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# Catching-up or falling behind - Role of S&T in growth of emerging economies'

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**Catching-up or falling behind - Role of S&T in growth of emerging economies'**

## 1. Introduction

Brazil, Russia, India, China and South Africa - the BRICS countries or the emerging economies - have attracted the attention of researchers, policy makers and politicians in both developing and developed countries. This is because of two reasons – their robust growth in the last 10-15 years[1] and the likelihood of surpassing G6[2] countries in the next few decades. A 2001 report by Goldman Sachs (2001)[3] approximated that if things happen as per expectations, in less than 40 years, the BRICS economies together could be larger than the G6 in US dollar terms. By 2025 they could account for over half the size of the G6 and in 2050, of the current G6, only the US and Japan may be among the six largest economies in US dollar terms. This implies the BRICS countries are expected to become the engine of the world economy and new demand growth. This however raises a very pertinent question – if BRICS[4] are growing so fast and are likely to be become engine of growth – what are the drivers of their growth?

The theory of economic growth and its drivers is still evolving. The theory has looked the growth from two different aspects - the overall economic growth and its drivers, whereas the other looks into how a particular sector is driving the economy. For economy as a whole, since the 1980s, efforts have been focused on "endogenous growth" models, in which the process of technological innovation is modelled explicitly. The literature in this has identified several growth-promoting channels including education, role of income distributions, research and development (R&D) etc. In this context, it is important to note that among all the channels, the literature has found the role of R&D and innovation as pivotal.

An important class of endogenous growth model is based on the Schumpeterian idea of "creative destruction". This group of models yields some testable positions where the long-run rate of growth will increase with - a) R&D productivity; b) the flow of patents, c) the rate of new firm creation, d) the rate of exit of firms; e) the rate of obsolescence of capital (Tregenna, 2007). It can easily be seen that these factors are heavily oriented towards innovation as being the ultimate source of economic growth.

Thus, the acknowledgement that innovation, an outcome of effective science and technology (S&T) policy - is of vital importance to the development and growth of a nation is universal. Even for less developed countries, S&T is prerequisite for development (Bernardes and Albuquerque, 2003; Perez and Soete, 1988). Several reasons exist indicating why a strong S&T is needed for economic growth. A strong S&T implies that each of the three core components of

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[1] The data shows that these countries have grown at the rate of 6.23 in the last 10 years with China and India leading the pack with 9.8 and 7.2% growth following by Russia (6.9%), South Africa (4%) and Brazil (3.1%). These growth rates are much higher than the one achieved by OECD countries or the rest of the world.

[2] G6 refers to a group of six countries namely the U.S.A, Japan, the U.K., Germany, France and Italy.

[3] Dreaming with BRICs: The Path to 2050, Global Economics P*aper No: 99* (www2.goldmansachs.com/ideas/brics/book/99-dreaming.pdf accessed in Jan. 2009).

[4] It is to be noted the original term, as coined by Goldman Sachs was BRIC (not the BRICS) and South Africa was not part of the group. Later on policy makers started counting South Africa also, thereby changing BRIC to BRICS. For our study we include South Africa also.

S&T – basic research, applied research and research labs[5] – to perform distinct functions facilitating economic growth. The combined effect of these three is new products, new firms, new markets and hence economic growth.

However, S&T are distinct from commodity as they cannot just be imported from elsewhere. Rather it requires sustained efforts from the policy makers if a nation wants to get benefit of S&T. According to a recent report by Inter-Academy Council (IAC, 2005), there are three crucial aspects of S&T, whose fulfilment is essential if a country wants to enjoy the full benefits of S&T. These are: a) policy for S&T: a national commitment, by both the public and private sectors, to promote science and technology; b) S&T for policy: a mechanism for providing S&T inputs into decision-making; and c) dissemination of knowledge: procedures for broad public participation in critical issues, especially regarding their S&T aspects.

Under this backdrop, this paper looks into what has caused the growth of the BRICS countries or in other words, what role S&T has played in the growth of BRICS countries. The organization of remaining paper is as follows. Section 2 gives evidence on impact of investment in S&T and economic growth. Section 3 gives the methodology adopted to see the impact of S&T on economic growth of BRICS countries. This is followed by the data used for the analysis in section 4. Section 5 gives the results with conclusion in Section 6.

## 2. Investment in S&T and Economic Growth - evidence

The present section gives evidence on how knowledge or focus on Science and Technology (S&T) can lead to increased growth and be at the core of any country's development process. There are two key components of S&T – investment in human capital (primary, secondary and tertiary education) and investment in R&D. Successful economies, such as those of the 'East Asian Tigers,' have achieved high growth in the recent 3-4 decades much by focusing on education and investing in R&D.[6] The figures from South Korea (2.55 percent), Taiwan-China (1.97 percent), and Singapore (1.47 percent) are testimony to this.[7]

With respect to investment in R&D several issues often crop up. How much should countries invest in R&D? In which sectors countries should invest? What should be the role of private sector? These issues attain high importance given the fact that there are many competing claims on scarce public resources.

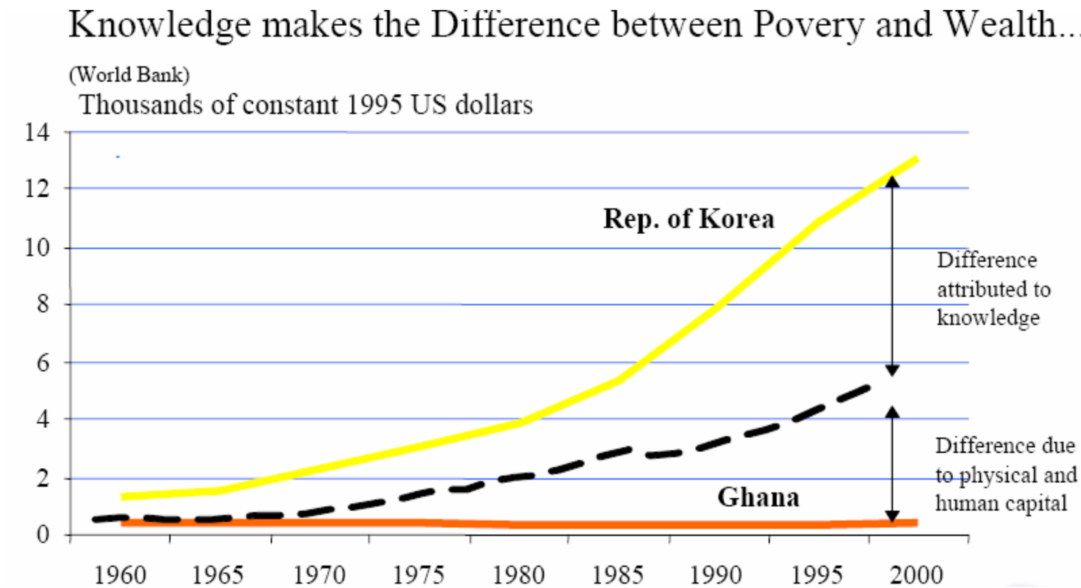
How S&T can be at the core of development process is vividly illustrated in the following Figure 1 for the Ghana and the Republic of Korea. In 1960 the per capita income of Korea and Ghana were the same. However, by 2000 Korea's per capita income has increased by a factor of

[5] Basic research produces new knowledge and major breakthroughs. Applied research, on the other hand, develops new applications for existing knowledge. Research labs train human resources to be used for basic and applied research.

[6] R&D investments here include all expenditures within a country for basic, strategic, applied, and adaptive research, and development of new products and services - from all sources, including governmental and nongovernmental organizations and for-profit companies, for both nondefense and defense purposes.

[7] Source: National Science Board, Science and Engineering Indicators 2002 (Arlington, VA: National Science Foundation, 2002) (accessible at www.nsf.gov/sbe/srs/seind02).

nearly 9 in real terms, while for Ghana, it has decreased almost by 0.1 (World Bank, 2000). It has been estimated that more than half of the difference can be attributed to Korea's success in acquiring and using knowledge (Figure 1).




