

REUTERS/Nicky Loh

BUILDING BRICKS

EXPLORING THE GLOBAL RESEARCH AND INNOVATION IMPACT OF
BRAZIL, RUSSIA, INDIA, CHINA AND SOUTH KOREA

FEBRUARY 2013

Jonathan Adams
David Pendlebury
Bob Stembridge



THOMSON REUTERS™

THE BRICK NATIONS REPRESENT
THE MOST SIGNIFICANT GROWING
INFLUENCE IN THE GLOBAL ECONOMY
AND RESEARCH LANDSCAPE.

TABLE OF CONTENTS

OVERVIEW	4
INVESTMENT: BRICK COMMITMENTS TO RESEARCH & DEVELOPMENT	5
<i>Figure 1: Growth in the Gross Domestic Product (GDP) of the BRICK Nations</i>	5
<i>Figure 2: Annual Change in Gross Expenditure on Research and Development</i>	6
<i>Figure 3: Business Expenditure on R&D (BERD)</i>	7
PEOPLE: PROFILING THE BRICK RESEARCH AND DEVELOPMENT WORKFORCE	8
<i>Figure 4: Number of Researchers Per Country</i>	9
PUBLICATIONS: BRICK RESEARCH OUTPUTS	10
<i>Figure 5: Annual Research Publication Output of the Five BRICK Countries</i>	10
<i>Figure 6: Prolific Fields of Research Output for the Five BRICK Countries</i>	11
ACADEMIC IMPACT	13
<i>Figure 7: Citation Impact of the Five BRICK Countries Relative to World Average</i>	13
<i>Figure 8: Papers Published by Country</i>	14
<i>Figure 9: Research Fields of Published Papers with High Citation Impact</i>	15
ECONOMIC IMPACT	17
<i>Figure 10: BRICK Innovation in Context: The Volume of Patent Filings</i>	18
<i>Figure 11: Annual Number of Invention Patent Applications Filed by the Five BRICK Countries</i>	20
<i>Figure 12: Patent Applications Filed in 2010 by Main Fields of Knowledge as a Percentage of Portfolio</i>	22
<i>Figure 13: Patent Applications Filed in 2010 by Main Fields of Knowledge (Relative Patenting Rates Compared to Global Patenting)</i>	23
CONCLUSION	25

OVERVIEW

Forty years ago, the research world looked an exciting but relatively homogeneous place. Significant discoveries were numerous, but most occurred in the well-established economies of Europe and North America. In 1973, about two-thirds of the nearly 400,000 research publications indexed by Thomson Reuters Web of KnowledgeSM had an author in one of the G7 countries.

Today, this has changed dramatically. Four times as many documents—more than 1.75 million journal publications—are being indexed, and barely half will have a G7 author. The volume of publications with at least one G7 author may have trebled over that period, but the volume on which no G7 country is represented has gone up six-fold. A significant part of that change is attributable to rapid research growth in five countries: Brazil, Russia, India, China and South Korea, known together as the BRICK nations.

The BRICK nations have often been noted for their growing influence in the global economy and research landscape. To that end, they are often referred to as emerging, making the process and shape of that emergence of critical interest. Because many of these nations demonstrated traditional strength and, now, global leadership in manufacturing (a point explored later in this report), should they continue to singularly invest in these sectors to attain global dominance? Would that move them from emerging to established? Or is the term 'emerging' used in relation to highly diversified knowledge economy states like Japan, the UK and US?

Many would argue the latter, charging these nations' policymakers with the complex task of continually benchmarking progress and making sound strategic investments. Human capital, a critical element in the knowledge economy, illustrates this challenge: it is far easier to train more R&D staff in manufacturing than to invest in an entirely new infrastructure to support the education, research facilities and employment opportunities for research workers in the life sciences, social sciences and other fields.

Thomson Reuters has previously published reports on the academic research base of four of the five BRICK countries: Brazil (June 2009), India (October 2009), China (November 2009), and Russia (January 2010). This report adds South Korea, bringing the countries together in a single review, and expands our view of the academic base to include the economic impact of that research with data from Thomson Reuters Derwent World Patents Index[®] (DWPISM).

This report snapshots the current BRICK research landscape in this 'emerging' context—both as a whole and as separate entities—by reviewing the national indicators that underlie sustained growth and influence, and, by some measure, the realization of a 'knowledge economy' through recurring themes explored in previous Global Research Reports on individual G7 nations: R&D investment (private and public), human capital, research publication output, academic impact, and economic impact on the global stage. The data help spotlight areas of strength, levels of diversity in the research portfolio, and potential next steps on the path from 'emerging' to sustained global power.

INVESTMENT: BRICK COMMITMENTS TO RESEARCH AND DEVELOPMENT

The European Commission has long expressed a view that the appropriate level of research investment for a mature economy should be around 2 percent of Gross Domestic Product (GDP). The average across the 27 nations of the European Union is now close to that, while the Organization for Economic Cooperation and Development (OECD) average is somewhat higher, around 2.4 percent.

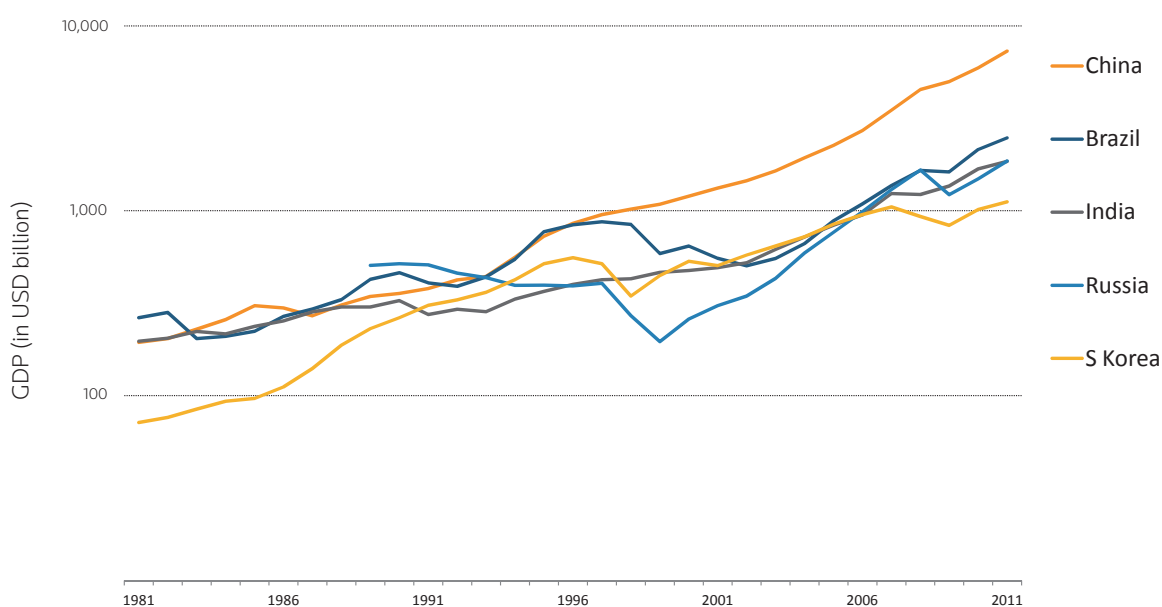
If an emerging economy is expanding rapidly from a much smaller base, and if there are other critical policy objectives for public resources, then we should not use the European Commission's guideline as a benchmark, although it does stand as an interesting reference point. Figure 1 illustrates the rate of GDP growth in BRICK countries over the

past 30 years; Figure 2 shows the percentage of GDP each country is investing in R&D.

World Bank data in Figure 1 confirm what the newspapers tell us: that the BRICKs are growing very rapidly indeed, although with the exception of China, they all suffered a blip in the late 1990s and took a smaller hit in 2008-9. South Korea showed the most rapid growth back in the 1980s, its 'tiger economy' phase, by which time its economy had grown to the size of Russia and India. China, however, has the extraordinary trajectory that has taken it continuously beyond the others. It is now second only to the US and is predicted by *The Economist* to reach GDP parity sometime before 2020.¹

GROWTH IN THE GROSS DOMESTIC PRODUCT (GDP) OF THE BRICK NATIONS

FIGURE 1



Source: Data from the World Bank expressed as US\$ current in the year for which the data are recorded (i.e., 2001 data at 2001 prices). Data not adjusted for purchasing power parity. Some sources query the precise values but not the profile for China.

