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—10th Zuckerman Lecture, Royal Society, London

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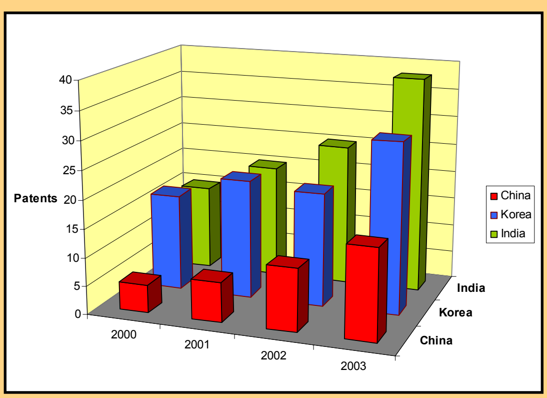
US drug, vaccine, or pharmaceutical patents by inventors from China, Korea and India



eJournal

An *e*Journal Sharing Creative and Innovative Ideas and Experiences about Global Issues in Agriculture, Health, and the Environment Facing Developing Countries

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Cornell University

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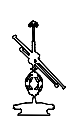
The telescope shown on the cover and below is that used by Galileo Galilei to determine that the earth revolves around the sun. The drawings are representations by Leonardo da Vinci, among others of rounded mirrors, the basis of modern telescopes.

Both Galileo and da Vinci transcend their time because they broke with the disciplinary conventions of their days, pushed the boundaries of science, revolutionized our understanding of the world and our place in it, and shifted humanity's perspective up to the present day.

The photograph of the Congolese woman grinding corn is intended to signify that innovation must make a real difference in people's lives while acknowledging that local cultures around the world are rich with the genius of innovation.

We hope this *e*Journal will contribute to new insights, knowledge and tools as authors share their creativity and original perspectives.



Understanding—and Unleashing—Innovation

Innovation Strategy Today, a new electronic Journal, takes an "innovation systems" approach to the pressing problems of international development, to the challenges of poverty reduction, to the goal of health for all, and to the dream of a more equitable world. We pursue this framework not for its own sake but for the valuable light it sheds on the specifics of these global challenges and goals. We are convinced that by considering key components within an innovation system, we will move beyond stale, polarizing debates and publish pragmatic analysis, proposals, and ideas that will re-ignite economic and social development.

Innovation Strategy Today builds upon the success of our *e*Journal *IP Strategy Today*. Established a few years ago, that journal has so far published two dozen comprehensive papers on a range of strategic issues related to intellectual property (IP) rights, public-private partnerships, and the transfer of agricultural biotechnology and health innovations to resource-poor farmers. Debates on these topics sometimes suffer from a single-minded focus on the minutiae of IP systems, with proponents at times viewing IP as an end in itself. Such an approach polarizes debate, and so the articles in *IP Strategy Today* have sought to place this discussion in a larger, more open context. *Innovation Strategy Today* continues this effort and will place IP and a range of other essential policy and strategy elements into the broader context of "innovation."

Innovation is not magic but the result of an integrated system, a system that can be traced, analyzed, and improved. Public and private institutions globally interact within this system to "deliver" the benefits of new knowledge and/or new technologies to society. *Innovation Strategy Today* focuses on the intersections of innovation and international development to show how innovation can be better harnessed to benefit the billions of people in developing countries who are excluded from innovation in health and agriculture. This means thinking about the system of innovation as a set of interlinked and dynamic components. As the first paper in this series by Carlos Morel and colleagues demonstrates (pages 1-15), this system encompasses education, research and development, manufacture and production, domestic and export markets, IP management, regulatory systems, public-private partnerships, and the national policies that affect these. The paper further demonstrates the rapidly growing innovative capabilities of certain developing countries, which leads the authors to propose an *Initiative for Health Product Innovation in Developing Countries*: a strategy to maximize the growing global efforts to address diseases of the poor by unleashing the creative capabilities of innovation *in* developing countries.

To unleash innovation, the relevant multiple aspects of innovation systems must be adjusted with concurrent or synchronized initiatives. This is a very rich field of study—and action. To understand and improve this system we must imagine new ways of connecting centers of innovation, new kinds of interactions among and between the public and private sectors, and perhaps even new definitions of their roles.