**Original Source: World Bank, K4D program**

**Figure 1: Impact on Knowledge on economic growth – Korea vs. Ghana**

With respect to the benefits of R&D, studies have argued that it is not easy to demonstrate a direct causation between the R&D investment[8] and outcomes in terms of increased GDP, though a growing level of investment in R&D is generally correlated with improved GDP-growth outcomes (IAC, 2005). Apart from this, many a times the social returns to R&D are more than the private returns making it difficult to quantify the exact benefits. Table 1 gives the estimated returns on R&D investment as found by different researchers. The table indicates that against a private return of the range of 7-43, the social returns are at least three times higher (11-147 per cent).

**Table 1: Estimated Rates of Return on investment in R&D**

| **Author (year)** | **Estimated Rates of Return (%)** | |
|---|---|---|
| | **Private** | **Social** |
| **Nadiri (1993)** | 20-30 | 50 |
| **Mansfield (1977)** | 25 | 56 |
| **Terleckyj (1974)** | 29 | 48 – 78 |
| **Sveikauskas (1981)** | 7-25 | 50 |
| **Goto-Suzuki (1989)** | 26 | 80 |
| **Bernstein-Nadiri (1988)** | 10 – 27 | 11 – 111 |
| **Scherer (1982, 1984)** | 29-43 | 64-147 |
| **Bernstein-Nadiri (1991)** | 15-28 | 20-110 |
| ***Total Range*** | ***7-43*** | ***11-147*** |

Source: Griffiths, 2005

For R&D as a whole at a country level, it is seen that most OECD countries – Australia, Canada, Japan, South Korea, the United States, and northern and western Europe – all spend between 1.5

per cent to 3.8 per cent of their GDP on R&D, whereas the countries of Eastern Europe tend to have R&D/GDP ratios of less than 1.5 percent. The South Asian and African countries devote less than 0.5 percent of their GDP to R&D.[810] It is to be noted that countries making heavy investment in R&D also have strong high-technology industrial and service sectors. And it is noteworthy that the private sector finances most of the research in these countries.[9] In fact, as countries grow, the contribution of private sector increases as is evident in case of Korea. In Korea, the S&T capacity moved towards corporates with their share going from 13 per cent to 76 per cent in three decades as given in following table.

**Table 2: Shift of S&T capacity from government towards industry**

| | 1970 | 1975 | 1980 | 1985 | 1990 | 2001 |
|---|---|---|---|---|---|---|
| **Public Institutes** | 84 | 66 | 49 | 24 | 22 | 13 |
| **Universities** | 4 | 5 | 12 | 10 | 7 | 10 |
| **Corporates** | 13 | 29 | 38 | 65 | 71 | 76 |
| **Total** | 100 | 100 | 100 | 100 | 100 | 100 |

Source: Griffiths, 2005

Thus, the lower the per capita income of a country, the greater tends to be the role of government in funding R&D. With severe competitive pressures for limited government budgets, the result is modest overall spending for R&D and relatively low R&D/GDP ratios.

It is heartening to note that BRICS economies have already approached the lower-end R&D/GDP ratios of OECD countries. For example, India allocates 1.2 percent; Brazil, 0.91 percent; and China, 0.69 percent) to R&D.[10]

Thus, a strong S&T capacity translates into accelerated industrial and economic development in what can be termed a positive spiral of mutual reinforcement. S&T has also been the prime-mover of US economy for the last 5 decades (Griffiths, 2005). Emphasis on S&T has led to discovery of transistors, semi-conductors, software, biotech among others. Not only emphasis has led to discovery, even some of the key players in different areas are offshoot of University research. These include Intel, Hewlett Packard, Microsoft, Genentech among others.

[8] U.S. National Science Board, Science and Engineering Indicators 2002 (Arlington, Virginia: National Science Foundation, 2002), text table 4-13, pg. 4-47 (accessible at www.nsf.gov/sbe/srs/seind02); United Nations Development Programme, Human Development Report 2003 (New York, NY: UNDP, 2003)) (accessible at www.undp.org/hdr2003).

[9] The Commission of the European Communities has agreed to set a goal of R&D funding at 3 percent of EU GDP by 2010, of which two-thirds would be funded by the private sector; see Commission of the European Communities, 'Investing in Research, An Action Plan for Europe,' communications from the Commission, April 30, 2003; Brussels, Belgium, 2003 (accessible at http://europa.eu.int/eur-lex/en/com/cnc/2003/com2003_0226en02.pdf).

[10] Same as 7.

## 3. Methodology[11]

The literature on economics of technology has evolved in the past from linear role of S&T to growth to inverted model[12] to interactive model. The first model was suggested by Schumpeter (1911) where innovation pushes economic development. However, Roseberg (1982, 1990) using examples from developed countries emphasized the role of science for innovation and suggested an interactive approach. The nineties saw the works of Freeman (1995), Nelson and Rosenberg (1993) highlighting the institutional division of labour between different components of innovation system – facilitating growth. Lastly, the works of Pavitt (1991), Klevorick et al. (1995), Narin et al. (1997), Freeman and Soete (1997), Bernardes and Albuqerque (2003) among others investigated the specific roles of science, technology, and their interactions, for industrial and economic development.

All these models highlight the relevance of S&T in growth, though their importance and interactions differs depending on the level of development (Bernardes and Albuqerque, 2003). In the case of developed countries, which already have scientific and technological capabilities, there are interactions and mutual feedbacks between the two. For middle income countries, which are trying to catch-up, the science plays two way roles: source of absorptive capability and provider of public knowledge for the productive sector. On the other hand, less developed or developing countries are caught in a "low-growth trap" given, their low levels of scientific production.

Using data on paper publications and patents generated, Bernardes and Albuqerque (2003) have argued that countries can be grouped in three States. State I are those countries for which scientific production is so low that it does not result in technological production.[13] The end result is countries in a 'low growth trap'. For these countries, it is 'other' factors such as cheap labour, availability of natural resources, demographic factors, etc. that are key for growth.

In State III are those countries, where scientific production, technological output and growth are in interactive mode. A high significant scientific production yields to greater technological output and economic growth, which in turn leads to more scientific production and technological output. Thus, there is a mutual feedback between scientific production, technological output and growth (Fagerberg, 1994; Dosi *et al.*, 1994). In State III if these interactions are well-functioning, the role of 'other' factors becomes minimal.

In between these two extremes, there can be a group of countries which are striving to come out of this 'low growth trap' to 'catch-up with the leaders'. For this group of countries – State II – the growth is caused by two channels. Scientific production may be inducing more technological output leading to economic growth. Apart from spurring growth indirectly through technological output, scientific production also directly affects the growth. However, reverse causality may not

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[11] This section builds on Bernardes and Albuqerque (2003)

[12] An inverted model suggests that first economic growth takes place, which ensures resources available for technological development and finally, the growth of scientific institutions.

[13] For instance in 1998, there were 30 countries with publications (scientific production) but no patents Bernardes and Albuqerque (2003).

be true for countries in State II. Figure 2 gives the three possible States. As can be seen from the figure, as a country grows, its economic growth is more caused by its scientific and technological resources and their interactions and less by the 'other' factors.