1. "The dating game: we invite you to predict when China will overtake America," *The Economist*. Dec 2011. http://www.economist.com/blogs/dailychart/2010/12/save_date

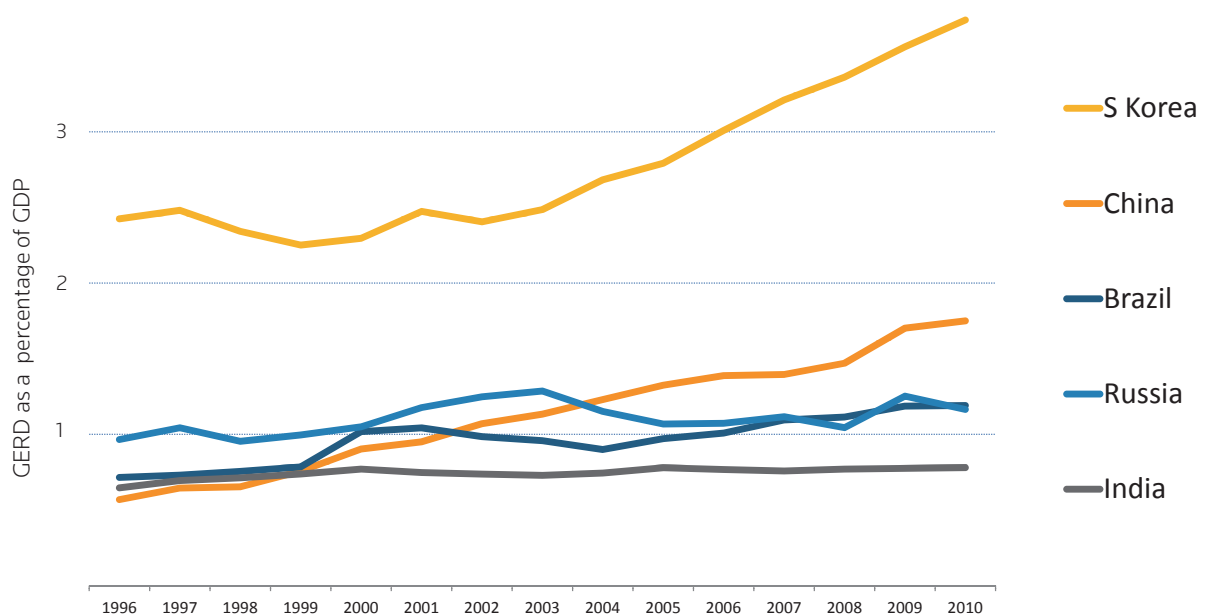
What are the implications of these growth figures for research spending? Greater GDP implies that there may be more money available to invest in R&D, leading to greater innovation and competitiveness, thus sustaining the economic growth trajectory. However, research cannot be turned off and on like a tap. It takes time to get from investment decisions to the implementation of new projects and programs, especially where these require cutting-edge facilities or new laboratories. What takes even longer to build up is the intellectual capacity invested in a highly trained research workforce. BRICK policymakers need to view R&D investment as a long-term strategy, continually supporting high priority programs and initiatives year after year.

Figure 2 uses data from several different sources to build a picture of how the relative research investment pattern has changed in the BRICKs. The indicator used here is Gross Expenditure on R&D (GERD), which covers both the public and private sectors. Brazil, Russia and India have

maintained but not increased their GERD. Brazil did step up its relative spend in the late 1990s, and that improvement has recently begun slowly to increase again. These three nations remain well behind the two percent European Union investment objective. China, on the other hand, has steadily ramped up its R&D investment (recall that the Chinese industry is dominated not just by traditional manufacturing, but by monolithic state enterprises under central influence) with a 2.5-fold relative increase in GERD/GDP during a period when its GDP grew by an order of magnitude. That brings it up to an investment level alongside France and the UK, but with a far bigger driver. This somewhat shades South Korea's signal achievement, but South Korea is in fact investing relatively much more in R&D than even Germany (Eurostat indicates 0.8 percent in 2010) and has a powerful technology base to show for it. The investment trajectory remains steeply upwards.

ANNUAL CHANGE IN GROSS EXPENDITURE ON RESEARCH & DEVELOPMENT (GERD) AS A PERCENTAGE OF NATIONAL GROSS DOMESTIC PRODUCT (GDP)

FIGURE 2



Source: OECD and Network for Science and Technology Indicators (RICYT); analysis: Thomson Reuters

One measure of the confidence that others have in the economic investment strategy is the balance of GERD that is contributed by the commercial sector. This is Business Expenditure on R&D (BERD, strictly an expenditure in the business sector that includes government grants). Figure 3 summarizes a revealing pattern of BERD for the BRICK economies at five-year intervals (there are no data for India). Brazil and South Korea remain on a level investment ratio throughout the period, despite other changes. They are well structured and progressively growing economies. Industrial confidence in South Korea is evidently high, but BERD levels for Brazil seem anomalously low. That is possibly an artifact caused by unusually high levels of public R&D investment especially from a highly supportive tax regime in the São Paulo region.

Russia reflects all the problems of a significant loss of general investment and falling business confidence. This is not an environment for secure commercial expectations of innovation. China, by contrast, offers an environment into which business is rushing to participate. Recall from Figure 2 China's rising level of GERD in a growing volume of GDP and then note that—even in this rapid expansion—the relative business share is up by 25 percent. Of course, a downside of that is that China is acting like a sponge for R&D investors and that makes it even more difficult to compete for funds elsewhere.

BUSINESS EXPENDITURE ON R&D (BERD) AS A PERCENTAGE OF TOTAL NATIONAL GERD

FIGURE 3

	2000	2005	2010
BRAZIL	44.73	48.29	47.88
CHINA	59.96	68.32	74.45
INDIA	N/A	N/A	N/A
S. KOREA	74.05	76.85	74.80
RUSSIA	70.86	67.98	60.51

Source: OECD and Network for Science and Technology Indicators (RICYT); analysis: Thomson Reuters

For emerging economies, a sustained focus on significant GERD and BERD investment, although difficult during global, regional, or even domestic upheaval, will ultimately encourage the research innovation and economic confidence vital to becoming a more established global player.

How are other nations faring? Eurostat indicates BERD as a share of GDP is rising in France and Germany but falling in the UK. Other sources indicate that it is rising in Japan and static in the US. It seems likely that the next decade will see a further drift of business research investment to Asia.

PEOPLE: PROFILING THE BRICK RESEARCH AND DEVELOPMENT WORKFORCE

Human capital is the essential component of the research base and also its most important product, because people can carry their knowledge-handling and problem-solving capabilities into all other parts of the economy.

It takes time to recruit and train talented people and even longer for them to become independent researchers, training others in their turn. Money can be switched into new areas more quickly than the research base can respond because even established researchers will take time to develop new skills and build their competency. So BRICK research capacity needs time to grow. It also needs to diversify beyond R&D support for a traditional manufacturing base. As it does so, it provides huge spin-off benefits throughout

the economy as more trained and skilled people become available for wider employment.

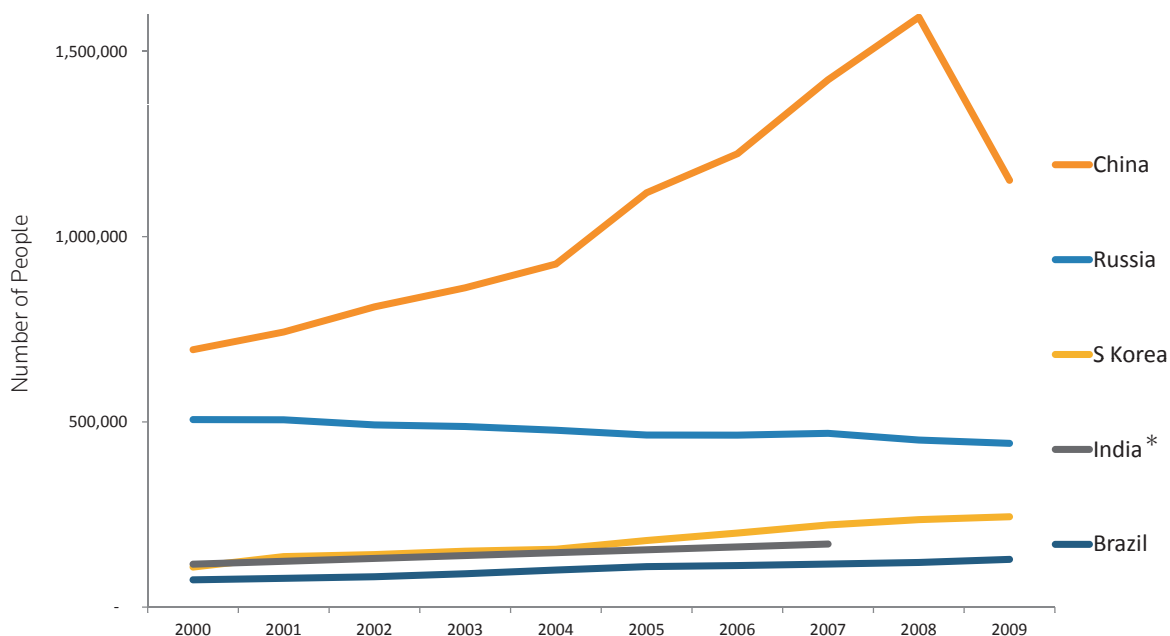
It is a challenge to find suitable sources of comparable data on 'skilled workers' across the BRICK countries. Although the OECD has well established definitions of R&D workers and of researchers in its Frascati manual, these definitions take time to be adopted in national statistical agencies. Definitions are inevitably subject to some interpretation, and this is particularly so in the case of China and Brazil, so doubts arise as to precise comparability, and final national statistics tend to lag considerably on real-time information. Nonetheless, an interesting picture begins to emerge.



