

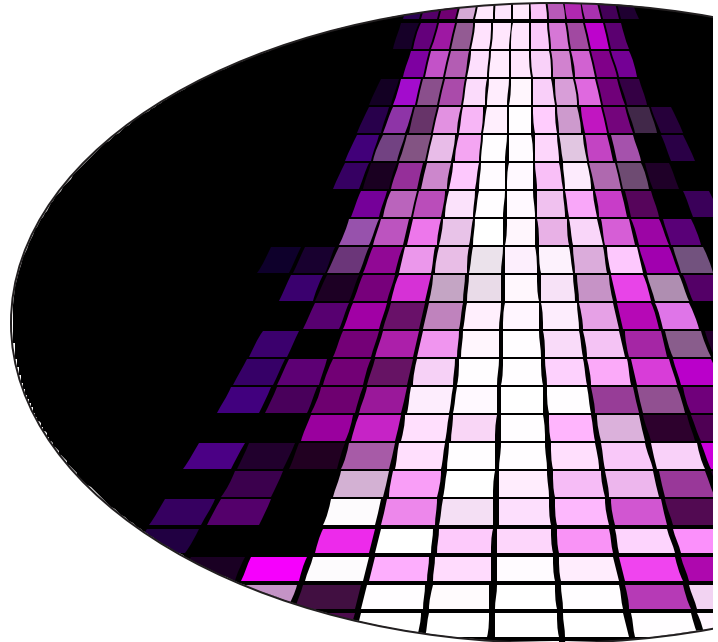
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**R&D Management Trends in the United States, India and China**

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# R&D Management Trends in the United States, India and China

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## Abstract

*This study researches the Management of Research and Development (R&D) in the emerging economies of India and China and compares theirs with R&D in the United States (US). The purpose of this research is to forecast the future of R&D in these three countries. Because R&D is changing rapidly, particularly in China, understanding where they will be in the future is of interest to the scientific, academic, government and business segments of each country. Our research consisted of gathering industry standard measures of R&D from 1996 through 2009. These measures are as follows: R&D spending as a percentage of GDP (total government, industry and universities), researchers per million inhabitants, number of patents granted each year, number publications each year and total number of graduates in all programs in thousands. We gathered and logged the metrics for each year from 1996 through 2009 and used the historical data to forecast future positioning of R&D in these countries. An overview of each country is provided in the introductory portion of this paper. This provides the context for the historical performance of R&D and for expected future performance of R&D in the US, India and China.*

**Keywords:** R&D, Research Progress, United States, China, India.

## INTRODUCTION

A country's R&D investments and outputs are key indicators of its commitment to science and technology. R&D investment is also a driving factor of a country's economic growth (Meng et al., 2006). This paper analyses R&D in the two leading emerging economies of China and India and compares them to R&D in the mature economy of the US.

R&D Management in the United States, India and China was analyzed by examining R&D in the primary segments of the government, universities and industries. R&D in each country was also analyzed for strengths, weaknesses, opportunities and threats (SWOT). This approach is based on industry standards obtained from numerous Web sites, such as R&D Magazine's analyses of China's R&D (R&D Magazine, 2009). R&D Magazine gathered these data from other sources such as OECD(OECD, 2010), further demonstrating the standard metrics we've used in this paper. Moreover, following the OECD model, Gross Domestic Expenditures on R&D (GERD) forms the basic unit of measurement.

With respect to government, laws, regulations and practices were researched. Important information includes the nature of the government's

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involvement in R&D in universities and industries. University research facilities are reviewed as to availability of research facilities and number of researchers. Universities are noted for level of collaboration with government and industry. R&D in industry and its level of collaboration with government and universities are also analyzed.

### **R&D SCENARIO IN THE UNITED STATES**

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R&D investment generally reflects on a government's or organization's effort to improve current and future performance in its ability to conduct research and development. According to Dooley (2008), the United States is one of the top eight spenders in terms of percentage of GDP. Most R&D activities are conducted by centers belonging to industries, universities and state agencies. Typically, US industrial companies spend about 3.5% of revenues in R&D, while high technology companies may spend 7%. This compares to pharmaceutical companies, such as Merck & Co. or European companies such as Novartis and Ericson that generally spend over 15% for R&D (BIS, 2010).

As a republic, the United States has continued to grow its R&D expenditures over the past century. According to the (National Science Board, 2010), the total R&D comes from industries, universities and federal support. As seen in Figure 1 below, industries have dominated the amount of R&D spending since the space age years (1960s). Computer and electronic products, manufacturing and industrial R&D constitute 70 percent of the national total. The remainder of R&D exists at universities, colleges, nonprofit organizations and federal agencies.

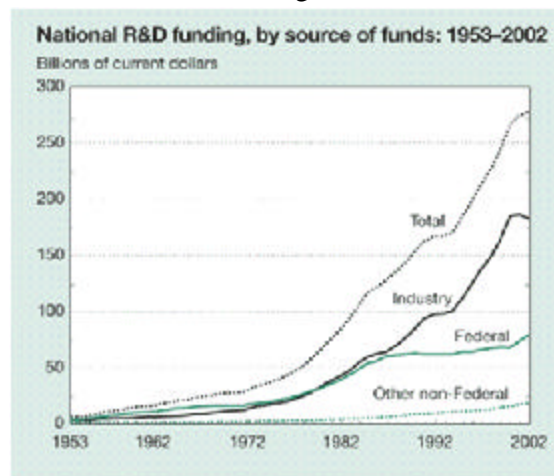


Figure 1: National R&D funding (1953-2002)

## Industrial R&D in the US

Industrial support for R&D grew at an average of 7.7 percent since it surpassed the Federal Government's support in the early 1980s. Ever since, industries have invested more in R&D than the Federal Government. However, between the mid 1980s and mid 1990s, the growth in R&D funding from the industrial sector slowed. Following this slowdown, industrial R&D spending grew rapidly again until 2000 due to the market and economic demand for technology in the 21st century. In early 2000, industrial R&D support declined again. This reduction was due to the terrorist attacks of September 11, 2001. Those attacks were followed by a sharp decline in R&D activities within the manufacturing sector (Ehie and Olibe, 2009).

