent in 2008.

Some of Brazil's main innovation accomplishments include the development and implementation of methanol-based alcohol as an alternative fuel; multiple agricultural innovations lead by EMBRAPA (the public research development and extension services) that have increased productivity in agriculture; deep-water exploration by Petrobras (the state-owned oil company); wells; and the development of an internationally competitive aircraft producer (Embraer—once a state-owned company but now private). Brazil also has many innovative and internationally competitive

private companies, including Gerdau (basic metals); Votorantin, Suzano, and Klabin (cellulose and paper products); JBS-Bribol and Marfig (crop and natural animal production); Camargo Correia, Duratex (construction); Weg (electrical equipment); Magnesita (nonmetallic minerals); Brazil Foods and Minerva (food products); Natura (cosmetics); and Metalfrio and Romi (manufacture of machinery and equipment).

Brazil's growth performance during the early part of the military period was high. However, growth stagnated with the global oil price increases of the early 1970s (this was the motivation for the development alternative fuel program) and the country became highly indebted and also suffered macro instability in the 1980s. Its performance during the 1980s was poor. It was not until the early 2000s that Brazil resumed growing. This was the result of successful macro stabilization but also of the high demand for commodity exports from China. The rate of investment has been low, which has prevented Brazil from incorporated technological advances as fast as China. As a result, the contribution of productivity growth and innovation has been low, except in agriculture.

India

India had a very autarkic policy toward research after independence from Britain. It set up a large network of government labs to develop the technologies the country needed. This infrastructure was focused primarily on the needs of government, particularly the large number of state enterprises. It was only after India's trade liberalization starting in 1991, when the private sector started to face international competition, that the government research infrastructure started to respond to the needs of the private sector. India has been spending about three quarters of a percent on of GDP on R&D for a long time. However, more than 80 percent of this spending has been by the public sector. The government has been trying to get the private sector to spend more on R&D. Between 2003 and 2007 it managed to get the private sector to increase its share from 18 percent to 28 percent. This increased spending was in part the result of attracting investment from transnational corporations (TNCs), but increased R&D by some domestic firms was also significant. The country's investment in R&D has now increased to almost 0.9 percent of GDP.

Some of India's innovation accomplishments in the state sector include the Green Revolution (an international cooperative R&D program) and space technology (though more limited than China). Strong, innovative private sector companies have also flourished, including Infosys, HCL, WIPRO, Tata Consulting Services, Patni Computer Systems, Hexaware Technologies, i-Gate Global Solutions, NIIT, and Birlasoft (information technology); Ranbaxy, Dr. Reddy's Laboratories, Sun Pharmaceuticals, Biocon, and Piramal Healthcare (pharmaceuticals); Tata (a conglomerate with products including iron and steel, autos, telecoms, IT services, and chemicals); Mahindra and Mahindra (autos); Larsen and Toubro (engineering and construction); Bharat Forge (forging and auto components); Videocon (a conglomerate with products including electronic picture tubes, mobile phones, and telecommunications); and Suzlon (windmills).

India's overall growth performance was a low 2–4 percent per year until it began to open up to the trade with the world after 1991, when growth increased to 5–6 percent. India's rate of investment was also low at around 20 percent until the early 2000s. After 2003, India started to grow at over 8 percent. This was in part due to the dynamic growth of its information-enabled service industries (which though small, had

strong multiplier effects), and of knowledge services more generally. In addition to faster growth, investment increased from around 20 percent through the early 2000s to over 35 percent in the second half of the 2000s. With greater liberalization came higher investment and greater tapping of global knowledge, all of which helped to improve productivity across the economy.

Similarities

The BICs have some interesting similarities. Early on they focused on large, mission-oriented projects. All included nuclear, aerospace, and space. China and India developed their own nuclear weapons. All three have developed aerospace and space technology. Brazil has developed one of the four largest airplane producers in the world. China is now developing its airplane industry—somewhat later than Brazil, but faster. China also has a very strong space program and is one of only three countries (besides the United States and Russia) to have launched a man into space. All three BICs have significantly improved agricultural productivity. All three have also developed their automotive industries. India initially developed its own domestic auto industry and then went for joint ventures. Brazil has relied on foreign multinationals. China has developed its own industry and also has relied on multinationals. India and Chinese domestic firms are already exporting domestically developed automobiles, and China has very ambitious export plans. All three countries have concerns about income inequality. Brazil has the highest inequality. It has developed an integrated program for reducing inequality, including measures addressing children's education, health, and food, which is having some success. Inequality is increasing rapidly in China and India. The governments of all three countries are now developing programs to support product, process, and service innovations that address the needs of the low-income population ("inclusive innovation" as it is called in India).