REUTERS/Michael Dalde

NUMBER OF RESEARCHERS PER COUNTRY, COUNTED AS FULL-TIME EQUIVALENTS

FIGURE 4



Source: OECD and RICYT; analysis: Thomson Reuters.

This data is derived from a comparison among OECD, United Nations Educational, Scientific and Cultural Organization (UNESCO) and Spanish Foundation for Science and Technology (FECYT) data. There has been a significant revision to the data recorded for 'researchers' for China but this has not been backdated. *Visualization for India is based on a projection from limited original data points.

The research capacity of Russia is declining but remains substantial. There is growth in Brazil, India and South Korea and it is relatively significant (typically at least doubling researcher numbers over the decade 2000-2009). But it is again China that dominates the picture, even with a marked revision of the 'researcher' definition applied to the data after 2008.

Questions remain about what the 'researcher' figures actually mean. Some commentators, including leading Chinese scientists, suggest that while there may be more warm bodies in research, the nature of domestic research training remains less focused on innovation and there is a lack of creative capacity and thus innovation. India, meanwhile, may lack the volume of

researchers but is able to generate highly original approaches to research appropriate to a frugal economy, according to a recent report from the UK's Nesta.²

While national research capacity may be reflected in a number of indicators, the desirable work attribute in a knowledge-based economy is likely to be knowledge competence: the ability to identify and tackle problems, draw on knowledge from outside or across fields, manage solutions and risks, and accommodate uncertainty. In the case of BRICKs, a growing research base, patiently cultivated, can help these economies transition from emerging to established.

2. "Our Frugal Future: Lessons from India's Innovation System," Nesta. July 2012

http://www.nesta.org.uk/home1/assets/features/our_frugal_future_lessons_from_indias_innovation_system

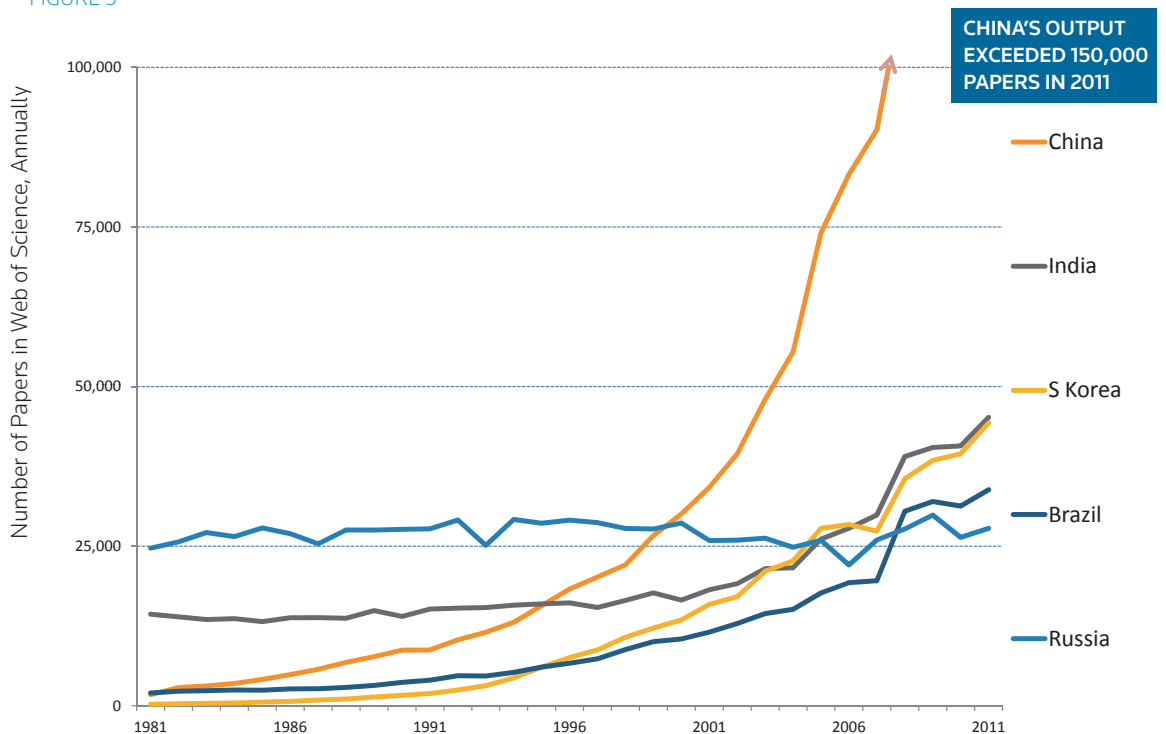
PUBLICATIONS: BRICK RESEARCH OUTPUTS

As nations invest in R&D and their workforce capacity, their researchers contribute to regional and international scholarship (and field advancement) via publications—they are the outputs or ‘fruits’ of a sustained strategic investment. National publication trends can be compared with global benchmarks to reference growth and progress, and they can uncover specialty areas of focus (or atrophy) that may warrant increased attention by policymakers.

Data on publications, citations, citation impact and the proportion of papers that are relatively highly cited by field and year are available from the databases in the Web of Knowledge. Thomson Reuters Web of Science aggregates the 11,500 journals that it tracks across some 250 subfield categories on the basis of their stated focus and their cited and citing relationships. We also use the 22 broad field categories of Thomson Reuters *Essential Science Indicators* database. It should be noted that papers published in multidisciplinary journals such as *Nature* and *Science* are selectively assigned to their appropriate fields within *Essential Science Indicators*.

ANNUAL RESEARCH PUBLICATION OUTPUT OF THE FIVE BRICK COUNTRIES

FIGURE 5



Source: Thomson Reuters Web of Knowledge. (See also Figure 7 on trajectories of patent output.)

Figure 6 takes these aggregated data curves and breaks out the most prolific fields for each BRICK country during the last five years (2007-2011). Because these 'fields' vary in size around the world (there is more medical research than physics research), we do not use absolute measures of output, but instead we relate each country's activity to the world total for that field. That allows us to see their relative contribution, indexed as a percentage of the world total.

The general trend for the BRICK countries is upwards, as we said at the outset of this report. China has soared into a different paradigm while South Korea and Brazil have developed a steady upwards curve. India has been the 'sleeping giant' but has now begun to stir and is probably on a path that will see it matching leading EU countries at around 100,000 papers per year by 2020. Russia stands out in this company as having had a marked lead which it then lost before slipping to back-marker with an almost constant output of 25,000 papers per year throughout the period.

PROLIFIC FIELDS OF RESEARCH OUTPUT FOR THE FIVE BRICK COUNTRIES (AS PERCENTAGE OF WORLD OUTPUT)

FIGURE 6

BRAZIL (2.6)		RUSSIA (2.4)		INDIA (3.4)		CHINA (11)		S. KOREA (3.3)	
Agricultural Sciences	8.8	Physics	7.3	Chemistry	6.4	Materials Science	24.5	Materials Science	6.3
Plant & Animal Science	6.6	Space Science	6.8	Pharmacology & Toxicology	6.1	Chemistry	20.2	Computer Science	5.6
Pharmacology & Toxicology	3.7	Geosciences	6.6	Agricultural Sciences	6.1	Physics	17.9	Engineering	5.1
Microbiology	3.3	Mathematics	4.7	Materials Science	5.9	Mathematics	15.7	Pharmacology & Toxicology	4.8
Environment / Ecology	3.0	Chemistry	4.5	Microbiology	5.1	Engineering	14.8	Physics	4.7
Social Sciences	2.8	Materials Science	3.1	Physics	4.3	Computer Science	13.1	Microbiology	4.2
Clinical Medicine	2.6	Engineering	2.1	Engineering	4.1	Geosciences	12.3	Chemistry	3.7
Biology & Biochemistry	2.6	Molecular Biology	2.0	Plant & Animal Science	4.0	Pharmacology & Toxicology	10.1	Agricultural Sciences	3.4
Neurosciences	2.6	Microbiology	1.7	Geosciences	3.7	Environment/ Ecology	9.8	Biology & Biochemistry	3.3
Immunology	2.5	Biology & Biochemistry	1.6	Biology & Biochemistry	3.6	Biology & Biochemistry	8.8	Clinical Medicine	2.8

Source: Thomson Reuters *Essential Science Indicators*. Subject fields ranked by share of global publications for the most recent five years (2007-2011). The values against each country name show the overall average of that country's share of world output. Fields that are broadly in the 'life sciences' are highlighted with blue text while fields that are broadly in the 'physical and technological sciences' are highlighted with gray. Mathematics (represented in black) is assumed to have equal relevance to both areas. World share is expressed as a percent.