Based on decades of experiences in India, the second paper by R. A. Mashelkar (pages 16-32) provides a pragmatic underpinning for the first article. His lecture shows how innovation, fuelled by investments in science and technology, is promoted by sound government policies and nurtured in a flexible, competitive, and dynamic economic environment. Mashelkar identifies "openness" as a key component of India's innovation system: "*In a developing country context, this means building on reforms that emphasize openness to new ideas, new products, and new investments.*" Noting that innovation is a "*many splendored endeavor*," he highlights the roles that both low and high technology can play in solving the problems of the poor (e.g. the *Simpulator*, a handheld internet appliance invented by young creative minds at the Indian Institute of Science in Bangalore). Mashelkar concludes by exhorting us to remember that *"with proper support and encouragement, we can change the direction of people and institutions to eventually benefit humanity at large."*

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Both of these papers show that unleashing "innovation" cannot be achieved in isolation; it is not a matter of merely focusing on certain reforms and investments in one country. We live in an increasingly interconnected world, and both developed and developing countries, both public and private sectors, must find new ways to work together to create and unleash innovation. We believe that this is not a matter of luck but of analysis, understanding, and rational choice.

The images on the cover of *Innovation Strategy Today* proclaim these intentions and aspirations. A woman in the Democratic Republic of the Congo grating corn on a stone signifies the *e*Journal's dual recognition that innovation must make a real difference in people's lives and that some of the most valuable innovations are developed at the grass-root level. Indeed, indigenous cultures around the world are rich with the genius of innovation.

To globally unleash innovation appears to require a change of perspective. Images on the cover from some of history's most innovative geniuses attempt to convey this point and to inspire us by recalling a period of rapid, breathtaking innovation. We may well be entering a new period of fast-forward progress as "innovative developing countries" take the lead. Mashelkar perceives this acceleration at work in the "Brain Gain" of developing countries, an observation echoed in the popular press (e.g. "NRIs, expats fuel biotech boom in India", *The Economic Times* of 12 April). The frontispieces thus express our hope that *Innovation Strategy Today* will help give birth to a renaissance in our own field. We take inspiration from Leonardo da Vinci, who produced ingenious designs for optical instruments, giant and rounded mirrors (the basis of modern telescopes), flying machines, and fantastic mechanisms of all kinds. His *Codex* drawings of the flight of birds, elaborate trains of gears, the workings of the human heart, and, perhaps best known of all, the *Vitruvian Man*, all testify to the creative power of the human imagination. Da Vinci has come to stand for this period of boundless scientific discovery and technological invention, coupled with sublime works of art and towering achievements in the humanities. Polymath theorist, scientist, and inventor, da Vinci continues to inspire the modernity he ushered into existence. He transcends his time because he broke with the disciplinary conventions of his day, pushing past these boundaries in ways that did not fit in with the expectations of his contemporaries.

Some might argue that the papers published by *Innovation Strategy Today* might also appear not to fit our field's established conventions, but that is because the papers we accept must exceed *your* expectations. We take intellectual risks. We encourage the flight of the imagination. Just as the Renaissance provided science with innovative instruments that greatly enhanced its powers and shifted paradigms, we hope that *Innovation Strategy Today* will share with the world new ideas and fresh approaches to long-standing problems in international development. When Galileo Galilei turned his famous telescope to the night sky, he illuminated a new cosmos. The tools were ready to hand (contrary to popular belief, Galileo did not invent the telescope) but he imagined a new use for this new technology, revolutionizing our understanding of the world and our place in it.

It is in this spirit of imaginative innovation and intellectual risk taking that we place representations of da Vinci's drawings and of Galileo's telescope on the cover of *Innovation Strategy Today*. On every page of the journal, the telescope also serves as our mascot, reminding us of Galileo's daring genius and the imaginative leap that shifted humanity's perspective. Let us be inspired to better understand innovation. This will provide us with new insights, new knowledge and tools, and the creativity of new perspectives that are needed to meet the plight of the world's excluded people, particularly those of the burgeoning—and innovatively budding—developing world.