Differences

A major difference between China, India, and Brazil is that the first two are very labor rich but natural resource poor on a per capita basis. Brazil is very rich in natural resources and not as populous as the first two. In the 1950s all three countries began import substitution strategies. China and India were much more autarkic than Brazil, which was more open to foreign direct investment. Brazil developed a broad-based industrial sector and increased the share of manufactures in its exports. However, in the last 10 years the majority of its exports have been natural resources and commodities as a result of the large import demand from China. Surprisingly, China, the communist country, was the first to go for a traditional strategy of export of manufactured goods, supported by foreign direct investment. This strategy started in the late 1970s when China began to open up to the world and established its first export processing zones. It quickly built on its export strategy and eventually joined the WTO in 2001. It has become the world's largest merchandize exporter, mostly manufactured products. India has not been much of an exporter until recently. It opened up to trade in the early 1990s, and its strength is in information-enabled service exports rather than manufactured products.

What can they learn from China?

Given China's tremendous success, what can the other two countries learn from its experience? China's innovation strategy can be described as following three strands. The first and most successful strand to date has been to be fast learner. China has been the most effective at tapping into global knowl-

edge. This has included formal mechanisms as well as informal ones. The main formal ones have been trade, foreign direct investment, technology licensing, and foreign study. The informal ones have been attracting back expatriated Chinese citizens and copying and reverse engineering. China's use of reverse engineering is not just larger in absolute terms, but also relative to the size of its economy.

China has been able to incorporate a lot of new technology into its economy because it has had a very high ratio of investment to GDP. This ratio has averaged over 40 percent over the last two decades and has increased to nearly 50 percent in the last five years. To be able to absorb and effectively use this technology China also has made massive investments in tertiary education. By 2010 it had more than 30 million students enrolled in higher education institutions, compared to 19 million in the United States, and only 14 million in India. An important element of China's strategy has been that it has become well integrated into global value chains controlled primarily by foreign firms. Thanks to its investments in education, particularly higher education, Chinese firms have been able to move up these value chains from simple labor-intensive activities to those requiring greater technological capability.

The second part of China's strategy has been an explicit plan announced in 2006 (the Medium and Long Term Science and Technology Plan) to go from catch-up or imitation to its own frontier innovation. Starting in 2006 China began to significantly increase its R&D. By 2010 it was the second-largest spender in R&D in the world, second only to the United States.

China has also leveraged its large domestic market to improve its innovation capacity in several ways. First, its large market has given domestic firms opportunities to develop their capabilities and to reap economies of scale. Second, its large market has been a very strong magnet for TNCs. They have not been able to resist participating in China's booming market, even if they know that their technology will be pirated.

A new element of China's innovation strategy is massive investments in alternative energy technologies. This includes investments in nuclear energy, hydropower, wind, and solar, as well as investments in carbon capture and sequestration. China is making the largest investments in the world to develop these technologies. Moreover, the large needs of the Chinese market in this area is also attracting foreign companies to develop and scale up these technologies in China, because the Chinese government offers very attractive terms to set up and operate businesses with these new technologies in China. China's focus on green technologies is not just an element of developing alternative energy but also of strategic energy security. It is very likely that with these massive investments China will soon be the world's technology leader in these areas.

China's challenges

China has many economic challenges. These include an asset bubble; a reduction in import demand from developed countries that are still suffering anemic growth in the aftermath of the 2008–09; the consequent need for China to restructure its economy towards domestic demand; risks of a protectionist backlash from the rest of the world; and rapidly rising inequality. In addition, China's rapid growth makes intensive use of environmental resources and technology, which has lead to rising costs of air and water and increased pollution.

A major challenge for China is how to main its high rate of growth. In the short term this is more difficult in light of the fall in global demand for its exports. In the medium

to long term different challenges emerge. China will catch up with the technological frontier; the contribution of labor growth will decrease as population growth slows as a result of the one child policy; and the dependency burden of the graying population will increase. China is counting on innovation to help it maintain a high rate of growth.

On the innovation side there are three main challenges. First, China must able to reap returns commensurate with its increased investment into output into the R&D. The rapid raise in technical and scientific publications suggests that it will. However, there has been concern about significant fraud and cheating in research and scientific publications and that many patents are of little value. The argument is that this activity has proliferated because promotions and salary increases in universities and research labs have been reoriented to be based on publications and patenting.

Second there is concern that continued violations of international intellectual property laws could increase frictions with the international suppliers of technology and bring about retaliatory trade actions through the Trade Related Aspects of Intellectual Property Rights (TRIPs) mechanism of the WTO. In spite of China's very large investments in R&D, it is not likely that its own innovations will give it the 2–3 percentage points of growth it is seeking through this means. China will continue to rely heavily on technology that it gets from the rest of the world, making it important not to antagonize the suppliers of that technology.

Finally, there is increasing speculation that China's authoritarian regime may constrain innovation, particularly radical innovation, despite the country's rapidly increasing investments in R&D. So far none of the eight Nobel prizes in science awarded to persons of Chinese origin have been to a scientist working in mainland China. It also appears that although China has an aggressive program to recruit top scientists and engineers of Chinese origin and has been successful in the past, in the last five years it has been having more trouble recruiting the talent it is seeking.