National output in the top 10 fields ranked by world share is usually above the country's overall average unless it exactly matches the balance across the global portfolio. The fields where there are greater than average shares therefore reflect the type and degree of specialization for that country.

Brazil stands out as distinctly different in its research portfolio. Every one of the 10 fields in which it has a relatively high share of global outputs is in the life sciences. It has been described by Kirsten Bound in a Demos report³ as the 'natural knowledge economy' and that is confirmed in this analysis. The biology and biochemistry field, which provides a core underpinning to both biomedical and biotechnology developments, is also in the 'top 10' for the other BRICKs but there is otherwise a much more variable focus on life science areas. India and South Korea have a mix of life and physical sciences. India is the country that comes closest to Brazil in its portfolio structure, with three life science fields in its top five where South Korea has just one. China and Russia are much more evidently dominated by the physical sciences.

For China, the top seven fields—all in the physical sciences—show a greater than average share (i.e., that is where China has a greater share than its 11 percent overall). For Russia, this applies to just six fields, again all physical sciences. That means that in the rest of the 22 *Essential Science Indicators* fields used in this analysis, these countries have a below average global share. They are really very focused on these technology-orientated fields.

India is the most diverse. For all 10 of the fields in the table, it exceeds its overall share, spreading its specialization across a wider range than China; Brazil and South Korea also have a good spread across their top 10. This may be important in allowing these countries to move in and out of different research focus areas. Certainly for India and South Korea, it reflects the mature, long-term establishment of their research base. For Brazil, it might be argued that the absence of any physical science technologies in its main areas of effort could become a limiting factor on economic development.

3. Brazil: "The Natural Knowledge Economy," Bound, Kristen. July 2008. <http://www.demos.co.uk/publications/brazil>

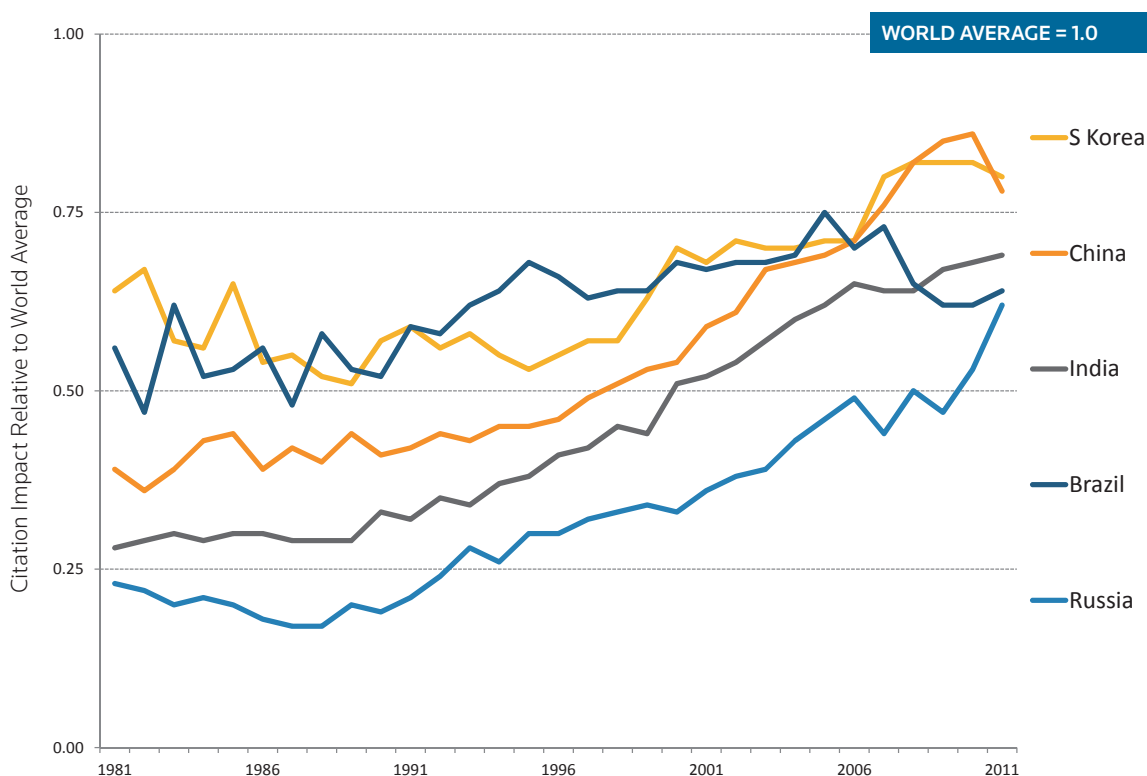
ACADEMIC IMPACT

Investment in higher education and research builds up a country's knowledge capacity, its ability to use discovery and innovation to create economic wealth, and its potential to realize benefits in health, culture and the quality of life. The increases in output that reflect the growing level of investment will not immediately be translated into world-class research because, as we noted, it will take time to train a new generation of researchers. It will also take time to draw the quality of the new research to the attention of the rest of the world.

That said, we can already begin to see strong signals of improving research impact among the five BRICK countries (as seen in Figure 7). In order to get a handle on research 'excellence,' we have used the frequency with which publications are cited by later works as an index of their impact on the rest of the research community. Citation rates vary by field and citation counts grow by year, so the actual citation count is adjusted (or normalized) for both discipline and year of publication as a ratio on the appropriate world average in the same Thomson Reuters Web of Knowledge data, to give a Relative Citation Impact index (where world average = 1.00).

CITATION IMPACT OF THE FIVE BRICK COUNTRIES RELATIVE TO WORLD AVERAGE

FIGURE 7



Source: Thomson Reuters Web of Knowledge. Although the average citation impact of much of the research remains below world average (which is set at 1.00), it is evident that the impact trend is generally consistently upwards for all these countries. Several BRICKs show an impact drop in the last few years, but this is a data artifact associated with atypically early citation of papers published in G7 economies.

This overall picture hides some of the real diversity of impact, including the highs and lows within each country's research. There is also a likelihood that the analysis will tend to favor those countries—such as Brazil—that have a relatively high volume of life sciences research, because this tends to be more frequently cited than physical sciences. However, the analysis is a useful aggregate starting point in considering the global research impact that the BRICKs now have.

The BRICK countries had a citation impact between one-quarter and one-half of world

average citation impact (normalized at 1.00 in these analyses) at the start of the 1990s, whereas by the end of the period of analysis, they had all risen to well over one-half of world average. The hidden diversity at subject level is matched by hidden diversity of impact within the expanding volume of activity, so we need to consider that as well. All these countries are also producing a growing number of exceptionally highly-cited research papers. For China, the sheer volume of output means that although its average impact is about three-quarters that of world average, it is already producing a huge number of papers cited well above world average.

PAPERS PUBLISHED BY COUNTRY, CITED IN THE TOP 1 PERCENT FOR SUBJECT CATEGORY AND YEAR OF PUBLICATION

FIGURE 8

	BRAZIL		RUSSIA		INDIA		CHINA		S. KOREA	
	Highly cited papers	% of National Output	Highly cited papers	% of National Output	Highly cited papers	% of National Output	Highly cited papers	% of National Output	Highly cited papers	% of National Output
2002	56	0.43	92	0.35	68	0.36	262	0.66	110	0.64
2003	71	0.49	86	0.33	77	0.36	334	0.70	127	0.60
2004	73	0.48	103	0.41	101	0.47	363	0.66	143	0.63
2005	98	0.55	106	0.41	108	0.41	514	0.70	181	0.65
2006	94	0.49	91	0.41	110	0.40	563	0.68	152	0.54
2007	98	0.50	106	0.41	124	0.42	618	0.68	202	0.74
2008	129	0.42	101	0.36	148	0.38	839	0.74	234	0.66
2009	133	0.42	120	0.40	191	0.47	995	0.78	253	0.66
2010	165	0.53	130	0.49	189	0.46	1113	0.83	275	0.70
2011	168	0.50	152	0.55	235	0.52	1131	0.72	328	0.74

Source: Thomson Reuters Web of Knowledge. Counts are shown as a percentage of national output in that year. Output of highly cited papers would match world average output of such papers if the count reached 1 percent of national output.