Anatole Krattiger
Editor-in-Chief
April 2005

Health Innovation in Developing Countries to Address Diseases of the Poor

Carlos Morel[1], Denis Broun[2], Ajit Dangi[3], Christopher Elias[4], Charles Gardner[5], RK Gupta[6], Jane Haycock[7], Tony Heher[8], Peter Hotez[9], Hannah Kettler[10], Gerald Keusch[11], Anatole Krattiger[12], Fernando Kreutz[13], Keun Lee[14], Richard Mahoney[15], R.A. Mashelkar[16], Hong-ki Min[17], Stephen Matlin[18], Mandi Mzimba[19], Joachim Oehler[20], Robert Ridley[21], Pramilla Senanayake[22], Halla Thorsteinsdóttir[23], Peter A. Singer[24], Mikyung Yun[25]

The concepts presented here were crystallized at a meeting convened by the Rockefeller Foundation at the Bellagio Study and Conference Center, 10–13 May 2004. Twenty-three participants attended from Brazil, Canada, France, India, Korea, South Africa, the United Kingdom and the USA. Following the meeting, a number of other individuals made significant intellectual contributions, and they are included as authors of this paper. The authors are grateful to all who contributed to this paper and to the Rockefeller Foundation for financial support. The views expressed are nevertheless those of the authors in their individual capacities and do not necessarily reflect those of their respective institutions, nor of the publishers, editors and supporters of *Innovation Strategy Today*.

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Abstract

There is a great unmet need for health technologies to address diseases of the poor in developing countries. At the same time, there is a rapidly growing capability to undertake health innovation[a] in many developing countries (Innovative Developing Countries - IDCs). IDCs have the capacity to develop, manufacture, ensure safety, and market new health products and to develop, test and introduce new health policies or strategies. They are distinguished by their rapidly growing strength in health innovation as illustrated by increasing patenting and publishing activities; increasing investments in technology by both the public and private sectors; rapidly growing number of health technology companies[b]; and health systems able to analyze, evaluate and adopt new practices and technologies.

This innovation capability provides an underleveraged opportunity to accelerate the development of new products, policies and strategies for diseases of the poor. We call for the formation of an *Initiative for Health Product Innovation in Developing Countries*. Its primary mission will be to accelerate the translation of new knowledge into health innovations relevant to the diseases of the poor and to economic growth, taking into account national priorities and sensitivities. The Initiative could promote innovation through programs to (i) support research on health innovation systems; (ii) promote collaboration and coordination among countries to develop, disseminate and implement good practices; and (iii) implement demonstration projects.

Such an Initiative would help maximize existing and growing investments by developing countries in health research, and complement global efforts to address health disparities and achieve the Millennium Development Goals.[1]

[a] We use the term 'health innovation' to include the development of new drugs, vaccines and diagnostics as well as new techniques in process engineering/manufacturing and new approaches/policies in health systems and services.

[b] Throughout this paper, we will refer to specific developing countries. These are illustrative and there are many additional countries with strengths in innovation.

Southern Needs, Northern Response and Global Strategies

Recent evidence shows that improved health is more than a consequence of development. It is a central input into economic and social development and poverty reduction. Good health, economic development and individual economic well being are intimately interdependent. The importance of investing in health cannot be overstated.[2] The magnitude of the health problems facing the poor in developing countries are immense.[3,4] Approximately 10 million children die each year with "undernutrition as an underlying cause of child deaths associated with infectious diseases, the effects of multiple concurrent illnesses, and recognition that pneumonia and diarrhea remain the diseases that are most often associated with child deaths."[5] In addition, global health experts are increasingly recognizing the growing relative importance of chronic diseases in the developing world where, in contrast to the infectious diseases that primarily affect children, middle aged and older people are the most vulnerable. Chronic diseases are the world's largest cause of death with 33 million deaths worldwide in 2003. The leading chronic diseases are cardiovascular disease, cancer, chronic respiratory disease, and diabetes.[6]