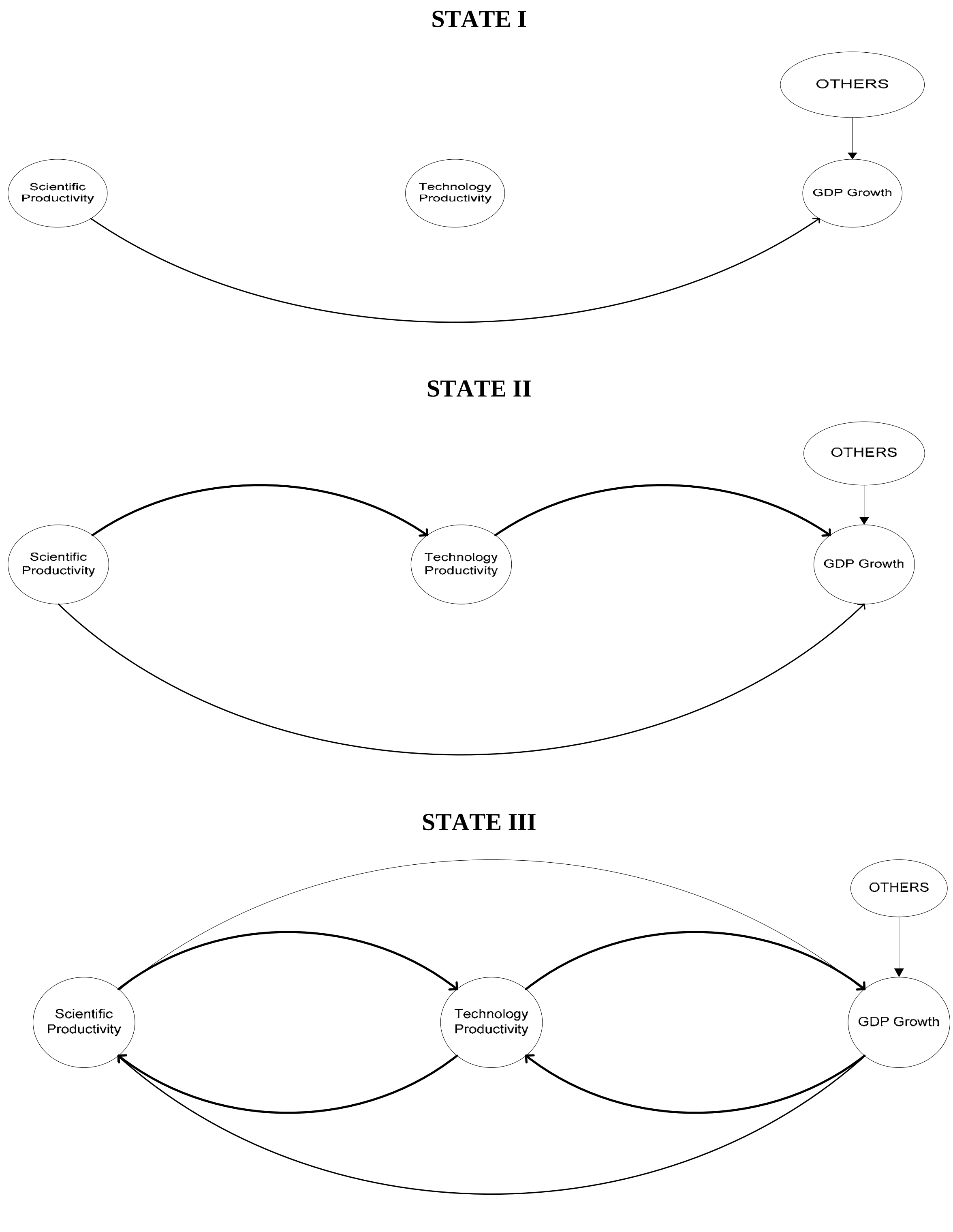



**Figure 2: Three different States depending on interaction between scientific production, technological output and growth**

Having described the three possible States, our take is that for such high growth of BRICS countries in the recent past, this would not have been possible if they are not in State III or at least nearing it. This however can be tested using technique from time-series. One way to address this is using technique proposed by Granger (1969) and popularized by Sims (1972). Testing causality, in the Granger sense, involves using *F*-tests to test whether lagged information on a variable *Y* provides any statistically significant information about a variable *X* in the presence of lagged *X*. If not, then "*Y* does not Granger-cause *X*." Thus, Granger Causality can test the statistical causality between science and technology during the growth process.

A variable *y* is said to Granger-cause a variable *x* if, given the past values of *x*, past values of *y* are useful for predicting *x*. A common method for testing Granger causality is to regress *x* on its own lagged values and on lagged values of *y* and test the null hypothesis that the estimated coefficients on the lagged values of *y* are jointly zero. Failure to reject the null hypothesis is equivalent to failing to reject the hypothesis that *y* does not Granger-cause *x*.

More formally, assume a particular autoregressive lag length *p*, and estimate the following unrestricted equation by ordinary least squares (OLS):

$$x_t = c_1 + \sum_{i=1}^{p} \alpha_i x_{t-i} + \sum_{i=1}^{p} \beta_i y_{t-i} + u_t$$

$$H_0: \beta_1 = \beta_2 = \ldots = \beta_p = 0$$

Conduct an *F*-test of the null hypothesis by estimating the following restricted equation also by OLS:

$$x_t = c_t + \sum_{i=1}^{p} \gamma_i x_{t-i} + e_t$$

Compare their respective sum of squared residuals.

$$RSS_1 = \sum_{t=1}^{T} \hat{u}_t^2 \qquad RSS_0 = \sum_{t=1}^{T} \hat{e}_t^2$$

If the test statistic

$$S_1 = \frac{(RSS_0 - RSS_1)/p}{RSS_1/(T-2p-1)} \sim F_{p,\,T-2p-1}$$

is greater than the specified critical value, then reject the null hypothesis that *Y* does not Granger-cause *X*. It is worth noting that with lagged dependent variables, as in Granger-causality regressions, the test is valid only asymptotically. An asymptotically equivalent test is given by

$$S_1 = \frac{T(RSS_0 - RSS_1)}{RSS_1} \sim \chi^2(p)$$

Another caveat is that Granger-causality tests are very sensitive to the choice of lag length and to the methods employed in dealing with any non-stationarity of the time series.

Thus, if our results show that scientific production Granger-causes technological output and economic growth and vice versa, then we can say that for BRICS countries mutual feedback is not only working but also acting as the driver of their growth. Depending upon the causality, the Granger causality test also facilitate us to see whether linear or inverted or interactive model fits to BRICS countries.

## 4. Data

In order to see whether linear or inverted linear or interactive model fits well for the BRICS countries, we require data on economic growth, publications (indicator of scientific production) and patents (an indicator of technological output). For the purpose, we have taken data about GNP per capita (US$, PPP, according to the World Bank, at constant prices), patents (for the period 1976 to 2007, according to the USPTO, 2008),[14] and scientific papers (for the period 1976 to 2007, according to the Institute for Scientific Information (ISI), 2008)[15] for the BRICS countries. The economic data for the BRICS is taken from the World Development Indicators from the World Bank website.[16]

It is well acknowledged that papers are not a perfect measure of scientific production, and patents are not a perfect measure of technological innovation. The literature has both used these data and warned about their problems, limitations and shortcomings.

Scientific papers, as collected by the ISI, have several shortcomings (refer Patel and Pavitt, 1995; Velho, 1987 for these limitations). These include from language bias to the quality of research performed. Since the coverage of ISI database is of international journals, many of the problems of BRICS or for that matter any country are local, the research may not translate in international papers, but only in national publications not captured by the IS1 database. Paper citations though is a better indicator reflecting quality of scientific input, we however, could not get access to the citations.

Patents are obtained from the USPTO data, which also have important shortcomings (refer Griliches, 1990; Patel and Pavitt, 1995 for a discussion on these shortcomings). Some of the problems with using patents data include the necessity of commercial linkages with the US for the patent, the quality of the patent, among others. Many of the local innovations are imitations or minor adaptations in the initial phases of development. These imitations or minor adaptations do not qualify for a patent in the USPTO. Similarly, many firms for want of secrecy do not go for patenting, thereby under-representing the activity.

We are aware of these important limitations. While interpreting the results these limitations need to be kept in mind. Despite these problems, these two datasets appear to be useful and can

[14] The data source for patents is www.uspto.gov.

[15] The data source of publications is www.isiknowledge.com.