For all the BRICK countries, the trend is for an increasing share of the papers in the world's top 1 percent most cited for that year. Figure 8 shows that by 2010, China was producing over 1,000 of such highly-cited papers per year. That is similar to the UK's annual average, although the UK's

research output in total is much smaller; this volume of highly-cited research is around 0.72 percent of China's output but about 1.4 percent of the UK's. South Korea is producing about the same relative output of high impact papers to China, but Brazil, Russia and India are somewhat further behind, at around 0.5 percent.

The overall data on citation impact are readily broken down into the main subject areas that we used in Figure 6, where we looked at the balance across each country's output portfolio.

In Figure 9, we look at the fields where their research has the greatest citation impact. Those fields in which the average impact is above world average are highlighted with an asterisk(*).

RESEARCH FIELDS OF PUBLISHED PAPERS WITH HIGH CITATION IMPACT (2007-2011)

FIGURE 9

BRAZIL	RUSSIA	INDIA	CHINA	S. KOREA
Physics*	Physics	Psychiatry & Psychology* Only 508 papers	Engineering*	Materials Science*
Mathematics*	Immunology Only 270 papers	Engineering*	Agricultural Sciences*	Space Science*
Engineering*	Clinical Medicine	Physics*	Mathematics*	Plant & Animal Science*
Computer Science	Plant & Animal Science	Computer Science*	Economics & Business*	Chemistry*
Geosciences	Pharmacology & Toxicology	Materials Science	Plant & Animal Science*	Physics*
Space Science	Engineering	Social Sciences	Social Sciences*	Agricultural Sciences*
Psychiatry & Psychology	Mathematics	Mathematics	Computer Science*	Geosciences*
Environment & Ecology	Space Science	Space Science	Psychiatry & Psychology*	Engineering*
Clinical Medicine	Biology & Biochemistry	Environment & Ecology	Materials Science*	Mathematics*
Materials Science	Environment & Ecology	Chemistry	Environment & Ecology*	Psychiatry & Psychology*

Source: Thomson Reuters *Essential Science Indicators (ESI)*. Research fields (ESI journal categories) in which the BRICK countries have recently (2007-2011) published papers of relatively high average citation impact. An asterisk (*) indicates fields in which a country has impact greater than 0.8 times world average. Fields that are broadly in the 'life sciences' are represented with blue text while fields that are broadly in the 'physical and technological sciences' are represented with grey. Mathematics (represented in black) is assumed to have equal relevance to both 'life sciences' and 'physical and technological sciences'; 'social sciences' are represented in purple.

The subjects in Figure 9 (quality—citation impact) appear rather different to those in Figure 6 (quantity—publication output). For example, Brazil is represented in Figure 9 by a swathe of physical science and technology fields rather than the life sciences which dominated Figure 6.

One reason for this is that there is no necessary and direct relationship between impact and volume, either at a national or institutional level. Countries often invest strategically in research areas important to their economic development and competitiveness. China and India have a substantial industrial base and much of their recent research has been directed at the support of that base. This has led to the establishment of a major industrial research sector through political requirements rather than scientific competitiveness. Under such circumstances, there has been a proliferation of industrially relevant research activity with low levels of selective peer review, and this research is now being reported but not cited in the wider literature.

By contrast, Russia's nascent immunology research sector (Figure 9 indicates its small size) has had to excel to survive. Only the best acquire funding and their publications are evidently highly regarded.

The fields identified in Figure 9 all represent opportunities for the next stage of BRICK building. These are the areas of greatest promise. For South Korea, high achievement in materials science is no surprise; it is a niche area of exceptional strength and depth. Russia's achievements in physics are also globally acknowledged. Brazil may benefit by transferring some of its resources into physical sciences to complement its natural knowledge research base. China can benefit its own population further by investing in its research competency in plant and animal sciences.

In the next section we consider how research achievement and research potential are being translated into intellectual property.

ECONOMIC IMPACT

There are many definitions of innovation. The one that resonates most closely in the context of economic impact is “the process of translating an idea or invention into a good or service that creates value or for which customers will pay.”⁴

‘Creating value’ is why governments and organizations around the world recognize that innovation is a key driver of global economic growth and prosperity. In the US, this comes from the top. President Obama, in his 2011 State of the Union address said, “We’re the nation that put cars in driveways and computers in offices; the nation of Edison and the Wright brothers; of Google and Facebook. In America, innovation doesn’t just change our lives. It is how we make our living.”⁵ In Europe also, European Commission President José Manuel Durão Barroso has commented on the importance of innovation: “Innovation is the cornerstone of the Europe 2020 Strategy, our European blueprint to get the economy back on track over the course of the decade. It is indeed about turning new ideas into growth, prosperity, jobs and well-being.”⁶

Among the BRICK countries, China has fully embraced innovation as a driver of economic growth through successive five-year plans designed to transform China from a manufacturing to a knowledge economy. The latest five-year plan identifies some specific targets to achieve that objective⁷:

- Increase in R&D expenditure from 1.75 percent of GDP in 2010 to 2.2 percent in 2015
- Improvement in ranking of citations to international papers from 8th to 5th
- Increase in invention patent ownership per 10,000 population from 1.7 to 3.3

How do we measure innovation so we can compare trends across different regions? Although not perfect, patents are one of the best tangible measures we have to track innovation. A patent is in essence a contract between the individual and the state whereby the individual is given the right to exclude others from practicing their invention without permission (in effect, to realize an economic return for their invention). In return, the individual must fully disclose how their invention is achieved (thereby contributing to the sum of human knowledge). This provides a clear and direct link between creativity and commercial return.

4. <http://www.businessdictionary.com/definition/innovation.html>

5. <http://www.whitehouse.gov/the-press-office/2011/01/25/remarks-president-state-union-address>

6. http://europa.eu/rapid/press-release_SPEECH-11-847_en.htm

7. “12th National Five-Year Plan on Science & Technology Development,” Ministry of Science and Technology of the People’s Republic of China. July 2011

There is also evidence to show that there is a positive correlation between GERD and patent output volume both in European and in US data by industry⁸ and by country/region.⁹ This provides the premise on which the analysis of patents as a proxy for innovation is based. So, by measuring the number of patents to an individual, organization or country, we have a sound method for indexing underlying innovation in those constituencies.

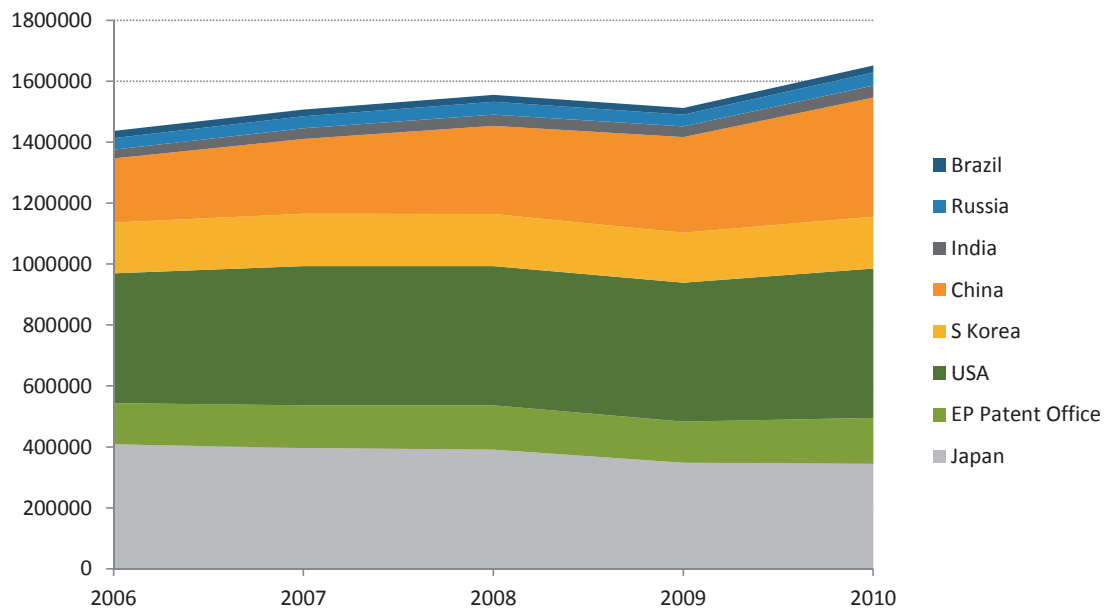
For the patent analyses in this report, we use the Thomson Reuters editorially-enhanced patent collection that is captured in Derwent World Patents Index (DWPI). DWPI contains over 20.7 million unique inventions covering more

than 50 million patent records from 50 major patent-issuing authorities, and the invention-based documentation allows us to see worldwide protection for a single invention. DWPI thus provides access to established and emerging innovation centers globally, covering technology areas critical to BRICK economies, including agricultural and veterinary medicine, chemistry, pharmaceuticals and polymers, electronic/electrical engineering, and high technology.