R&D in US industries began to increase soon after the economy improved after 2002. Some major companies, such as those from the software/IT/Internet sectors, which include Microsoft, IBM, Google, Apple and Yahoo, began to expand and invest more in R&D. The R&D funding in companies like these has increased up until 2008, when it started to decline again due to the global recession (Grueber, 2010). Much of US R&D activities are outsourced to other countries. According to Grueber (2010), US investment in global R&D fell and now ranks eighth in the world.

## Federal R&D in the US

The Federal Government was once the main source of the nation's R&D funds, especially when the space age started in the 1960s. Adjusting for inflation, government R&D spending decreased in the 1980s and its percentage of growth began to gradually decline. Soon after the terrorist attacks of September 11, 2001, the trend in R&D spending reversed and more funding has been put into defense-related R&D (National Science Board, 2010). In addition to defense-related R&D, the US has invested toward other areas such as health, space, energy, natural resources and environment (Dooley, 2008). Figure 2 below illustrates the major areas of focus.

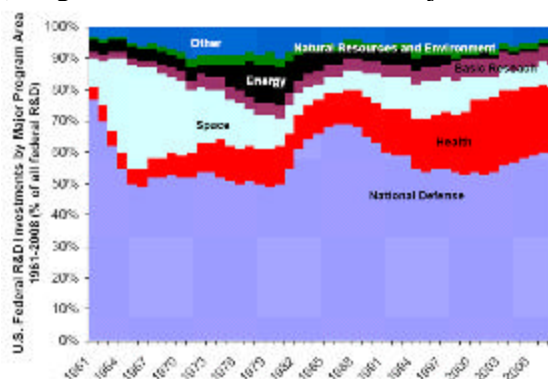


Figure 2: U.S. Federal Government Investments in R&D by Major Area of Focus (Dooley, 2008)

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### Non-Federal R&D in US

Funding for non-Federal R&D is generated by industry. The amount of support grew in the 1980s and continued to grow as seen in Figure 3 below, which is listed as academic and other funding. Most of the funds in non-Federal R&D went toward research performed within academic sectors, such as universities and colleges (National Science Board, 2010). Funding from academic institutions is expected to increase as the growth rate is impacted by the economic climate.

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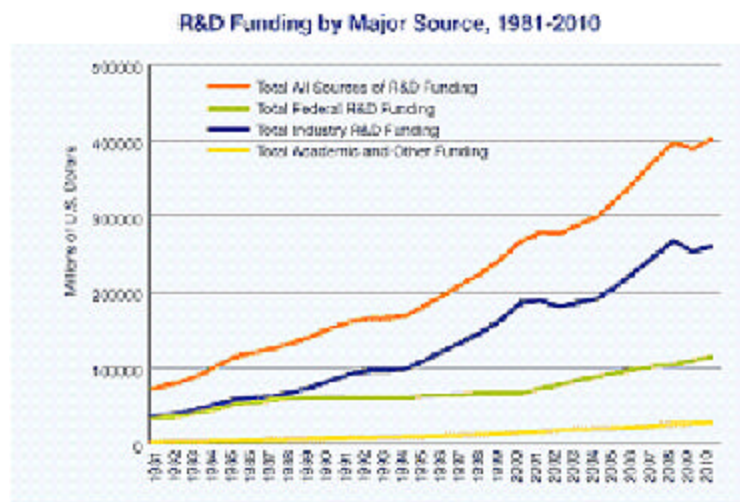


Figure 3: R&D Funding (1981-2010)

Although there has been a recent reduction in R&D activities in industry, federal agencies, and non-federal sectors, the growth of R&D investment will still continue to increase and re-emerge in 2010 (Grueber, 2010). Continued economic uncertainty may impact R&D spending and performance in some sectors, but overall, R&D spending in the US should quickly improve over the next few years.

### R&D SCENARIO IN INDIA

India is the world's largest democracy. Since its independence from Britain, all economic development has been around setting up public sector enterprises in steel, railways and power generation. In the twentieth century, a majority of the R&D institutions in the nation were government controlled and were for defense purposes. Organizations like the Indian Space Research Organization (ISRO), the Defense Research and Development Organization (DRDO) and

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Bhabha Atomic Research Center (BARC) were setup to collaborate on space research, nuclear power research and other defense related projects.

With the opening of the markets in the late 1990s and the inflow of foreign investment, the R&D structure of the country changed. Today, private investment is visible in diverse areas such as Information technology, pharmaceuticals and automobiles. One thousand multinational companies operate in India, 500 of them in Bangalore alone (known as the "Silicon Valley of India"). In the twenty-first century, many multinational companies have opened research centers in India, particularly in the areas of information technology.

Examples of R&D networks setup by Multinational Companies (MNCs) in India are as follows:

SAP, Microsoft, Cisco and IBM have R&D centers in Bangalore. Free scale Semiconductor, a spinoff from Motorola, opened in India its largest R&D center outside the US. GE employs 4,000 people in different R&D offices throughout India. Intel uses its R&D lab in India for development of advanced processors and employs 800 people there. All of the leading pharmaceutical companies have set up research operations in India. Many large Indian conglomerates, like TATA and Ranbaxy, opened centers of excellence in the areas of automotive and pharmaceuticals.

Recently, India has been in the news for developing low cost laptops and cars. Laptops that sell for USD100 and cars that sell for USD 2,000 have been prominent R&D projects. Although India has made huge progress in the last decade, India has not attained the position it seeks in the world of R&D and Innovation. Between 1997 and 2001, India produced less than 1% of the total citations and approximately 2% of the publications worldwide. By comparison, the US produced 50% of the citations and 37% the publications worldwide during this timeframe.