There are many interventions and strategies for improving health including strengthening health systems to improve the delivery of goods and services, education about desirable individual behavior, and introduction of water and sanitation systems. However, limitations of existing technologies, or the absence of appropriate technologies and other innovations, impede the achievement of desired health improvement goals. All health interventions draw upon innovations as essential tools to achieve the desired health improvement outcome. Such innovations include vaccines to prevent HIV, malaria, respiratory, and diarrhoeal diseases; drugs to treat TB, malaria, cancers, and diabetes; other hardware such as weighing scales; software such as disease surveillance systems; and diagnostics and medical devices. These are a necessary part of a broader package of interventions including improvements in health delivery, surveillance, and policy formulation to improve the health of those most in need in the developing world.

Efforts to accelerate the development and distribution of health products for diseases of the poor have intensified over the past decade. Product development public private partnerships (PD-PPPs) have been established to develop new vaccines and drugs against HIV, malaria, TB , diarrhea and other infectious diseases, and related diagnostics and medical devices. These partnerships include the International AIDS Vaccine Initiative (IAVI), the International Partnership for Microbicides (IPM), the Medicines for Malaria Venture (MMV), the Malaria Vaccine Initiative (MVI), the Global Alliance for TB Drug Development (TB Alliance), the Aeras Global TB Vaccine Foundation, the Human Hookworm Vaccine Initiative (HHVI), the Foundation for Innovative New Diagnostics (FIND), the Drugs for Neglected Diseases Initiative (DND*i*) and the Institute for OneWorld Health. These initiatives have made significant progress, but are still relatively young and have therefore not yet achieved their intended goals.[7]

In addition to the PD PPPs, major global funds have been also established over the past five years to procure and distribute existing drugs and vaccines. These include the Vaccine Fund that works with the Global Alliance for Vaccines and Immunizations (GAVI) and the Global Fund to Fight AIDS, Tuberculosis and Malaria. Sustained and increasing support from donors will be needed for product development and procurement efforts to have their desired impact over the next decade. Access by the poor, either to existing or new products, depends upon numerous factors, but especially health delivery systems. The need for more attention, research and resources in this area was the subject of the annual meeting of the Global Forum for Health Research, and the World Health Organisation (WHO)-Mexico Ministerial Summit on Health Research, both held in Mexico City November 16-20, 2004[8].

Growing Capabilities of Developing Countries in Health Innovation

One commonly identified impediment to effective health systems in developing countries is the difficulty of translating promising product concepts into affordable and accessible products. However, at least in some developing countries, this difficulty is beginning to be addressed. The rapidly growing health innovation capabilities of some developing countries represent a phenomenon that should complement the PD PPP efforts described above.

The concept of "health innovation systems" encompasses interlinked components including education, R&D, manufacture, domestic and export markets, intellectual property (IP) management, regulatory systems and the national policies that affect all of these (including public-private partnerships)[9] [10]. An effective health innovation system, extending from concept research through delivery at the program and health systems level, depends upon the design and implementation of policies that recognize the dynamic linkages among all components of the system.

Developing countries themselves are building innovative capacity for new health technologies, products and services[11]. Collectively they already invest at least $2.5 billion per year in health research.[12] This compares with about $200 million per year by various PD PPPs.[13] Public and private sectors in some developing countries are also working to build innovative capacities through the establishment of IP management systems, drug and vaccine manufacturing facilities, and regulatory capabilities.

Some developing countries are more scientifically advanced and have the greatest capacity to discover, develop, manufacture, ensure safety, and market new health products. Innovation can occur in any locality, and this paper highlights recent dramatic progress in a few countries. [14]

Mashelkar has introduced a construct for understanding the special category of IDCs (Table 1).[15] [16]. He writes (for the full paper, see page 16-32 in this volume of *Innovation Strategy Today*):

Table 1: *Economic strength and innovation capability*

	Low	*High*
	Innovation Capability	
High **Economic Strength** *Low*	I	II
	III	IV

Adapted from Mashelkar 2005.[15]