But first, we need to consider how the overall pattern of patenting for the BRICK economies compares to the mature regions of the US, Europe and Japan.

BRICK INNOVATION IN CONTEXT: THE VOLUME OF PATENT FILINGS (2006-2010)

FIGURE 10



Source: Thomson Reuters Derwent World Patents Index (DWPI)

8. "Study on the Trend of Research and Development from Patent Application," NISTEP, Report No. 9.
 9. "Patents and R&D expenditure," Bernard FÉLIX, Statistics in Focus—Science and Technology, 16/2006

Globally, there has been a general growth of 14.9 percent in patent filings over the five years from 2006 to 2010. In 2010, the mature economies accounted for nearly 60 percent of the total patent filings. In the same year, China and South Korea accounted for 84 percent of BRICK patent filings. The data therefore shows that Brazil, Russia and India are lagging on this aspect of innovation, not only behind mature economies, but also behind the other BRICKs.

An interesting anomaly appears if we compare Figure 10 data to the data in Figure 2 on GERD as a percent of GDP. GERD for Brazil, Russia and India is at a relatively lower level than China and South Korea. This comparison among the BRICKs is therefore in accord with the trend noted in Europe and the US with a lower level of patenting matching lower levels of R&D investment.

China, relatively speaking, appears to get far more bang for the GERD buck. For 2009 (the latest year for which statistics are available), despite spending 3.56 percent of GDP on R&D, South Korea produced only 164,000 filings or 45.9 thousand patents per percent GERD, whereas China produced over 314,000 filings at the rate of 185,100 patents per percent GERD. This is a four-fold productivity gain on GERD investment for China compared to South Korea. That marked contrast is also reflected in the recently released Top 100 Global Innovators report,¹⁰ only this time in reverse. Whereas seven of the Top 100 most innovative organizations in the world are from South Korea, China is notable by a complete absence from this list. The metrics used to determine the list include not only quantity metrics for innovation but also quality of innovation. It seems that, although South Korea delivers a lesser quantity of patents per GERD than China, external observers judge that the quality of South Korea's innovation is higher than China.

10. Top 100 Global Innovators, Thomson Reuters. December 2012 <http://top100innovators.com>

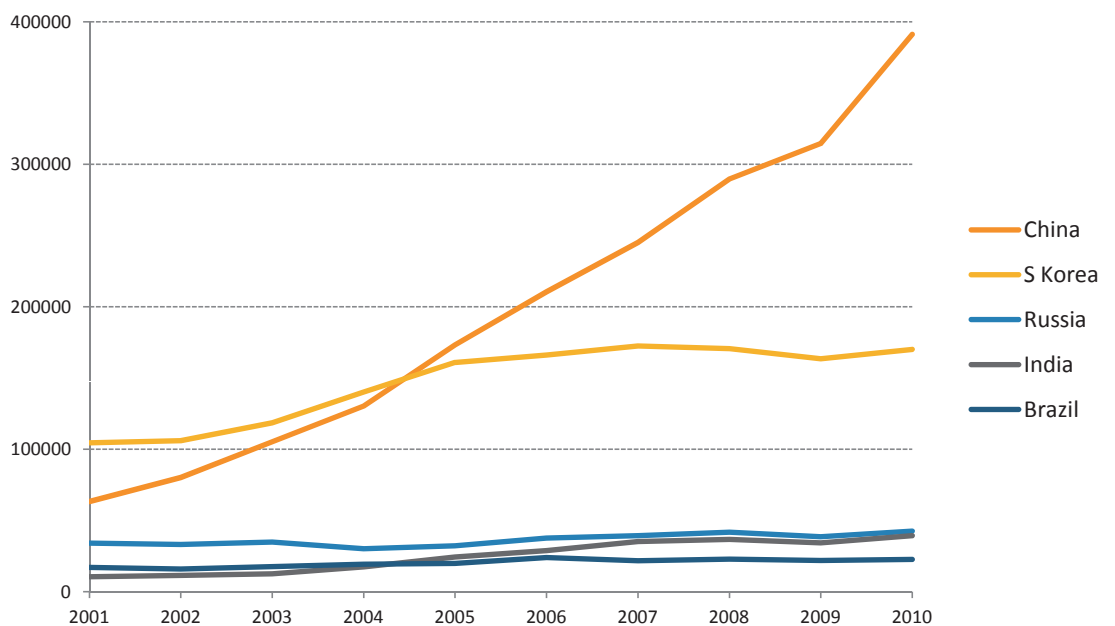
Despite differences in quality, China's prominence amongst the BRICKs continues unabated, and 2011 was a year of patenting firsts for China. Not only did China overtake the US to become the number one filing country in the world for invention patents with 526,412 applications compared to the US count of 503,582, China also outpaced the US in patents granted to residents (112,347 compared to 108,626). Only Japan had a higher rate of patents granted to residents, with 197,594 in 2011.

China also dominates when we examine patent filing growth trends for the BRICK nations in more

detail (Figure 11). China has consistently shown double digit growth year-on-year (apart from 2009) with filings growing six-fold to 390,000 in 2010 from 63,000 a decade ago. After a period of growth from 2001-2005, South Korea has plateaued at around 170,000 filings per year. Russia and Brazil have both shown gradual growth over the period of 2.9 percent and 3.5 percent, respectively. India has performed relatively well in moving from 5th to 4th place at an average 16.6 percent compound annual growth rate (CAGR) and is poised to move beyond Russia into 3rd place next year.

ANNUAL NUMBER OF INVENTION PATENT APPLICATIONS FILED BY THE FIVE BRICK COUNTRIES

FIGURE 11



Source: Thomson Reuters Derwent World Patents Index (DWPI)
See also Figure 5 on trajectory of publication output.

The patenting activities show a somewhat different picture from that drawn by analysis of scientific output shown in Figure 5. China is the common factor, however, with soaring growth in scientific activity matched by accelerating patenting activity. Both are in line with China's intent to transform itself from a manufacturing economy to a knowledge economy by 2020.