Scientists and engineers who return back to India from the US get involved with business in India, rather than research. Also, there is very poor connection between high technology companies and the local research base. Top Institutes, such as Indian Institutes of Technology (IIT), find it difficult to recruit faculty. India is developing strengths in its core areas of space research, nuclear power and clinical research; however, no solid roadmap exists for emerging nanotechnologies, fuel cell research and biotechnology.

## **R&D SCENARIO IN CHINA**

China has implemented economic reforms that have allowed entrepreneurs to start and create businesses that compete domestically and globally in

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many industries and products. This growing market-oriented economy and flourishing private sector have fueled China's growth. China, in 2010, has overtaken Japan to become the world's second-largest economy (McDonald, 2010). China's economic growth, as measured by year-over-year percentage increase in GDP, averaged 9.25% from 1996 through 2009 (Davies, 2010). R&D growth paralleled this economic growth during this period, growing from 0.57% of GDP in 1996 to 1.5% of GDP by 2009 (Refer to Table C1 in Appendix I). Investment by the Government in University and Industry R&D infrastructure and cooperation among these entities will determine the long term success of China's R&D. The Chinese government is the catalyst which is able to stimulate continued growth in R&D and its conversion to economic value.

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China is on its way to overtake the US if the growth continues at the present level. Thompson Reuters, which indexes 10,500 scientific papers from approx 10,000 journals worldwide, analyzed the performance of Brazil, Russia, India and China. (These are often referred to as "BRIC".) For the last 3 decades, China has outperformed the other 3 nations with particular strength in Chemistry and Material Science (R&D Magazine, 2009).

The three main factors driving the growth of scientific research in China are (1) huge investments by the Government at all levels of the system, from schools to post graduate research; (2) organized flow of knowledge from basic science to commercial applications; and (3) reverse brain drain of scientists and engineers from the US and Western Europe back to China. (Amsden and Tschang, 2001)

In 2005, 750 R&D centers had been set up in China by foreign companies. This represents an increase of 500% between 2003 and 2005. This increase is based on five factors:

(1) multinational companies (MNC's) wanted to establish innovative 'listening posts' to monitor development in China's growing market; (2) requests from Chinese Government officials; (3) pressure from leading companies; (4) desire to establish R&D functions alongside manufacturing that is already offshore in China; and (5) China's rich supply of skilled engineers.

Nonetheless, inefficiencies exist in China's national innovation system. These inefficiencies hinder technological innovation and its conversion to marketable products as measured by output relative to OECD countries (OECD, 2010). While R&D outputs have grown rapidly, such as R&D investment, publications and patents (Refer to Appendix I), some limitations exist. Human resources and infrastructure necessary for extending R&D discoveries to business products have not grown at the same pace as R&D

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itself. The business sector has not utilized R&D advances. The availability of inexpensive labor has been a key factor in the moderate pace of the adoption of innovation (OECD, 2010). With cheap labor readily available, it is more cost effective to simply hire more people to get more output. This may be changing as current demographics in China may accelerate the adoption of technological innovation by businesses. The Chinese workforce is aging and labor shortages are leading to an increase in the wages of available workers. Some business owners and managers are now investing capital in machines that reduce the need for headcount to produce the same output. This creates a more cost effective, scalable operation and drives innovation from the research lab to the factory floor. As China's industries shift from labor intensive to more technologically based, availability of scientists and skilled experts will be increasingly important.

Quality of research in China is still mixed, although it is improving. Chinese Research has become very collaborative. Almost nine percent of papers originating in China have at least one US based co-author. Exploitation of knowledge is not allowed by Chinese traditions and cultures. As a result, China never progressed in the research of materials and nature. Another issue MNC's face conducting research in China is the lack of creativity among Chinese employees (Sun et al., 2007). Intellectual property (IP) problems in China are very serious. For example, Cisco had to surrender their intellectual property and its advantages to Huawei due to the pressure from the Chinese government and government owned companies. Also, Google had to ultimately close their office in China after hacking attempts by internal employees.

Yun Chung Chen examined the evolution of the Motorola and Microsoft innovation networks in China. Localization of MNC R&D has been a learning process. The MNC's learned from their experimental phase that it takes couple of years before R&D centers become productive and can deliver value in the form of innovation and products. In the case of Motorola, the upgrading of R&D is due to the increased market competition in China and the need to interact with other firms in the industrial clusters. In the case of Microsoft, R&D was expanded from simple technical services to fully incorporating technology development with both research and development. (Zedtwitz et al., 2007)

Thus, the benefits outweigh the costs; in spite of the many barrier and challenges, multinational companies are still setting up R&D centers in China.



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## IMPACT OF R&D MANAGEMENT ON ECONOMIC GROWTH

In developed nations, there is a close interaction among Universities, Industry and Government Labs for Research and Development activities. In order for this close interaction to be effective, R&D resources need to be managed effectively so investments in R&D produce the desired return in the form of new or improved technologies, products, businesses and markets. The compelling motive of R&D is the promotion of economic growth that raises the standard of living. Conducting research and producing patents are not enough. Efficient R&D Management effectively directs the outputs of R&D to ensure the discoveries lead to economic growth. Countries need to put their R&D money into areas which lead to their growth and are strategically important.

The following flow chart (Figure 4) shows how efficient R&D Management leads to economic growth.