Implications for advanced economies

There are opportunities and challenges for developed economies from the changing geography of innovation. The first opportunity is for TNCs from developed countries to do more R&D in the BICs, as they have a growing stock of qualified scientists and engineers with much lower salaries than in advanced countries. The second is for firms from advanced countries to innovate products and services that address the needs of the growing populations of these countries. Not only are their populations still growing, but so is their income, so they are very attractive markets. The third opportunity is for governments of advanced countries to do more science, technology, and innovation cooperative agreements that tackle issues of mutual interest, reflecting the growing capability in the public innovation infrastructure in emerging countries.

The first challenge is that there will be more competition from BICs firms as they continue to develop their capabilities. General Electric, for example, has announced that it has to develop innovations for markets in China and India because domestic firms there are producing those innovations. In addition, these lower-cost products and services developed for the emerging markets are beginning to be exported to developed-country markets and disrupting TNCs' home-country competitiveness. The second challenge is for the governments of developed countries. As TNCs from their countries pursue opportunities in emerging countries, they may act less in the interest of

the home countries. This may be clearest in the cases where TNCs locate more of their corporate functions, including research, in China. The externalities from this research spill out to the Chinese economy, not to TNCs' home countries.

Implications for other developing countries

There are also opportunities and challenges for other developing countries. For example, BICs may provide innovations that are relevant for developing countries' low-income populations, such as the Nano car and the $35 Aakash tablet computer. In addition, the competition from other developing countries is leading developed-country TNCs to innovate products and services that respond to the needs of lower-income countries. For example, GE's $1,000 portable electrocardiogram developed for the Indian market and the $15,000 personal computer–based ultrasound developed for the Chinese market are now being exported to other developing countries and even back to the United States. A second opportunity that goes beyond technology is that the growth of the BICs markets will create demand for exports of goods and services.

The principal challenge is that the increasing technological capability and innovation in the emerging countries will lead to greater competition across a wider range of goods and services. A second challenge is that although the diversification of technologies and the greater speed of technological development are very positive, there is also a downside. Taking advantage of the increased diversity and rate of technological change also means that countries have to increase their capability to acquire and make effective use of those new technologies. This requires upgrading of education and technology support infrastructure. The poorest developing countries will likely have the most difficulty taking advantage of rapid change and run the risk of being left farther behind.

Global challenges and opportunities

There are several challenges to the global system. The first is the risk of the increased competition from emerging economies. China in particular could lead to a protectionist reaction from advanced countries as well as other developing countries. This risk is heightened because of the very slow recovery, continued economic fragility, and high unemployment in the United States and the European Union. A second challenge is the risk of increased frictions over research and intellectual property. This is related to the composition of R&D spending. In the United States and developed countries, a higher proportion of their R&D spending is on basic research, which is largely a public good. In developing countries, including China, only a very small proportion of R&D is spent on basic research. Thus there is a growing concern that emerging countries with very successful catch-up strategies, such as China, are free riding on the basic research financed by developed countries. It is not clear how this will be worked out. Will it lead to a reduction in spending on basic research in advanced countries, particularly as their governments are facing severe fiscal constraints? Or will emerging countries feel increased pressure to do more basic research and put more effort into protecting the intellectual property of advanced countries? A third challenge is the continuing increase in inequality within most countries as well as across countries. This is an issue of internal and international political stability. It is also a humanitarian issue as many of the poorest countries have very limited capability to take advantage of the rapid advances of technology and are being left further behind.

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Many of them are also vulnerable to climate change, which is largely the result of the successful industrialization of the advanced countries and now the emerging countries.

The opportunities are to rise to these challenges and to develop better global systems to deal with them. Defusing the risk of growing trade frictions depends on actions from both trade deficit and trade surplus countries. Trade deficit countries need to increase their savings, successfully address their fiscal problems, and reestablish sound growth. Trade surplus countries like China (and Germany and Japan) need to develop their domestic markets rather than to continue to rely so heavily on an export-oriented development model. Addressing the issue of free riding requires more investment in basic research by large countries that rely mostly on the basic research of others, and more enforcement of international property rights. Addressing the problems of growing internal and international inequality requires more and better domestic and international redistributive policies, as well as more efforts to develop innovations that serve the needs of poorer populations, including addressing the global challenge of climate change.

Given the increasing innovation capability of the emerging countries, there are important opportunities to develop cooperative programs to address major global public goods issues. These include climate change, global pandemics, agricultural innovation to combat food shortages, innovations to deal with water shortages (including desalination technologies), and many other innovations to help ensure environmental sustainability. There are already good precedents for international public good actions that have involved international cooperation and appropriate innovations. These include the Green Revolution, the African Program to Eliminate River Blindness, and, most recently, the Global Health Challenges initiated by the Gates Foundation. Thus there are many opportunities to work out better outcomes. What is required is greater awareness of the interdependence of the world on the actions of the main countries, and greater leadership to make the first significant moves toward solutions.