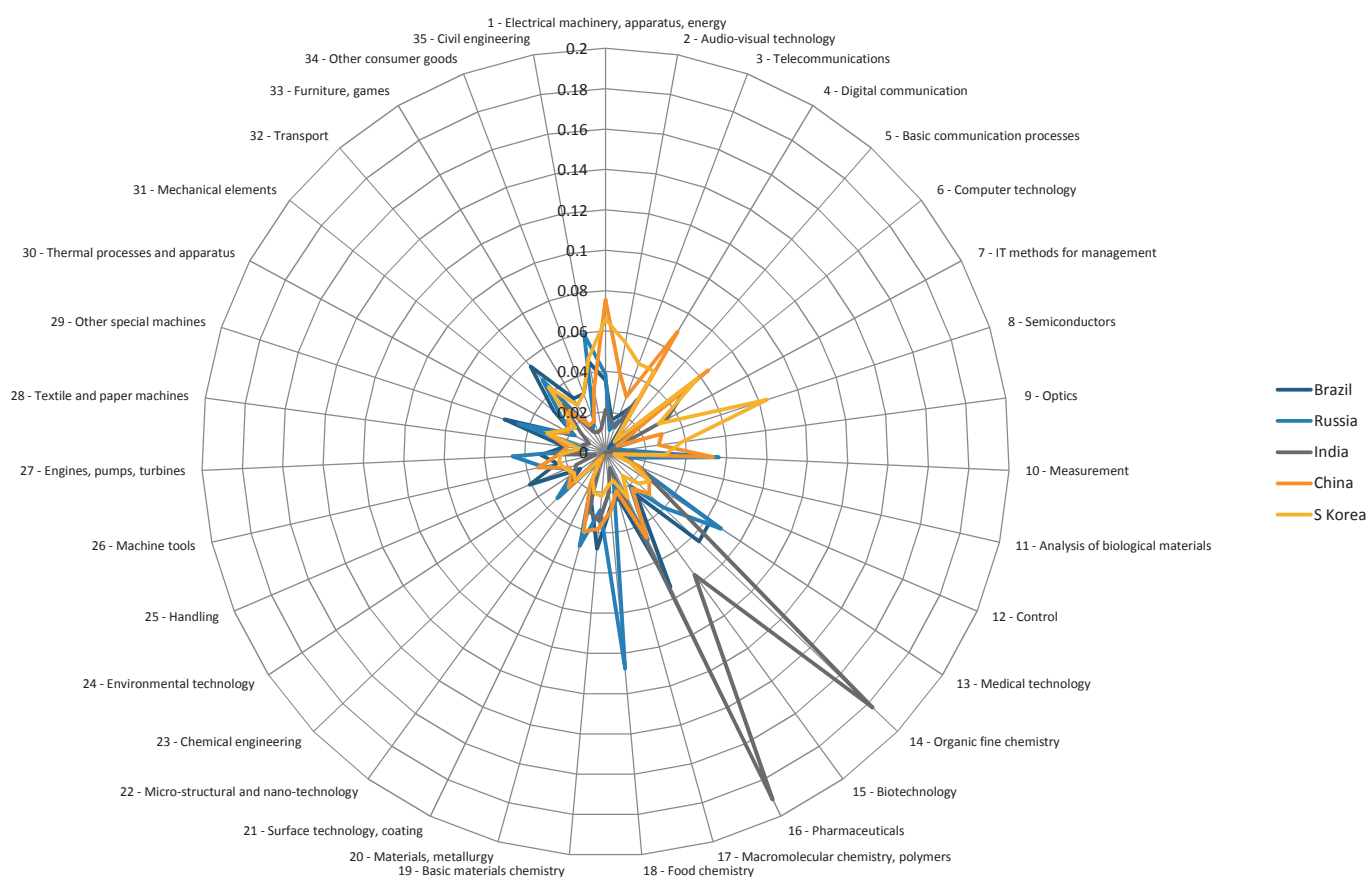
Steady growth in scientific publications from South Korea does not appear to have translated into patent filings in recent years. This may be a consequence of difficult economic conditions with a contraction of 4 percent in GDP from 2007-2010. For Russia, the scientific and patent output trajectories show a similar profile and the country has slipped from sector leader to a back-marker in science. Even more surprisingly, Russia is poised to be overtaken by India in patenting. For India and Brazil, both scientific publications and patent outputs have grown, although patents less quickly. This may indicate some inefficiencies in realizing economic return on the application of basic science in these countries. This is evidenced by the dramatic increase in backlog of patent applications awaiting examination at the Indian Patent Office which rose by 47.3 percent to 123,255 in the 12 months from March 2011 through April 2012. At the same time, the average lag between patent application and grant in Brazil is now around eight to nine years.

The profile for the total patent portfolio hides much detail and difference at the level of individual industrial sectors. To gain an understanding of technology areas in which patenting activity is focused for each of the BRICK nations, we looked at the percentage of each nation's portfolio of patent filings for 2010 by 35 standard technology areas defined by the World Intellectual Property Organization (Figure 12).

Brazil has a relatively even distribution of patents across technologies with some emphasis—as would be expected from its research profile—on life sciences (pharmaceuticals, organic fine chemistry and medical technology) and transport and machinery (other special machines). Russia shows stronger focus in food chemistry and medical technology; India's profile is dominated by a spike in pharmaceuticals and organic fine chemistry; China shows preference for high tech areas of electrical machinery, apparatus and energy, digital communication and computer technology; and South Korea also shows a high-tech profile with focus on semiconductors, electrical machinery, apparatus and energy, computer technology and audio-visual technology.

PATENT APPLICATIONS FILED IN 2010 BY MAIN FIELDS OF KNOWLEDGE AS A PERCENTAGE OF PORTFOLIO

FIGURE 12



Source: Thomson Reuters Derwent World Patents Index (DWPI)

Just as the volume of papers varies globally by research discipline, so also does the volume of patents. In other words, patenting is globally low in some technology areas and high in others. A complementary view of innovation is therefore to examine each region's filing activity for a specific technology relative to global filing activity in the same area. In this way, we gain an understanding of the relative innovation performance in technology sectors for each of the

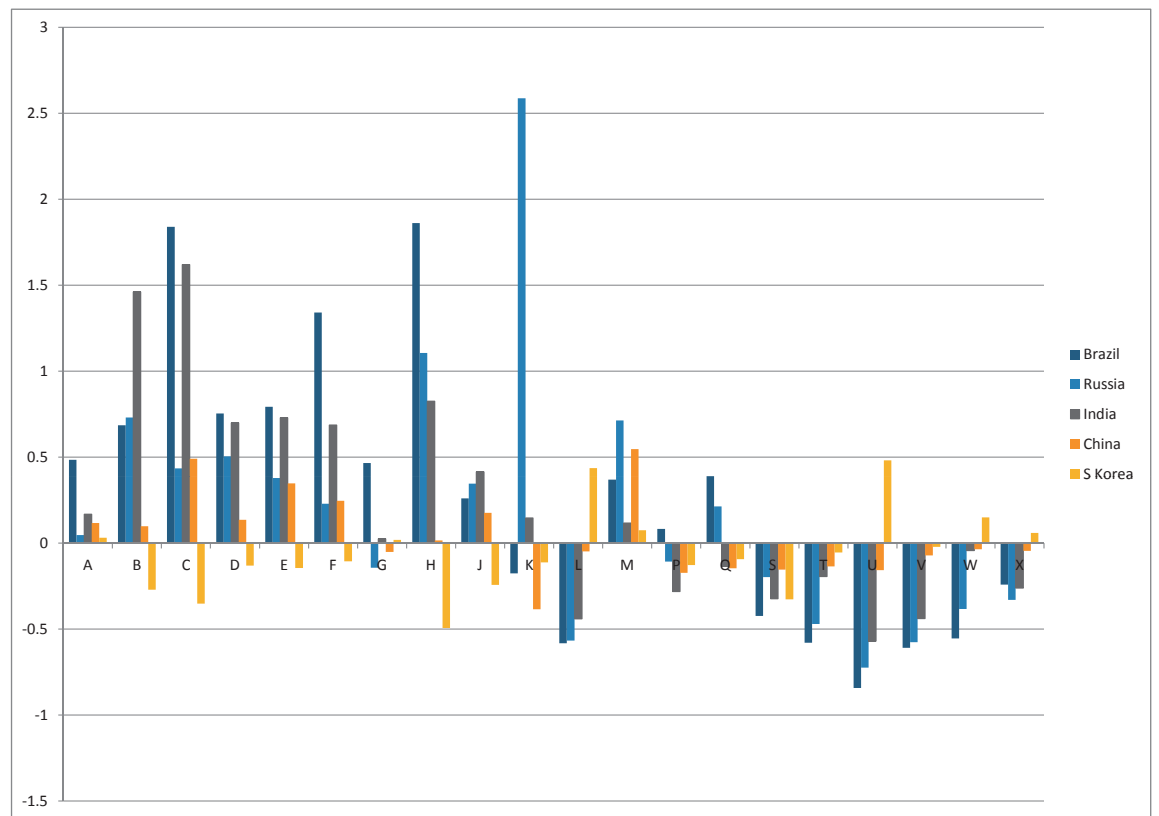
BRICKs compared to the innovation profile for the world. This analysis is performed using the classifications applied to each invention within the DWPI database. Each record is assigned detailed index and classification terms according to the technology of the invention described in the patent. A broad classification 'section' is also applied so that macro analysis of broad technology areas is possible and 20 such broad sections are available (table below Figure 13).

The breakdown by DWPI section for the BRICK countries relative to the world for 2010 is shown in Figure 13. For each section, the volume of patents as a percentage of total portfolio is set to zero for the world as the baseline, and then the relative activity (the percent variance from average) is revealed for each country. If the world has about three percent of its patents in steel and a country has six percent of its patents in steel,

then it would reach 1.0 on this scale (or zero, if three percent of its patents were in steel). For example, in section B (which is pharmaceuticals) Brazil, Russia and India patent relatively more than the world by 0.69, 0.73 and 1.46 times respectively; China patents about the same rate relative to the world; and South Korea patents relatively less than the world average by about 0.27 times.