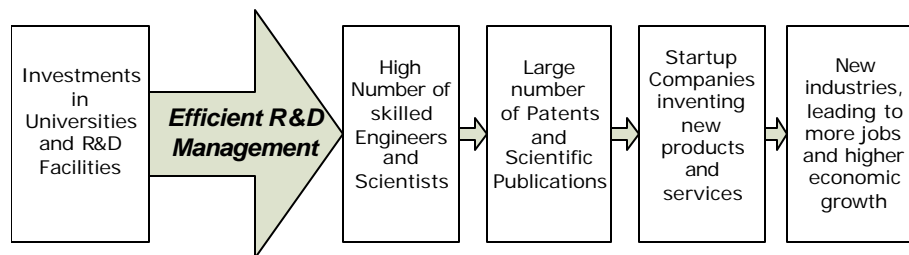


Figure 4: Efficient R&D Management and Economic Growth

The criteria analyzed in this paper are based on the factors shown in the above flow chart. These factors measure and track a nation's potential for improvements of its economic and technological competitiveness.

## METHODOLOGY AND MODEL

### Data - Criteria for Measuring R&D

Collection and collation of the following five criteria provide metrics for measuring historical and current R&D Management. This historical data allowed us to identify trends and thereby formulate predictions of the future of R&D in each country. Historical data was gathered for 1995 through 2009, providing the bases for forecasting R&D for 2020.

This method of analysis and these criteria are based on industry standards obtained from numerous Web sites, such as R&D Magazine's analyses of China's R&D (R&D Magazine, 2010). R&D Magazine gathered

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these data from other sources such as OECD (2010), further demonstrating the standard metrics we've used in this paper.

- R&D Spending as a percentage of GDP (total government, industry and universities)
- Researchers per million inhabitants
- Number of patents granted each year
- Number publications each year
- Total Number of Graduates in all Programs in thousands

### Data Collection and Processing

For each of the three countries, data for each criterion were researched and collected for the period from 1995 through 2009. Due to the lack of complete data samples, shorter periods were researched and collected for certain criteria pertaining to some of the countries under study. The data collected for each criterion per country is tabulated and presented in APPENDIX I. Using Excel, a scattered data graph was created for each criterion per country. In this case, regression trend analysis is used to predict the outlook of each country. Using the Excel trendline tool, three or four different trend lines were added to each graph to predict and analyze the future trend of each criterion for each country. The regression functions used in this study are as follows:

- Linear Regression: A linear trendline is a best-fit straight line that is used with simple linear data sets.
- Logarithmic Regression: A logarithmic trendline is a best-fit curved line that is most useful when the rate of change in the data increases or decreases quickly and then levels out.
- Exponential Regression: An exponential trendline is a curved line that is most useful when data values rise or fall at increasingly higher rates.
- Power Regression: A power trendline is a curved line that is best used with data sets that compare measurements that increase at a specific rate. For example, the acceleration of a race car at one-second intervals.

In order to determine the best trendline for each criterion per country, the trendline reliability was considered. A trendline is most reliable when its R-squared value is at or near 1. The R-squared value is a number from 0 to 1 that reveals how closely the estimated values for the trendline correspond to the actual data (Intel, 2010). The R-squared value was calculated and added to each trend line for each criterion. For each criterion,

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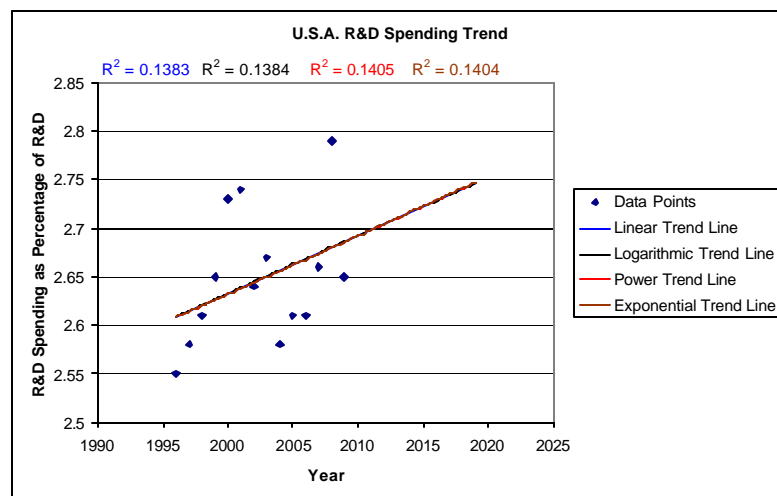
the trendline that produced the closest value to 1 was mainly considered in the analysis. The trendline for each criterion was extended to cover the next decade in order to provide predictions and criterion performance analysis for each country.

### Data and Trend Analysis

#### C1: R&D Spending as a percentage of GDP

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Figure 5 shows data graphs and trend analysis using different regression functions for total R&D spending as a percentage of GDP for each country. The original data was collected from 1995 through 2009. The US maintained a consistent yearly R&D spending of around 2.5%. The annual change in the US total R&D spending percentage was very minor. China, on the other hand, witnessed a constant annual increase in total R&D spending averaging 0.1% of GDP every year with a maximum of 1.5% in 2009. India also exhibited a continuous annual increase in total R&D spending percentage, but at a slower rate compared to china. As shown in figure 1, all trend and regression lines for the US data produce a similar R-square value with a maximum spending percentage not exceeding 2.75 by year 2020. The linear and logarithmic trendlines revealed similar and best R-square values in case of China with annual R&D spending projected to approach 2.5% of GDP by year 2020. As for India, the same trendlines produce the best R-square with an estimated total R&D spending of a little over 0.9% annually by year 2020.