"We can, in a simple-minded way, position all the countries in a single diagram in terms of their relative economic strength and indigenous capacity in science and technology (Table 1). In the top right-hand corner are such developed nations as the USA, Japan, countries in Europe, etc. They have a very high indigenous science and technology capacity and a very high economic strength. In contrast, in the lowermost left-hand quadrant are the least developed countries, including those in sub-Saharan Africa, where indigenous science and technology capacity as well as economic strength are low. In the top left-hand quadrant are countries that have attained very high economic strength by the strength of their natural resources (such as the oil rich Middle East countries). But these do not have any significant indigenous science and technology capacity. The most interesting quadrant is the lower right-hand area. These countries have high indigenous science and technology capacity but relatively low economic strength. They include India, China, Brazil, Argentina, Chile, South Africa, etc. Of course, the positions of developing nations in this diagram are not static. Different countries in different times of history occupied different positions on this map. For instance, not too long ago, Korea belonged to the lower right- hand quadrant. But they moved upwards to attain the status that OCED countries enjoy today."

While economic strength is easily measured, and reasonably well-understood, innovation capability presents more difficulty. Given the complex set of activities involved in the innovative process, measurement of "innovative capability" must be based on several indicators. Cross-country comparative data for a broad set of measures are limited. One often used measure of innovation is the number of US patents issued.[17] Innovative efficiency, by extension, may be measured by the number of US patents per GDP/capita. Patents do not necessarily translate into products, and US patents represent only a subset of all innovation in a country. Thus, while instructive, this is an indirect measure of innovation capability. However, because of the global dominance of US markets, it has the advantage of creating a common yardstick against which to measure all countries.

Table 2 shows the top 25 countries in the world by rank order, analyzed for all US patents issued where at least one inventor is from the subject country. Several IDCs, indicated by shading, appear in the table. Note that India and China are at 3^{rd} and 4^{th} places. Other developing countries on the list are Brazil, South Africa, Thailand, Argentina, Malaysia, Mexico and Indonesia (in rank order).

Table 2: *US patents, GDP per capita, and US patents per GDP/capita (2003)*

	Country	US Patents	GDP per capita	US patents per GDP per capita
1	USA	99,386	36,006	2.760
2	Japan	37,779	31,407	1.203
3	*India*	444	487	0.912
4	*China*	724	989	0.732
5	Germany	13,110	24,051	0.545
6	Korea, Rep.	4,246	10,006	0.424
7	France	4,682	24,061	0.195
8	Canada	4,410	22,777	0.194
9	UK	4,803	26,445	0.182
10	Italy	2,206	20,528	0.107
11	Israel	1,392	15,792	0.088
12	*Brazil*	209	2,593	0.081
13	Sweden	1,771	26,929	0.066
14	*South Africa*	142	2,299	0.062
15	Australia	1,174	20,822	0.056
16	Switzerland	1,845	36,687	0.050
17	Belgium	998	23,749	0.042
18	Finland	1,009	25,295	0.040
19	Austria	753	19,749	0.038
20	*Thailand*	64	2,060	0.031
21	*Argentina*	76	2,797	0.027
22	Singapore	564	20,886	0.027
23	*Malaysia*	95	3,905	0.024
24	*Mexico*	129	6,320	0.020
25	*Indonesia*	16	817	0.020

Source: US Patents: www.uspto.gov
GDP per capita: www.worldbank.org

The productivity of IDCs is a relatively new phenomenon which may have contributed to the relative lack of attention it has received. Figure 1 shows the growth in numbers of US patents by inventors from several IDCs[a] from 1990 through 2003 where the words "drug", "vaccine", or "pharmaceutical" appear in the patent abstract.[18] The rate of patenting was relatively constant during the first half of the 1990s, but accelerated dramatically since 1996.

Figure 2 compares the two most active patenting IDCs, China and India, with Korea. Korea has been an OECD country since 1995 and is often used as a benchmark for developing countries because its GDP per capita has grown exceptionally rapidly since 1960[19].

Citations of published articles are another proxy indicator of innovative capacity. A recent analysis by King[20] of highly cited publications from 1993-1997 and 1997-2001 also suggests a rapid increase in capabilities in IDCs. Comparing the two periods of the study, several IDCs increased the number of highly cited papers significantly and either exceeded or equaled the average percent increase in highly cited papers of all countries that were analyzed (Table 3).