PATENT APPLICATIONS FILED IN 2010 BY MAIN FIELDS OF KNOWLEDGE (RELATIVE PATENTING RATES COMPARED TO GLOBAL PATENTING)

FIGURE 13



Source: Thomson Reuters Derwent World Patents Index (DWPI)

- | | | |
|--|--|--|
| A. Polymers and Plastics | H. Petroleum | S. Instrumentation, Measuring and Testing |
| B. Pharmaceuticals | J. Chemical Engineering | T. Computing and Control |
| C. Agricultural Chemicals | K. Nucleonics, Explosives and Protection | U. Semiconductors and Electronic Circuitry |
| D. Food, Detergents, Water Treatment and Biotechnology | L. Refractories, Ceramics, Cement and Electro (in)organics | V. Electronic Components |
| E. General Chemicals | M. Metallurgy | W. Communications |
| F. Textiles and Paper-Making | P. General | X. Electric Power Engineering |
| G. Printing, Coating and Photographic | Q. Mechanical Engineering | |

This view of the world highlights again India's relative focus on pharmaceutical (B), agrochemical (C) and other chemical innovation (D, E) over the more mechanical and electrical technologies of sections P-X, which accords well with the general economic profile for that country with its strong presence of companies operating in the pharmaceutical and chemical sectors. Perhaps more surprising is Russia's relative dominance in nucleonics and explosives (K). This may, however, reflect the importance of the nuclear industry to power generation in Russia. From the world's first nuclear power station for electricity generation which was commissioned in 1954, Russia (as of February 2012) currently has 439 active nuclear power plants in operation. Brazil's innovation profile is weighted towards petrochemical (H), agrochemical (C) and textile technology (F), which is again a reflection of the current and future economy. With the tripling of the Brazilian population from 1951 -2005, the need arose to feed millions more people, which has led to today's complex agribusiness sector. Rich in natural oil reserves, the petroleum and petrochemical industries are also a major component of Brazil's economy. South Korean innovation alone shows a prominence relative to the world in high tech industries over chemical enterprises. With dominant global electronic companies such as Samsung and LG developing ever-improving devices, innovation to support those developments is clearly a major factor.

China shows no particular dominance in any one technology field indicating that innovation is broadly balanced across the spectrum when compared to global innovation. Whether this remains the case in the future will be interesting to monitor, partly because there have been suggestions that current industry is only weakly linked to emerging research innovation. It may be that new industries will show a far more closely correlated development to the new strengths in the research base. The latest five-year plan identifies seven "Strategic Emerging Industries" for specific investment in science and technology education and R&D expenditure. These are:

- New Energy – Nuclear, hydro, wind and solar power
- Energy conservation and environmental protection – Energy reduction targets
- Biotechnology – Drugs and medical devices
- New materials – Rare earths and high-end semiconductors
- Next-generation IT – Broadband networks, internet security infrastructure, network convergence, "Internet of things"
- High-end equipment manufacturing – Aerospace and telecomm equipment
- Clean energy vehicles – Battery cell technology; target to produce one million electric vehicles per annum by 2015

It seems reasonable to expect to see China's innovation profile—in terms of both research and patenting—progressively become modified to reflect these areas of focus.

CONCLUSION

This report set out to investigate the continued emergence of the BRICK countries, a status that has become a mainstay in the wider press and global community. To better capture their progress, we have reviewed data on R&D spending, human capital, research publications, and patent filings—key indicators that underlie much of the sustained, diversified innovation base enjoyed by many of the G7 knowledge economies. The data not only confirm and quantify the rising status of countries beyond the G7 axis, but also spotlight the individual complexities that offer a richer tapestry behind the ‘emerging’ label. China is a helpful benchmark in this regard. When we focus on the phenomenal and seemingly across-the-board growth of China in R&D investment (Figure 2), people (Figure 4), research output (Figure 5) and patents (Figure 11), it is also useful to cross-reference the dynamics of the other economies and recognize that there is no single explanatory pattern.

The research portfolios of the BRICK nations are particularly interesting (Figure 6) because Brazil stands out as so obviously different from the others. For the ‘RICKs, physics, chemistry, engineering and materials are the lead areas, but for Brazil, the ‘natural knowledge economy’, life and environmental sciences lead all the way. What will the effect of this be? Many commentators have focused on the geographical shift of manufacturing toward emerging nations, which will be accelerated by the growth of innovative manufacturing when all this research starts to feed through. The effect on life sciences has been less

evident, but the signal from Brazil suggests that there may be more disruptive changes to come for traditional G7 strengths in pharmaceuticals. Brazil, China and India also have strengths in agriculture which will likewise be important in global development.

Quantity is nothing without quality, however, and there is still some way to go before the BRICK research bases generally match G7 impact benchmarks (Figure 7). Still, there is clear evidence of a growing wedge of excellent research, and the numbers of very highly-cited papers has increased (Figure 8). It is also surprising to note that for many of the BRICKs, the areas in which they are delivering the most impact (Figure 9) are not matching the area where they have the greatest volume of output. This may in part be a hangover, with rapidly evolving investments, from a focus on traditional areas of manufacturing. Strategic work may be required by BRICK policymakers to achieve a better translation of investment and focus of effort to real achievements that are likely to deliver competitive benefits through new processes and products.

What drives the quantitative outcomes behind these research outputs and impact? This is of critical concern to policymakers and one that involves a complex interworking of social, economic, and political factors. We offer R&D investment, both public (GERD) and private (BERD), and human capital as solid starting points—these indicators correlate strongly with

research outcomes. For example, Russia's lack of investment no doubt plays prominently in the country's struggling research output. Policymakers can take immediate steps to increase transparency on these data (particularly human capital), improve systems to capture and report them, and incorporate the relevant data and benchmarks in local and national policy setting. There is a feed-through from investment in the research base that impacts the workforce, which is a signal not just of capacity to perform skilled research and development, but also of the availability of knowledge-competent workers who can move across the economy to power up other sectors. Although China's workforce is difficult to gauge precisely, we can be certain that capacity is increasing from its exceptional levels in public and private R&D investment.

So how does research growth translate into indices of economic innovation? The trajectories for research output (Figure 5) and invention patent applications (Figure 11) look remarkably similar, confirming the link between knowledge drivers across these five growing economies. For example, Brazil's patent focus on petrochemicals and agrochemicals matches its research in biofuels and investment in the agriculture sector. Overall, China and South Korea are clearly leading on patent applications while Brazil, Russia and India are lagging on world benchmarks (Figures 10 and 11). Within this, there are

important exceptions and anomalies that could be of key interest to policymakers. While China had relatively concentrated output (Figure 6), its patent application pattern is much more balanced across sectors (Figures 12 and 13). By contrast, India had the more even spread of research output across fields. There are some spikes in patent applications, but pharmacology as a major output field matches pharmaceuticals as a major patent sector.

At a detailed level, a match between research and patents can be less clear, but data offer deeper insights. In the instance of China, research on clean vehicle technology is already at a high level of achievement while that is not yet the case on the industrial side. This can help signal that the nation may require more aggressive investments and policy shifts that create space for innovation to thrive in applied research and commercial development, and thus reap the benefits of the gains in the basic research sector. Such observations are critical for policymakers, because when research and commercialization mesh together, there are often widespread economic, environmental and social effects.

The dynamic story of BRICKS' research will be a constant focus for us as well as others. The current report provides a benchmark that we will return to regularly. We will also look with interest at the interpretation and predictions that other commentators make in reviewing our data.

Science Head Offices

Americas

Philadelphia +1 800 336 4474
+1 215 386 0100

Europe, Middle East and Africa

London +44 20 7433 4000

Asia Pacific

Singapore +65 6775 5088
Tokyo +81 3 4589 3100

For a complete office list, visit:

ip-science.thomsonreuters.com/contact

ISSN: 205-7623

ISBN: 978-1-904431-35-0

1002026

Copyright © 2013 Thomson Reuters

ABOUT THE AUTHORS

Jonathan Adams is Director, Research Evaluation, for Thomson Reuters. He was a founding Director of Evidence Ltd, the UK specialist on research performance analysis and interpretation.

David Pendlebury, formerly Manager of Contract Research Services for Thomson Reuters, now serves as a Consultant on bibliometric analysis.

Bob Stembridge, formerly a Senior Patent Information Analyst at BP, is now an IP Analyst and Customer Relations Manager for Thomson Reuters.

ABOUT THOMSON REUTERS

Thomson Reuters is the world's leading source of intelligent information for businesses and professionals. We combine industry expertise with innovative technology to deliver critical information to leading decision makers in the financial and risk, legal, tax and accounting, intellectual property and science and media markets, powered by the world's most trusted news organization. With headquarters in New York and major operations in London and Eagan, Minnesota, Thomson Reuters employs approximately 60,000 people and operates in over 100 countries. For more information, go to thomsonreuters.com.



THOMSON REUTERS™