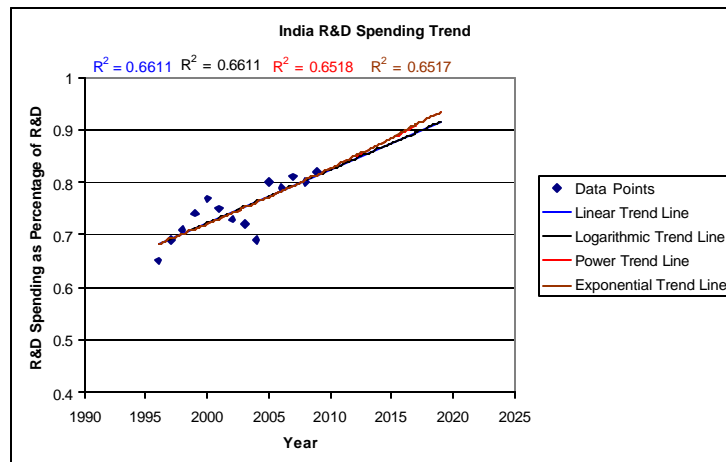
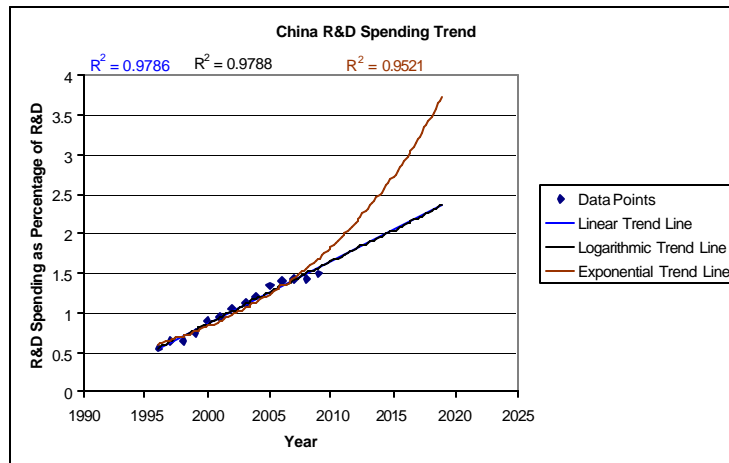


Figure 5: R&D Spending analysis and trending for U.S.A, China, and India

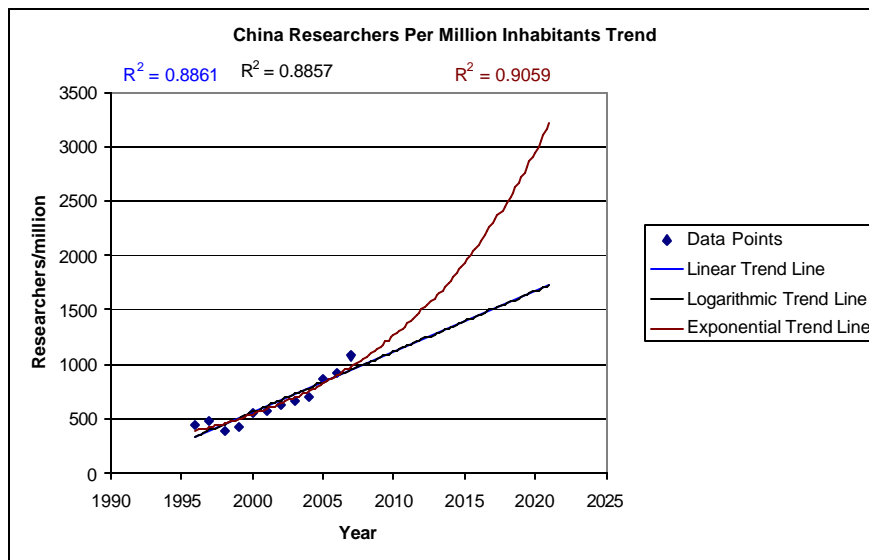
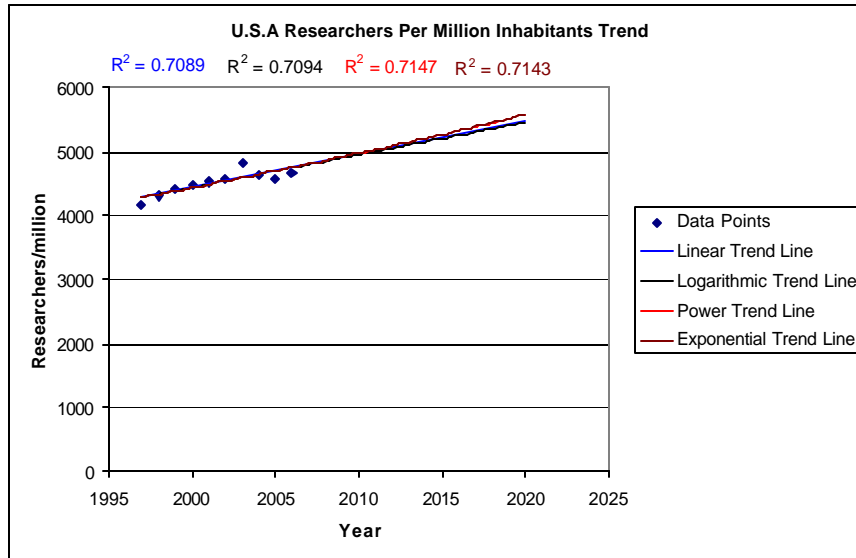
## C2: Researchers per million inhabitants

Figure 6 shows data graphs and trend analysis using different regression functions for the number of researchers per million inhabitants for each country. The original data collected for all countries was for the period from 1996 through 2008, with slight variations. The US enjoyed the highest number of researchers per million at more than 4,000 throughout the period and exceeding 4,600 at its peak in 2006. China followed with the maximum number of researchers exceeding 1,000 in 2007. India's maximum was a

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little over 200 in 2008. The best R-square trendlines for the US predict the number of researchers will exceed 5,500 by 2020. The exponential trendline produced the highest R-square value for China and projects the number of researchers at around 3,500 by the same year. All trend lines produced a nearly equivalent R-square value for India with slightly above 200 researchers per million inhabitants by year 2020.