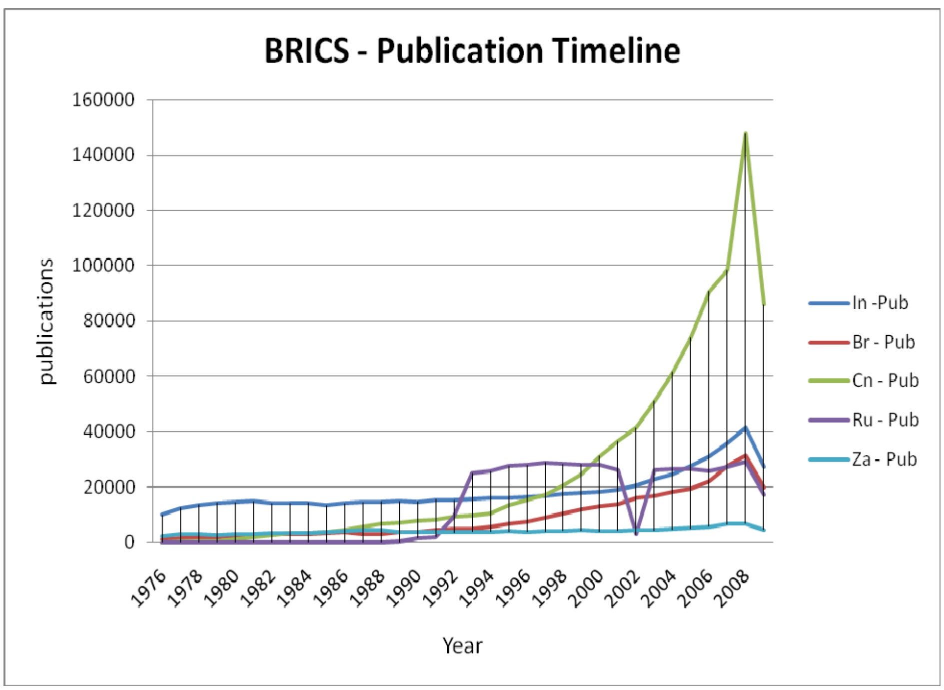
[16] Source: http://ddp-ext.worldbank.org/ext/DDPQQ/member.do?method=getMembers&userid=1&queryId=135.

address the research question posed. Table 3 gives the average values of GDP per capita, patents generated per 10,000 population and number of publications per 10,000 population for BRICS countries.

**Table 3: Average values of GDP per capita, scientific and technological output over 32 years period (1976 to 2007)**

| | Brazil | Russia | India | China | South Africa |
|---|---|---|---|---|---|
| **GDP per Capita (PPP)** | 3073.69 (1408.64) | 3417.10 (1996.44) | 399.16 (189.66) | 651.09 (591.41) | 3231.62 (1021.54) |
| **Patents per 10,000 population** | 0.49 (0.29) | 1.35 (0.84) | 0.14 (0.19) | 0.21 (0.36) | 3.16 (0.44) |
| **Publications per 10,000 population** | 46.42 (35.45) | 157.96 (61.28) | 19.60 (3.36) | 16.35 (20.40) | 105.79 (12.60) |
| **N** | 32 | 17 | 32 | 32 | 32 |

From the table, it can be seen that Brazil, Russia and South Africa are middle income countries and have high scientific and technological output per 10,000 population vis-à-vis China and India, which are still low income countries. Though scientific and technological output of China and India is higher than that of other three countries (Figures 3 and 4), their high population is making them look behind.




*Notes*: In – India, Br – Brazil, Cn – China, Ru – Russia, Za – South Africa. Before 1991, ISI did not have information about publications from Russia as it was collating information from erstwhile USSR.

**Figure 3: Publications from BRICS countries as given in ISI (1976 to 2009)**

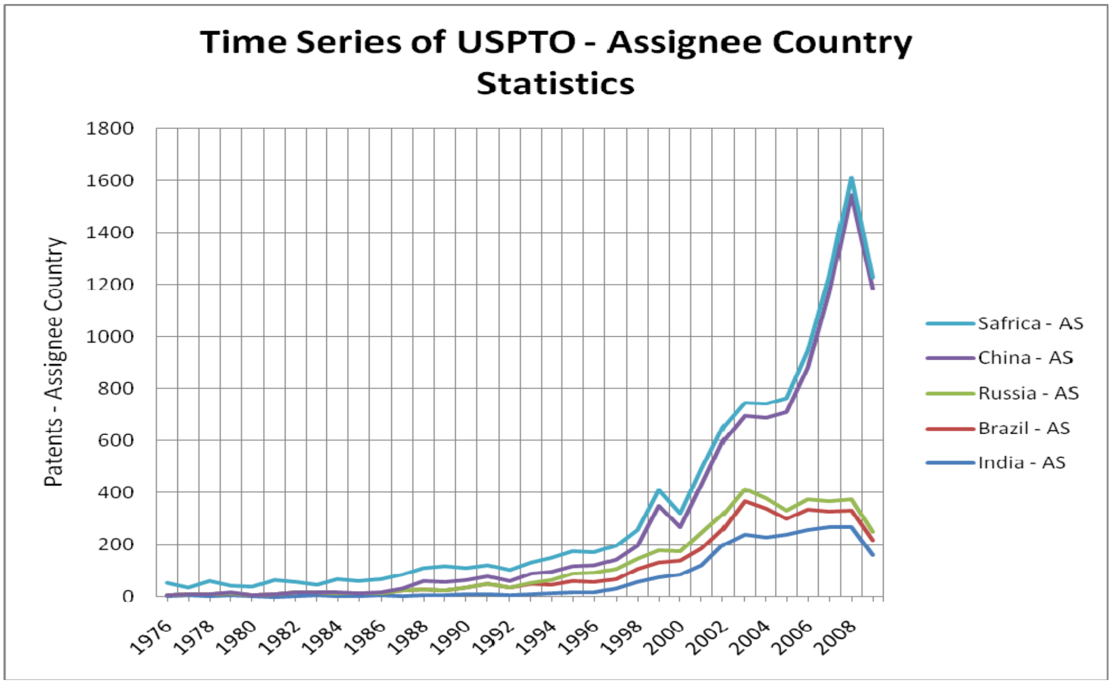



**Figure 4a: Patents at USPTO – Assignee Country Statistics**

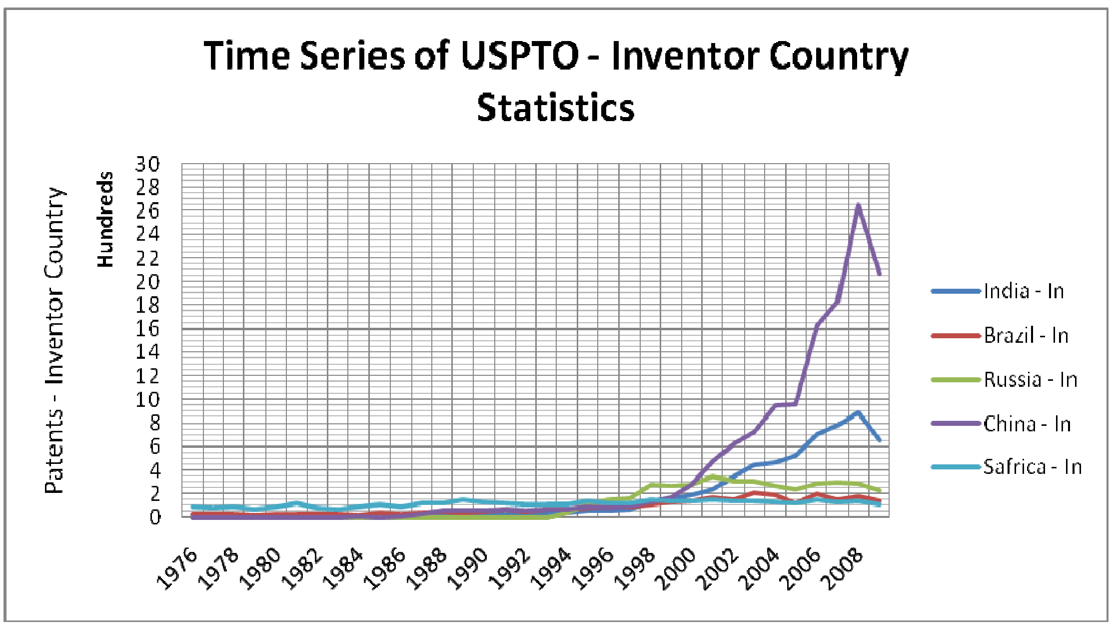



**Figure 4b: Patents at USPTO – Inventor Country Statistics**

*Notes*: i) In' refers to inventor nation and 'AS' refers to Assignee nation. The separate data was taken to understand how much of the patent system is being used by BRICS based firms. Inventor nation refers to the domicile of the inventor and Assignee refers to the domicile of the final ownership of the patent. ii) Before 1991, patents were granted to USSR as a whole and not to Russia – hence the data shows zero values for the Russia before 1991.