Comparing the efficiency of countries (publications per GDP/capita) shows that the top ten countries in the world (in rank order) are India, China, United States, Brazil, Germany, United Kingdom, Japan, South Africa, Canada, and Italy.

Table 3: *Numerical and Percent increases in the number of papers among the 1% most highly cited papers*

Country	**Numerical increase**	**Percent increase**
Brazil	88	88%
China	218	145%
India	93	83%
South Africa	30	59%
Top 30 countries average	112	59%

Figure 1: *US patents from selected countries. Patents are for drugs, or vaccines or pharmaceuticals*
(Countries included are Argentina, Brazil, China, India, Malaysia, Mexico, South Africa, and Thailand)

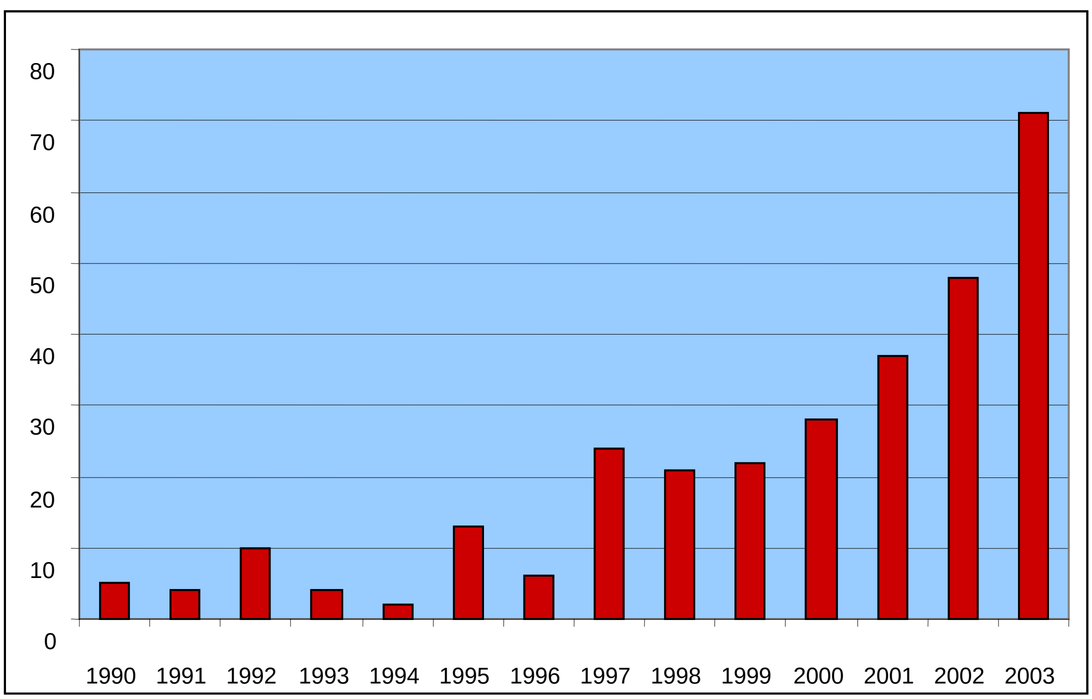
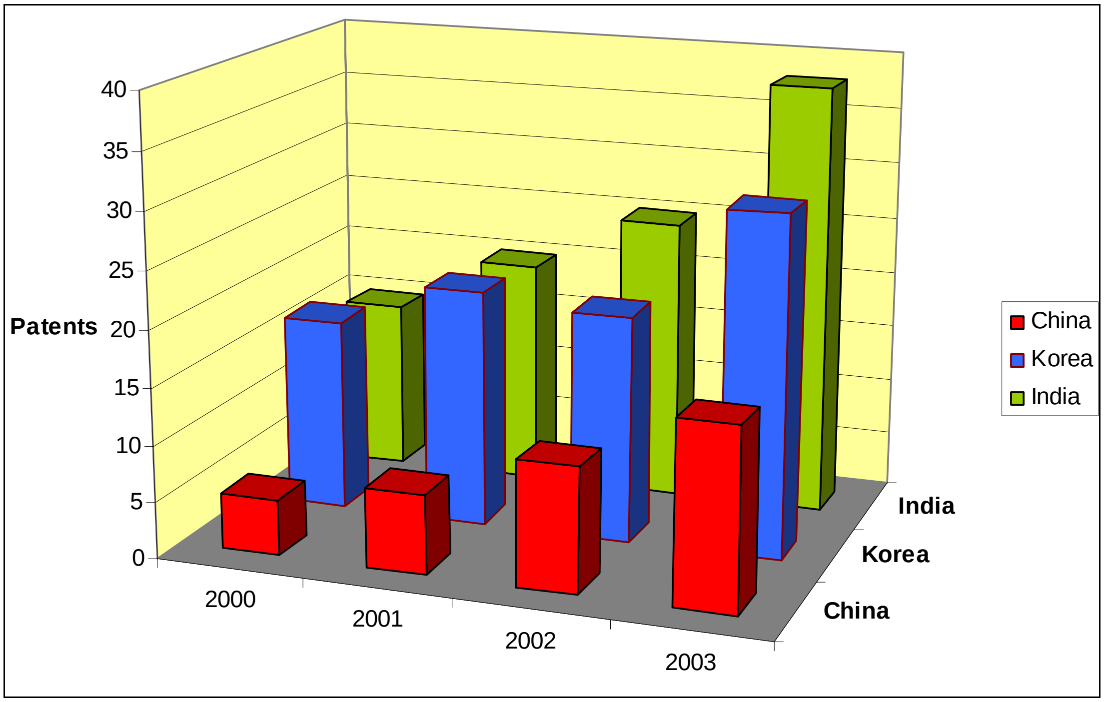