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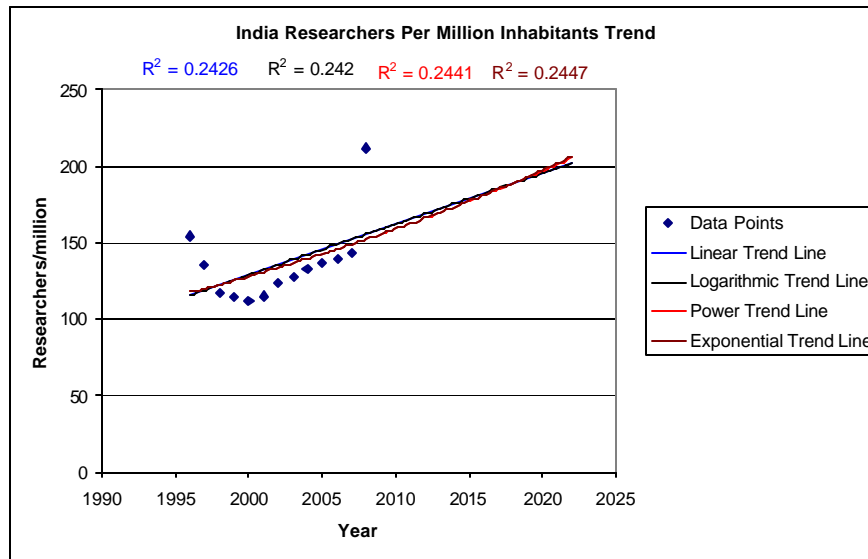


Figure 6: Researchers per Million Inhabitants for U.S.A, China, and India

### C3: Number of Patents Granted Each Year

Figure 7 shows data graphs and trend analysis using different regression functions for the number of patents granted to each country each year. The original data collected for all countries was for the period from 1996 through 2009. According to the historical data, the US is leading by far in the number of yearly annual patents granted. In 2006, the US was granted more than 102,000 patents, although this number decreased to a little above 95,000 in 2009. Both China and India have witnessed a continuous increase in yearly granted patents with 2,270 and 720 patents respectively in 2009. The rate of increase in the number of annual patents granted to India is lower when compared to China. The most reliable trendline, in case of the US, shows the number of annual patents at around 120,000 by 2020. The exponential trendline is the most reliable in case of China; it predicts more than 45,000 patents to be granted by 2020. As for India, the linear trendline has the best R-square value and puts the country at a little more 1,000 patents in 2020. The exponential trend line for India, which produces a closely matched albeit lower R-square value, projects the number of patents to be at around 9,000 by 2020.

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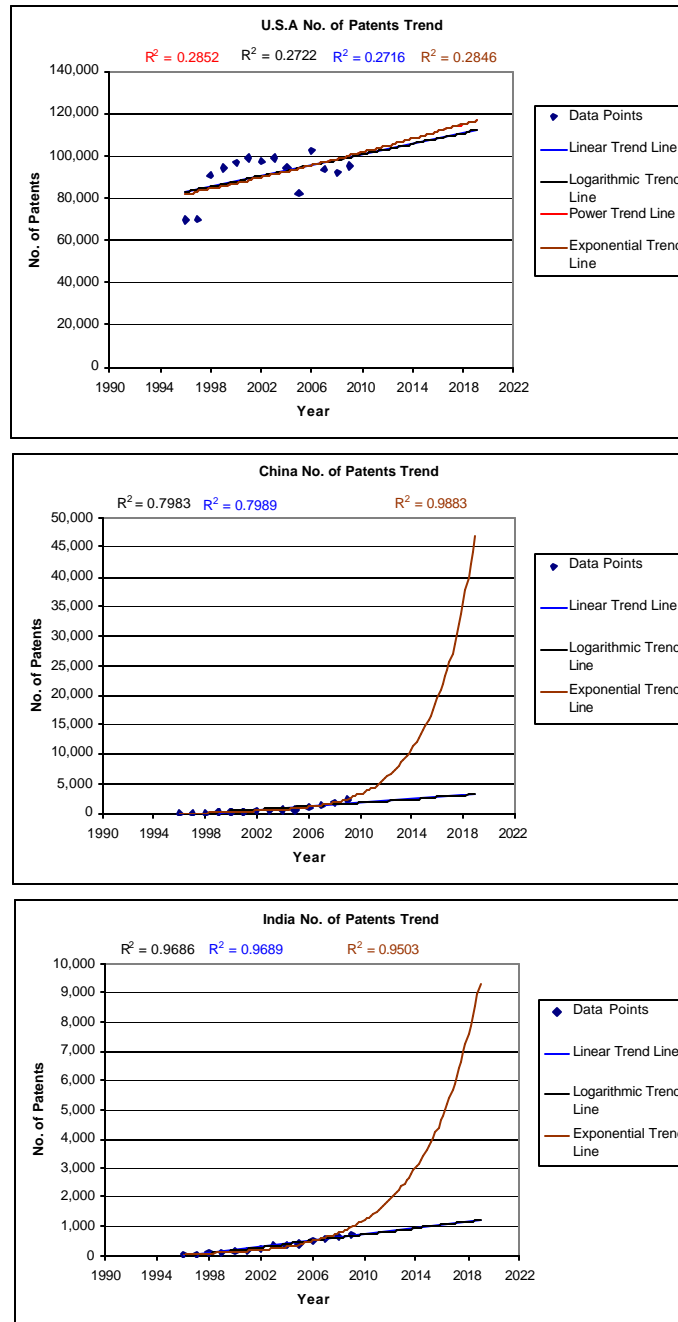
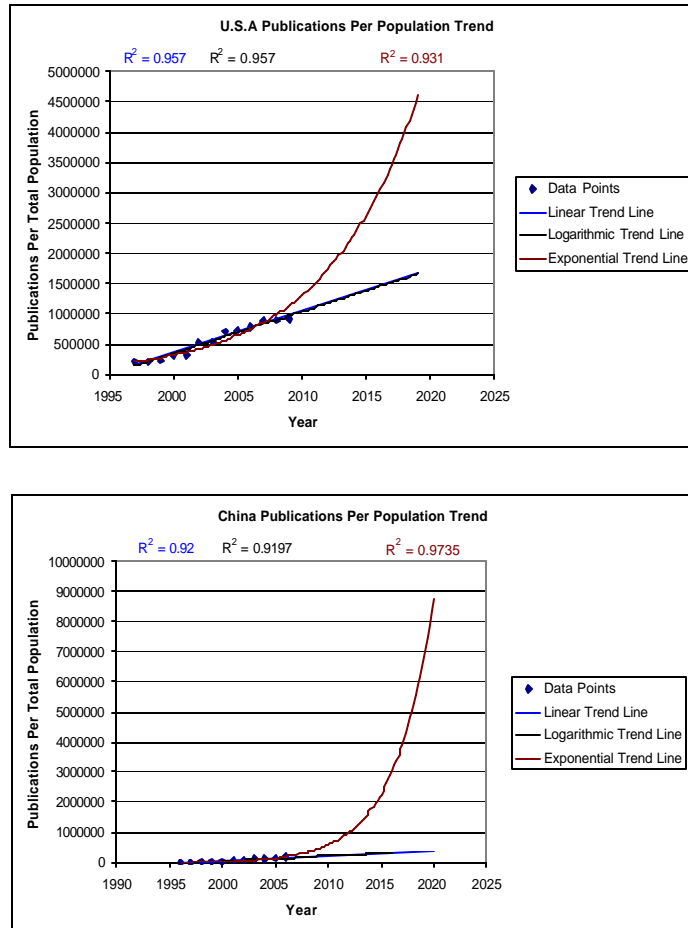