Starting with the lower base, the growth of China and India is far more than that of Brazil, Russia and South Africa as indicated in Table 4. The last row gives the growth rates of BRICS countries in the last 10 years.

**Table 4: Average Growth rates of BRICS (1976-2007)**

| Period | Brazil | Russia | India | China | South Africa |
|---|---|---|---|---|---|
| **1976-1980** | 6.7 | na | 3.2 | 6.6 | 3.1 |
| **1981-1985** | 1.2 | na | 5.2 | 10.8 | 1.4 |
| **1986-1990** | 2.1 | na | 6.0 | 7.9 | 1.7 |
| **1991-1995** | 3.1 | -9.0 | 5.1 | 12.3 | 0.9 |
| **1996-2000** | 2.0 | 1.8 | 5.8 | 8.6 | 2.8 |
| **2001-2007** | 3.3 | 6.6 | 7.7 | 10.4 | 4.3 |
| **Av. Last 10 years** | ***3.08*** | ***6.96*** | ***7.24*** | ***9.83*** | ***4.05*** |

*Note*: na – not available

## 5. Results

Before discussing the results, we would like to mention two caveats apart from the ones indicated in previous section. For Russia, USPTO and ISI database reports figures for patents and publications only after 1991, thereby having only 17 years of data. As a result, we could not carry out analysis for Russia. Secondly, since for all other four countries we had data for 32 years (1976 to 2007), we restricted our analysis to four lags only. Though results are sensitive to the lags, testing of causality with any further lag would have reduced the degrees of freedom.

Tables 5a to 5c give Granger causality results for Brazil for each of the three possible interactions – economic growth leading to more scientific output and vice versa, economic growth leading to more technological output and vice versa and lastly, scientific output causing more technological production and vice versa. For the remaining three nations (India, China and South Africa), the results are given in Appendix (Tables 1a to 3c).

**Table 5a: Granger Causality Tests for Brazil**

| **Part 1: Did the patents output lead to Economic Growth?** | | | |
|---|---|---|---|
| $GDPpcap_t = {}_{i=1}\Sigma^L \alpha_i GDPpcap_{t-1} + {}_{i=1}\Sigma^L \beta_i Patentpcap_{t-1} + \varepsilon_t$ | | | |
| $H_o$: $\beta_1 = \ldots\ldots \beta_L = 0$ (Patents output do not Granger cause Economic Growth) | | | |
| **L= no. of lags** | **F-statistic** | **P-value** | **$R^2$** |
| **1** | 1.53 | 0.226 | 0.84 |
| **2** | 2.5 | 0.102 | 0.88 |
| **3** | 2.56 | 0.0808 | 0.89 |
| **4** | 3.07 | .0417 | 0.91 |

| **Part 2: Did the economic growth lead to Patents Output?** | | | |
|---|---|---|---|
| $Patentpcap_t = {}_{i=1}\Sigma^L \alpha_i Patentpcap_{t-1} + {}_{i=1}\Sigma^L \beta_i GDPpcap_{t-1} + \varepsilon_t$ | | | |
| $H_o$: $\beta_1 = \ldots\ldots \beta_L = 0$ (Economic Growth do not Granger cause Patents output) | | | |
| **L= no. of lags** | **F-statistic** | **P-value** | **$R^2$** |
| **1** | 2.6 | 0.1178 | 0.77 |
| **2** | 1.7 | 0.2027 | 0.84 |
| **3** | 5.99 | .0038 | 0.91 |
| **4** | 3 | .0048 | 0.91 |

**Table 5b: Granger Causality Tests for Brazil**

| Part 1: Did the scientific output lead to Economic Growth? | | | |
|---|---|---|---|
| $GDPpcap_t = {}_{i=1}\Sigma^L \alpha_i GDPpcap_{t-1} + {}_{i=1}\Sigma^L \beta_i Publicpcap_{t-1} + \varepsilon_t$ | | | |
| $H_o$: $\beta_1 = \ldots.. \beta_L = 0$ (Patents output do not Granger cause Economic Growth) | | | |
| **L= no. of lags** | **F-statistic** | **P-value** | **$R^2$** |
| **1** | 2.91 | .0988 | 0.85 |
| **2** | 2.68 | .0883 | 0.88 |
| **3** | 5.04 | .0083 | 0.92 |
| **4** | 3.45 | .0280 | 0.92 |

| Part 2: Did the economic growth lead to Scientific Output? | | | |
|---|---|---|---|
| $Publicpcap_t = {}_{i=1}\Sigma^L \alpha_i Publicpcap_{t-1} + {}_{i=1}\Sigma^L \beta_i GDPpcap_{t-1} + \varepsilon_t$ | | | |
| $H_o$: $\beta_1 = \ldots.. \beta_L = 0$ (Economic Growth do not Granger cause Patents output) | | | |
| **L= no. of lags** | **F-statistic** | **P-value** | **$R^2$** |
| **1** | 6.19 | .0191 | 0.99 |
| **2** | 3.22 | .0569 | 0.99 |
| **3** | 5.56 | .0054 | 0.99 |
| **4** | 3.89 | .0180 | 0.91 |

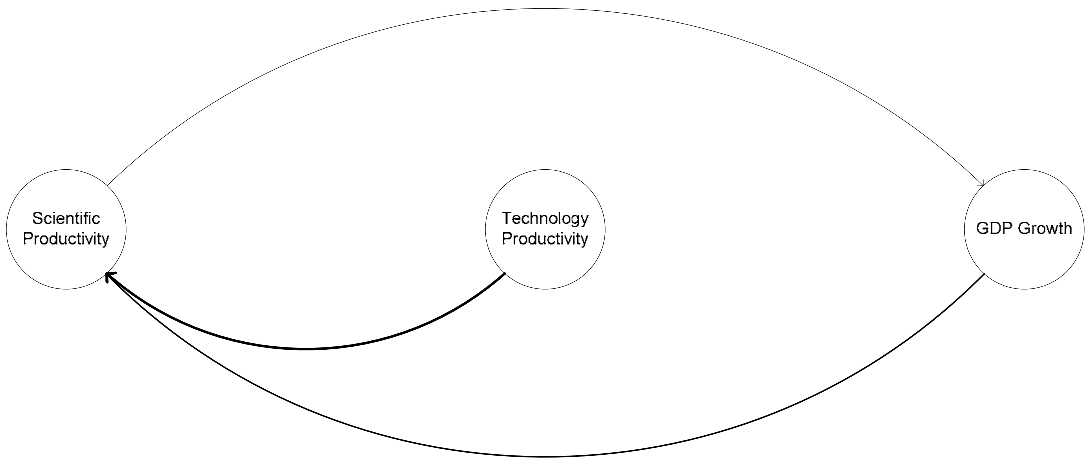
**Table 5c: Granger Causality Tests for Brazil**

| Part 1: Did the scientific output lead to Technological Output? | | | |
|---|---|---|---|
| $Patentpcap_t = {}_{i=1}\Sigma^L \alpha_i Patentpcap_{t-1} + {}_{i=1}\Sigma^L \beta_i Publicpcap_{t-1} + \varepsilon_t$ | | | |
| $H_o$: $\beta_1 = \ldots.. \beta_L = 0$ (Patents output do not Granger cause Economic Growth) | | | |
| **L= no. of lags** | **F-statistic** | **P-value** | **$R^2$** |
| **1** | 11.65 | .002 | 0.82 |
| **2** | 1.69 | 0.2051 | 0.84 |
| **3** | 1.83 | 0.1714 | 0.86 |
| **4** | 2.59 | .0696 | 0.90 |