Figure 7: Number of Patents Granted Each Year for U.S.A, China, and India

#### C4: Number Publications Each Year

Figure 8 shows data graphs and trend analysis using different regression functions for the total number of publications published by each country each year. The original data period collected for each country was from 1995 through 2009. The US has maintained a lead position in the number of publications with a more than 900,000 publication in 2009. The linear trendline has the best representation of the number of annual publications for the US; it predicts that the US will produce more than 1.5 million publications by 2020. China delivered more than 172,000 publications in 2006 and is predicted to deliver almost 9 million by year 2020, surpassing the US by 7.5 million publications. In contrast, the most reliable and optimistic prediction puts India at around 400,000 publications by 2020.





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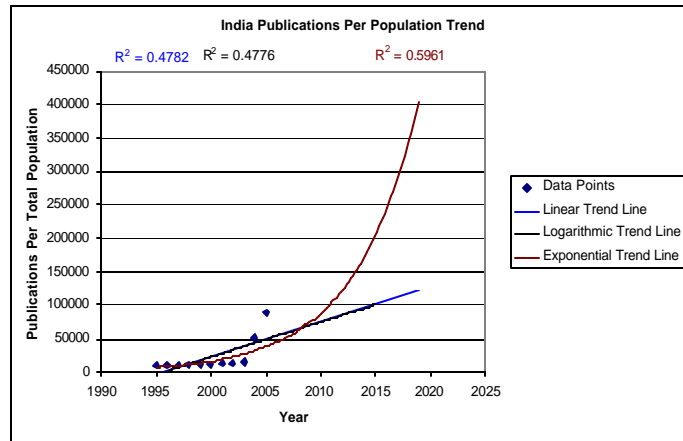
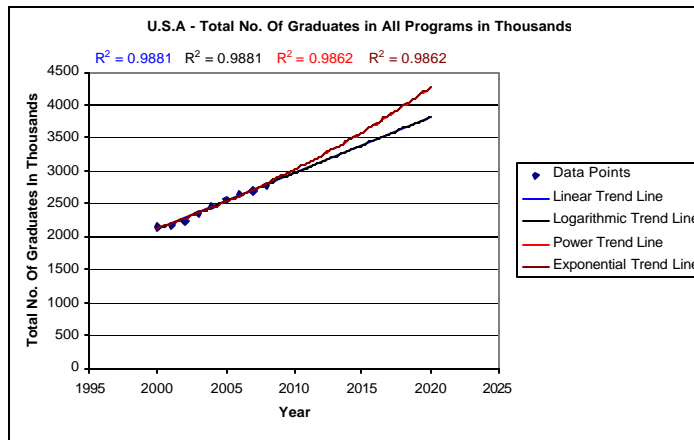


Figure 8: Number of Publications per Year for U.S.A, China, and India

**C5: Total Number of Graduates in all Programs in thousands**

Figure 9 shows data graphs and trend analysis using different regression functions for the total number of graduates in all programs in each country each year. The data collected for all countries ranged from 2000 through 2008. With a linear trendline that has the best representation of its data, the US is predicted to have more than 3.5 million graduate students by 2020, compared to 2.7 million in 2008. In 2008, China had more than 7 million registered graduate students and by year 2020 it's expected to have more than 15 million, according to the linear trendline with the best R-square value. India is growing exponentially in this area with more than 20 million graduates expected to be in this country by year 2020.