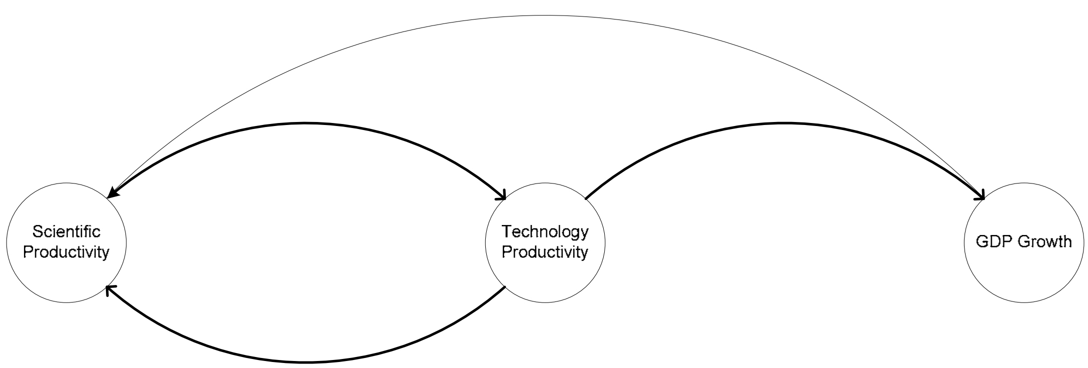
| Part 2: Did the technological output lead to Scientific Output? | | | |
|---|---|---|---|
| $Publicpcap_t = {}_{i=1}\Sigma^L \alpha_i Publicpcap_{t-1} + {}_{i=1}\Sigma^L \beta_i Patentpcap_{t-1} + \varepsilon_t$ | | | |
| $H_o$: $\beta_1 = \ldots.. \beta_L = 0$ (Economic Growth do not Granger cause Patents output) | | | |
| **L= no. of lags** | **F-statistic** | **P-value** | **$R^2$** |
| **1** | 0.02 | 0.8864 | 0.99 |
| **2** | 10.42 | 0.0005 | 0.99 |
| **3** | 8.94 | 0.0005 | 0.99 |
| **4** | 11.79 | 0.0001 | 0.996 |

Interesting differences emerge when we see the Granger causality results. Figure 5 plots the interactions between scientific output, technological output and economic growth for each of the four BICS countries based on the results. It can be seen that for Brazil, technological production is Granger causing Scientific output. Other interactions are not working. This result is different than what Rappini (2000) found earlier in the case of Brazil, where scientific production Granger causes technological production.

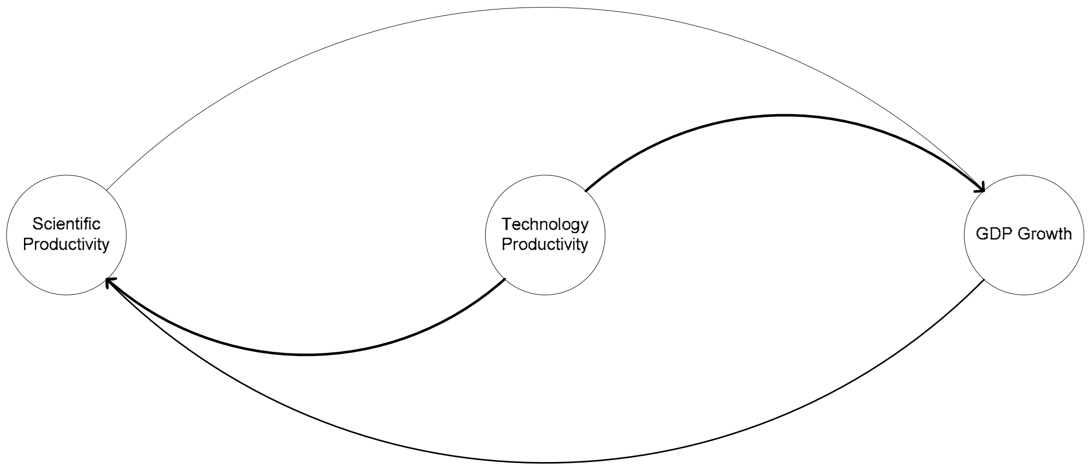
For China and India, results indicate that most of the interactions are working. Perhaps that may be the reason that these two countries have done better in terms of growth and scientific and technological outputs than their counterparts in BRICS. For China GDP growth causing technological output is not working. For India, apart from this, the link between technological output to scientific output is yet to become active. Surprisingly, for South Africa most interactions are not working. There is no link between its scientific output and technological output. There is only linear relation between technological output and GDP growth.



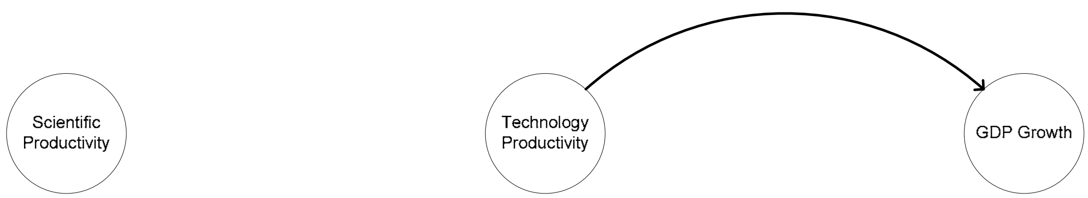

BRAZIL




CHINA




INDIA




SOUTH AFRICA

**Figure 5: Interactions between Scientific Output, technological output and growth – based on Granger Causality results**

Based on the Granger causality results, we can say that the driver for growth for all the four BICS countries is different. Not all countries are having interactive model of growth where scientific output affecting technological output and economic growth and vice versa. For South Africa it is a linear model, whereas for China and India, they are closer to interactive model. For Brazil, the growth is primarily coming from its scientific output.

## 6. Conclusions

Brazil, Russia, India, China and South Africa - the BRICS countries or the emerging economies - have attracted the attention of researchers, policy makers and politicians in both developing and developed countries. This is because of two reasons – their robust growth in the last 10-15 years and the likelihood of surpassing G6 countries in the next few decades. This paper looks into what role science and technology has played in the growth of BRICS countries.

This is tested using technique proposed by Granger (1969) and popularized by Sims (1972) – Granger causality tests. The technique also facilitates to see whether science and technology have linear influence on economic growth or through interactions they are affecting growth. In order to see whether linear or inverted linear or interactive model fits well for the BRICS countries, we used data on economic growth, publications (indicator of scientific production) and patents (an indicator of technological output) for the period 1976 to 2007.

Based on the Granger causality results, we find that the driver for growth for all the four BICS countries is different. Not all countries are having interactive model of growth where scientific output affecting technological output and economic growth and vice versa. For South Africa it is a linear model, whereas for China and India, they are closer to interactive model. For Brazil, the growth is primarily coming from its scientific output.

Why performance of Brazil and South Africa is different than China and India? It has been argued that in most Latin American countries the focus was only on R&D investment with less emphasis on innovation. On the other hand, recent history of Asian Tigers (Korea, Taiwan and Singapore) shows that it is both - investment in R&D and innovation that can pull a country from relative poverty to relative prosperity.

Given the results, it can easily be concluded that unless Brazil and South Africa invest in both R&D and innovation, China and India would leave them far behind – not only in growth but also in science and technology output. Even their catching-up with the other developed countries would not materialize. Though for India and China interaction between science and technology is growing fast, a full fledged interactive model with greater emphasis on growth would still require shifting of S&T capacity from government towards industry and academia, as the latter two categories would have greater returns.

## References


Bernardes A.T., Albuquerque E., 2003. Cross-over, thresholds, and interactions between science and technology: lessons for less-developed countries. *Research Policy* 32 (2003) 865-885

Dosi, G., et al., 1994. The process of economic development: introducing some stylised facts and theories on technologies, firms and institutions. *Industrial and Corporate Change* 3 (1).

Fagerberg, J., 1994. Technology and international differences in growth rates. *Journal of Economic Literature* 32 (September).

Freeman, C., 1995. The "national system of innovation" in historical perspective. *Cambridge Journal of Economics* 19, 1.

Freeman, C., Soete, L., 1997. *The Economics of Industrial Innovation*. Pinter Publishers, London.

Griffiths, P., 2005. Science, Technology, Innovation and Growth, http://sites.ias.edu/sig/system/files/ pdfs/Kaz_talk_VE8.pdf

Griliches, Z., 1990. Patent statistics as economic indicators: a survey. *Journal of Economic Literature* 28 (December).

http://portal.saude.gov.br/portal/arquivos/pdf/apresglobalforumingles.pdf R&D and Innovation in Health

http://www.colciencias.gov.co/portalcol/downloads/archivosContenido/658.pdf Evolution of Korean Innovation System.

http://www.globelics2005africa.org.za/papers/p0050/Globelics2005_Interactions-firms.pdf Interactions between firms and universities

IAC, 2005. http://www.interacademycouncil.net/Object.File/Master/6/731/Chapter%201.pdf different chapters

Klevorick, A., Levin, R., Nelson, R., Winter, S., 1995. On the sources and significance of inter-industry differences in technological opportunities. *Research Policy* 24, 185–205.

Narin, F., Hamilton, K.S., Olivastro, D., 1997. The increasing linkage between US technology and public science. *Research Policy* 26 (3), 317–330.

Nelson, R., Rosenberg, N., 1993. Technical innovation and national systems. In: Nelson, R. (Ed.), *National Innovation Systems: A Comparative Analysis*. Oxford University Press, Oxford, pp. 3–21.

Patel, P., Pavitt, K., 1995. Patterns of technological activity: their measurement and interpretation. In: Stoneman, P. (Ed.), *Handbook of the Economics of Innovation and Technological Change*. Blackwell, Oxford.

Pavitt, K., 1991. What makes basic research economically useful? *Research Policy* 20 (2), 109–119.

Perez, C., Soete, L., 1988. Catching up in technology: entry barriers and windows of opportunity. In: Dosi, G., Freeman, C., Nelson, R., et al. (Eds.), *Technical Change and Economic Theory*. Pinter Publishers, London, pp. 458–479.

Rosenberg, N., 1982. *Inside the Black Box: Technology and Economics*. Cambridge University Press, Cambridge.

Rosenberg, N., 1990. Why do firms do basic research (with their money)? *Research Policy* 19, 165–174.

Schumpeter, J., 1911. A Teoria do Desenvolvimento Econˆomico Nova Cultural, São Paulo, 1985.

Tregenna, F. (2007) Which sectors can be engines of growth and employment in South Africa? http://www.policyinnovations.org/ideas/policy_library/data/engines_of_growth_south_africa/_res/id=sa_File1/growth%20south%20africa.pdf

USPTO, 2009 (http://www.uspto.gov).

Velho, L., 1987. The author and the beholder: how paradigm commitments can influence the interpretation of research results. *Scientometrics* 11 (1/2), 59–70.

World Bank (2000) Knowledge For all, World Bank, Washington DC.

## Appendix Table 1a: Granger Causality Tests for India

**Part 1: Did the patents output lead to Economic Growth?**

$GDPpcap_t = \sum_{i=1}^{L} \alpha_i GDPpcap_{t-1} + \sum_{i=1}^{L} \beta_i Patentpcap_{t-1} + \varepsilon_t$

Ho: $\beta_1 = \ldots\ldots \beta_L = 0$ (Patents output do not Granger cause Economic Growth)

| L= no. of lags | F-statistic | P-value | $R^2$ |
|---|---|---|---|
| 1 | 21.93 | 0.0001 | 0.98 |
| 2 | 8.10 | 0.0019 | 0.98 |
| 3 | 5.17 | 0.0074 | 0.98 |
| 4 | 8.59 | .0004 | 0.99 |

**Part 2: Did the economic growth lead to Patents Output?**

$Patentpcap_t = \sum_{i=1}^{L} \alpha_i Patentpcap_{t-1} + \sum_{i=1}^{L} \beta_i GDPpcap_{t-1} + \varepsilon_t$

Ho: $\beta_1 = \ldots\ldots \beta_L = 0$ (Economic Growth do not Granger cause Patents output)

| L= no. of lags | F-statistic | P-value | $R^2$ |
|---|---|---|---|
| 1 | 2.82 | 0.104 | 0.98 |
| 2 | 1.61 | 0.2204 | 0.98 |
| 3 | 1.45 | 0.2545 | 0.99 |
| 4 | 0.76 | 0.566 | 0.99 |

## Appendix Table 1b: Granger Causality Tests for India

**Part 1: Did the scientific output lead to Economic Growth?**

$GDPpcap_t = \sum_{i=1}^{L} \alpha_i GDPpcap_{t-1} + \sum_{i=1}^{L} \beta_i Publicpcap_{t-1} + \varepsilon_t$

Ho: $\beta_1 = \ldots\ldots \beta_L = 0$ (Patents output do not Granger cause Economic Growth)

| L= no. of lags | F-statistic | P-value | $R^2$ |
|---|---|---|---|
| 1 | 10.01 | .0037 | 0.97 |
| 2 | 4.92 | .0158 | 0.98 |
| 3 | 3.45 | .0341 | 0.98 |
| 4 | 3.34 | .0313 | 0.98 |

**Part 2: Did the economic growth lead to Scientific Output?**

$Publicpcap_t = \sum_{i=1}^{L} \alpha_i Publicpcap_{t-1} + \sum_{i=1}^{L} \beta_i GDPpcap_{t-1} + \varepsilon_t$

Ho: $\beta_1 = \ldots\ldots \beta_L = 0$ (Economic Growth do not Granger cause Patents output)

| L= no. of lags | F-statistic | P-value | $R^2$ |
|---|---|---|---|
| 1 | 4.57 | .0413 | 0.90 |
| 2 | 11.87 | .0002 | 0.97 |
| 3 | 11.34 | .0001 | 0.98 |
| 4 | 7.36 | .0009 | 0.98 |

## Appendix Table 1c: Granger Causality Tests for India

**Part 1: Did the scientific output lead to Technological Output?**

$Patentpcap_t = \sum_{i=1}^{L} \alpha_i Patentpcap_{t-1} + \sum_{i=1}^{L} \beta_i Publicpcap_{t-1} + \varepsilon_t$

$H_o$: $\beta_1 = \ldots\ldots \beta_L = 0$ (Scientific Output do not Granger cause Technological Output)

| L= no. of lags | F-statistic | P-value | $R^2$ |
|---|---|---|---|
| 1 | 0.65 | 0.4276 | 0.98 |
| 2 | 0.63 | 0.5422 | 0.98 |
| 3 | 2.99 | 0.0529 | 0.99 |
| 4 | 1.43 | 0.2619 | 0.99 |

**Part 2: Did the technological output lead to Scientific Output?**

$Publicpcap_t = \sum_{i=1}^{L} \alpha_i Publicpcap_{t-1} + \sum_{i=1}^{L} \beta_i Patentpcap_{t-1} + \varepsilon_t$

$H_o$: $\beta_1 = \ldots\ldots \beta_L = 0$ (Technological Output do not Granger cause Scientific Output)

| L= no. of lags | F-statistic | P-value | $R^2$ |
|---|---|---|---|
| 1 | 19.96 | 0.0001 | 0.93 |
| 2 | 15.87 | 0.0000 | 0.98 |
| 3 | 12.58 | 0.0001 | 0.98 |
| 4 | 10.76 | 0.0001 | 0.99 |

## Appendix Table 2a: Granger Causality Tests for China

| Part 1: Did the patents output lead to Economic Growth? | | | |
|---|---|---|---|
| $GDPpcap_t = {}_{i=1}\Sigma^L \alpha_i GDPpcap_{t-1} + {}_{i=1}\Sigma^L \beta_i Patentpcap_{t-1} + \varepsilon_t$ | | | |
| Ho: $\beta_1 = \ldots\ldots \beta_L = 0$ (Patents output do not Granger cause Economic Growth) | | | |
| **L= no. of lags** | **F-statistic** | **P-value** | **$R^2$** |
| **1** | 11.97 | .0017 | 0.997 |
| **2** | 4.78 | 0.0174 | 0.998 |
| **3** | 3.84 | 0.0237 | 0.998 |
| **4** | 2.34 | 0.0916 | 0.998 |

| Part 2: Did the economic growth lead to Patents Output? | | | |
|---|---|---|---|
| $Patentpcap_t = {}_{i=1}\Sigma^L \alpha_i Patentpcap_{t-1} + {}_{i=1}\Sigma^L \beta_i GDPpcap_{t-1} + \varepsilon_t$ | | | |
| Ho: $\beta_1 = \ldots\ldots \beta_L = 0$ (Economic Growth do not Granger cause Patents output) | | | |
| **L= no. of lags** | **F-statistic** | **P-value** | **$R^2$** |
| **1** | 5.83 | 0.0225 | 0.96 |
| **2** | 1.71 | 0.2017 | 0.98 |
| **3** | 0.91 | 0.453 | 0.98 |
| **4** | 0.49 | 0.7438 | 0.98 |