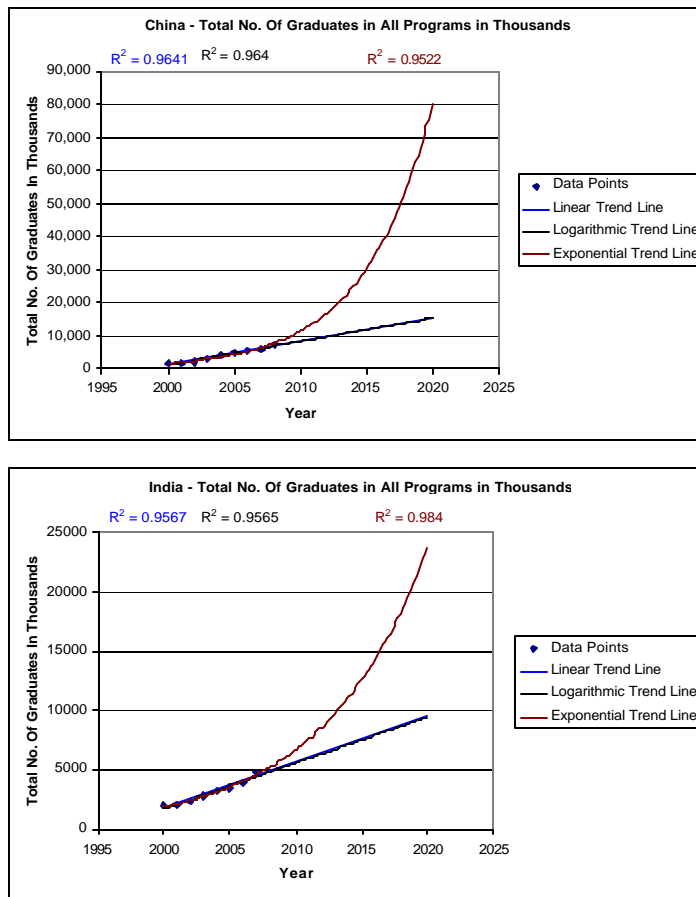


Figure 9: Number of Graduates in all Programs for U.S.A, China, and India

## CONCLUSION

Although India and China have made remarkable, high-growth economic progress, R&D is still not their strength. Almost a third of total R&D innovations are still done in the US. India and China have abundant human resources due to their large populations, but the interaction between Universities, Industries and Governments is still weak and under-utilized. China's economy remains primarily a low tech manufacturing based economy whereas India's is more of a business service based economy.

China continues to make huge investments in R&D and is expected to catch up by 2020 with the US in the number of publications.

For the US to maintain its competitive edge, it will need to refine its R&D policy and start looking into areas such as Technology Mining. Also,

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business methods like Total Quality Management (TQM) and Statistical Process Control (SPC) can improve the efficiency of R&D Management. During economic downturns, such as the current recession, investments in R&D can have a significant impact as new technologies create new industries leading to wealth creation and long term economic growth. Based on our research, it appears the main threat to the US in R&D is from China, not from India. It is clear from our study that, for the US to remain competitive, it will need to increase emphasis and spending on the education of highly skilled engineers and scientists. R&D requires engineering and scientific excellence for high quality and productive R&D performance and efficient R&D management.

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Growth of R&D in the US follows a linear pattern with small increments of growth for the majority of the criteria analyzed in this paper. In contrast, in China the trend is exponential for the majority of the criteria. This indicates that China is significantly increasing R&D management with large increased investments year-over-year in these areas. Growth of R&D management in India is slower than in China. For India, R&D investments and outputs mainly follow a linear trend. Nonetheless, India is gaining in the area of skilled graduates. We predict that China will catch the US by 2040 in R&D management as measured by the criteria analyzed for this paper, assuming continuance of current growth patterns.

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## APPENDIX I

### R&D Criteria

The data was compiled using the statistics from the following sources:

Data in red indicates data not available for that year; it is therefore calculated using the average of the previous year and the next year.

<http://statinfo.biz/Data.aspx?act=5772&lang=2>

Organization of Economic Cooperation and Development

<http://www.oecd.org/dataoecd/9/41/41850880.pdf>

<http://www.oecd.org/dataoecd/7/45/41270116.pdf>

<http://www.nationmaster.com>

US Government Patents Office

[http://www.uspto.gov/web/offices/ac/ido/oeip/taf/cst\\_all.htm](http://www.uspto.gov/web/offices/ac/ido/oeip/taf/cst_all.htm)

Department of Statistics - UNESCO

[http://www.uis.unesco.org/ev.php?ID=7122\\_201&ID2=DO\\_TOPIC](http://www.uis.unesco.org/ev.php?ID=7122_201&ID2=DO_TOPIC)

<http://stats.uis.unesco.org/unesco/ReportFolders/ReportFolders.aspx>

Ministry of Science and technology of the People's Republic of China

<http://www.most.gov.cn/eng/statistics/2007/index.htm>

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### APPENDIX I: R&D CRITERIA

C1 - R&D Spending as a percentage of GDP (total government, industry and universities)

Country	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009
USA		2.55	2.58	2.61	2.65	2.73	2.74	2.64	2.67	2.58	2.61	2.61	2.66	2.79	2.65
INDIA		0.65	0.69	0.71	0.74	0.77	0.75	0.73	0.72	0.69	0.8	0.79	0.81	0.8	0.82
CHINA		0.57	0.64	0.65	0.76	0.9	0.95	1.07	1.13	1.23	1.337	1.417	1.442	1.442	1.5

C2 - 2. Researchers per million inhabitants

Country	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009
USA			4179	4305	4432	4481	4535	4566	4818	4648	4584	4663			
INDIA		154	135	117	114	111	115	123	128	133	137	140	143	212	
CHINA		448	477	390	423	549	582	630	666	710	853	927	1071		

C3 - Number of patents granted each year

Country	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009
USA		69419	69923	90697	94089	97011	98655	97124	98590	94128	82586	102267	93690	92001	95037
INDIA		37	48	94	114	131	180	267	356	376	403	506	578	672	720
CHINA		48	66	88	99	161	265	390	424	597	565	970	1235	1874	2270

C4 - Number publications each year

Country	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009
USA			224532	227803	229987	305535	322947	524896	554968	716762	733921	784653	889030	889030	911185
INDIA	10469	10410	10352	11072	11792	12176	12561	13545	14529	51913	89297				
CHINA		14655	17007	19970	24553	30508	64526	77395	93352	111356	153374	172055			

C5 - Total Number of Graduates in all Programs in thousands

Country	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009
USA						2150	2174	2238	2355	2473	2557	2639	2704	2782	
INDIA						2000	2100	2350	2800	3300	3500	3900	4800		
CHINA						1,775	1805	1948	2963	3978	5004	5622	5872	7071	



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