## Appendix Table 2b: Granger Causality Tests for China

| Part 1: Did the scientific output lead to Economic Growth? | | | |
|---|---|---|---|
| $GDPpcap_t = {}_{i=1}\Sigma^L \alpha_i GDPpcap_{t-1} + {}_{i=1}\Sigma^L \beta_i Publicpcap_{t-1} + \varepsilon_t$ | | | |
| Ho: $\beta_1 = \ldots\ldots \beta_L = 0$ (Patents output do not Granger cause Economic Growth) | | | |
| **L= no. of lags** | **F-statistic** | **P-value** | **$R^2$** |
| **1** | 12.69 | 0.0013 | 0.997 |
| **2** | 5.95 | 0.0077 | 0.997 |
| **3** | 4.18 | 0.0175 | 0.998 |
| **4** | 2.99 | 0.0451 | 0.998 |

| Part 2: Did the economic growth lead to Scientific Output? | | | |
|---|---|---|---|
| $Publicpcap_t = {}_{i=1}\Sigma^L \alpha_i Publicpcap_{t-1} + {}_{i=1}\Sigma^L \beta_i GDPpcap_{t-1} + \varepsilon_t$ | | | |
| Ho: $\beta_1 = \ldots\ldots \beta_L = 0$ (Economic Growth do not Granger cause Patents output) | | | |
| **L= no. of lags** | **F-statistic** | **P-value** | **$R^2$** |
| **1** | 1.68 | 0.2053 | 0.995 |
| **2** | 1.57 | 0.2269 | 0.996 |
| **3** | 0.95 | 0.4352 | 0.996 |
| **4** | 1.26 | 0.3184 | 0.996 |

## Appendix Table 2c: Granger Causality Tests for China

| Part 1: Did the scientific output lead to Technological Output? | | | |
|---|---|---|---|
| $Patentpcap_t = {}_{i=1}\Sigma^L \alpha_i Patentpcap_{t-1} + {}_{i=1}\Sigma^L \beta_i Publicpcap_{t-1} + \varepsilon_t$ | | | |
| $H_o$: $\beta_1 = \ldots\ldots \beta_L = 0$ (Scientific Output do not Granger cause Technological Output) | | | |
| **L= no. of lags** | **F-statistic** | **P-value** | **$R^2$** |
| **1** | 16.63 | 0.0003 | 0.973 |
| **2** | 3.47 | 0.0469 | 0.982 |
| **3** | 2.43 | 0.0920 | 0.983 |
| **4** | 7.03 | 0.0012 | 0.993 |

| Part 2: Did the technological output lead to Scientific Output? | | | |
|---|---|---|---|
| $Publicpcap_t = {}_{i=1}\Sigma^L \alpha_i Publicpcap_{t-1} + {}_{i=1}\Sigma^L \beta_i Patentpcap_{t-1} + \varepsilon_t$ | | | |
| $H_o$: $\beta_1 = \ldots\ldots \beta_L = 0$ (Technological Output do not Granger cause Scientific Output) | | | |
| **L= no. of lags** | **F-statistic** | **P-value** | **$R^2$** |
| **1** | 11.21 | 0.0023 | 0.997 |
| **2** | 24.77 | 0.00 | 0.998 |
| **3** | 24.35 | 0.00 | 0.999 |
| **4** | 16.81 | 0.00 | 0.999 |

## Appendix Table 3a: Granger Causality Tests for South Africa

**Part 1: Did the patents output lead to Economic Growth?**

$GDPpcap_t = {}_{i=1}\Sigma^L\ \alpha_i GDPpcap_{t-1} +\ {}_{i=1}\Sigma^L\ \beta_i Patentpcap_{t-1} + \varepsilon_t$

Ho: $\beta_1 =$ ….. $\beta_L = 0$ (Patents output do not Granger cause Economic Growth)

| L= no. of lags | F-statistic | P-value | $R^2$ |
|---|---|---|---|
| **1** | 3.63 | 0.0671 | 0.84 |
| **2** | 2.97 | 0.0694 | 0.86 |
| **3** | 2.87 | 0.0598 | 0.86 |
| **4** | 1.88 | 0.155 | 0.86 |

**Part 2: Did the economic growth lead to Patents Output?**

$Patentpcap_t = {}_{i=1}\Sigma^L\ \alpha_i Patentpcap_{t-1} +\ {}_{i=1}\Sigma^L\ \beta_i GDPpcap_{t-1} + \varepsilon_t$

Ho: $\beta_1 =$ ….. $\beta_L = 0$ (Economic Growth do not Granger cause Patents output)

| L= no. of lags | F-statistic | P-value | $R^2$ |
|---|---|---|---|
| **1** | 0.2 | 0.6568 | 0.05 |
| **2** | 0.35 | 0.7062 | 0.07 |
| **3** | 0.23 | 0.8731 | 0.08 |
| **4** | 0.37 | 0.8252 | 0.15 |

## Appendix Table 3b: Granger Causality Tests for South Africa

**Part 1: Did the scientific output lead to Economic Growth?**

$GDPpcap_t = {}_{i=1}\Sigma^L\ \alpha_i GDPpcap_{t-1} +\ {}_{i=1}\Sigma^L\ \beta_i Publicpcap_{t-1} + \varepsilon_t$

Ho: $\beta_1 =$ ….. $\beta_L = 0$ (Patents output do not Granger cause Economic Growth)

| L= no. of lags | F-statistic | P-value | $R^2$ |
|---|---|---|---|
| **1** | 0.91 | 0.3489 | 0.82 |
| **2** | 1.09 | 0.3515 | 0.84 |
| **3** | 1.26 | 0.3130 | 0.84 |
| **4** | 0.8 | 0.5426 | 0.83 |

**Part 2: Did the economic growth lead to Scientific Output?**

$Publicpcap_t = {}_{i=1}\Sigma^L\ \alpha_i Publicpcap_{t-1} +\ {}_{i=1}\Sigma^L\ \beta_i GDPpcap_{t-1} + \varepsilon_t$

Ho: $\beta_1 =$ ….. $\beta_L = 0$ (Economic Growth do not Granger cause Patents output)

| L= no. of lags | F-statistic | P-value | $R^2$ |
|---|---|---|---|
| **1** | 0.24 | 0.6286 | 0.58 |
| **2** | 2.05 | 0.1492 | 0.75 |
| **3** | 0.79 | 0.5098 | 0.78 |
| **4** | 0.5 | 0.735 | 0.78 |

## Appendix Table 3c: Granger Causality Tests for South Africa

**Part 1: Did the scientific output lead to Technological Output?**

$Patentpcap_t = {}_{i=1}\Sigma^L\ \alpha_i Patentpcap_{t-1} +\ {}_{i=1}\Sigma^L\ \beta_i Publicpcap_{t-1} + \varepsilon_t$

$H_o$: $\beta_1 =$ ….. $\beta_L = 0$ (Scientific Output do not Granger cause Technological Output)

| L= no. of lags | F-statistic | P-value | $R^2$ |
|---|---|---|---|
| **1** | 1.61 | 0.2144 | 0.094 |
| **2** | 2.2 | 0.1319 | 0.18 |
| **3** | 5.18 | 0.0073 | 0.45 |
| **4** | 3.27 | 0.0336 | 0.46 |

**Part 2: Did the technological output lead to Scientific Output?**

$Publicpcap_t = {}_{i=1}\Sigma^L\ \alpha_i Publicpcap_{t-1} +\ {}_{i=1}\Sigma^L\ \beta_i Patentpcap_{t-1} + \varepsilon_t$

$H_o$: $\beta_1 =$ ….. $\beta_L = 0$ (Technological Output do not Granger cause Scientific Output)

| L= no. of lags | F-statistic | P-value | $R^2$ |
|---|---|---|---|
| **1** | 0.58 | 0.4521 | 0.58 |
| **2** | 4.57 | 0.0204 | 0.78 |
| **3** | 2.43 | 0.0922 | 0.82 |
| **4** | 1.94 | 0.1457 | 0.83 |