Figure 2: *US drug, vaccine, or pharmaceutical patents by inventors from China, Korea and India*



It is likely that for many of the IDCs, the impressive trends in patents and citations are a result of the recent and rapid increases in R&D investments, preceded by longer-term investments in science and engineering education. According to a 2001 study, in 1998 Argentina, Brazil, Costa Rica, Cuba, India, Malaysia, Mexico, Panama, Peru, the Philippines, Thailand, and Turkey spent a minimum of $2.3 billion for health research for national needs.[21] This number could be compared with the budgets of the UK Medical Research Council ($0.3 billion) and the US National Institutes of Health ($13.647 billion) in 1998. Notably, this figure does not include China for which data were not available. In developed countries the public and private sectors invest comparable amounts in health research, whereas in most developing countries the majority of health research is supported by the government and conducted in public institutions.

Each of these countries, including China, is committed to double digit percent increases in health research funding.[22, 23] We estimate total allocations in 2004 at no less than $3 billion. For the fiscal year beginning April 2005, the Indian government alone plans to increase spending in all R&D to $3.3 billion, implying a minimum 15 percent increase in all major projects.[24] The private biotechnology industry in India projects investments of $10 billion by 2010.[25] Some developing countries are aggressively creating high quality pharmaceutical and biotechnology industries on their own initiative.[26, 27] There is also rapidly growing capability to conduct clinical trials according to good clinical practices standards[28].

Manufacturing and markets in developing countries are important components of innovation systems. There is limited but growing evidence that IDC firms, if well networked and set up efficiently, are able to achieve significant cost advantages in production.[29] For example, a recent study by the Organization of Pharmaceutical Producers of India found a cost advantage of up to 50 percent compared with the United States.[30] Further analysis is needed, and cost advantages may differ significantly between drug and vaccine manufacturers, but developing country cost-advantages arguably could lead to lower prices for products directed to the poor. South-South trade in low-cost products is an important aspect of access by the poor to both new and existing health interventions. By value, 67% of India's drug exports, 74% of Brazil's and 92% of Argentina's go to other developing countries, while 63% of Uganda's drug imports and 54% of Tanzania's drug imports by value come from other developing countries.[31]

By volume, India is now the fourth largest producer of pharmaceuticals in the world (13th by value), the country holds 8% of the global pharmaceutical market by volume (1% by value), and India has the largest number of manufacturing facilities approved by the US Food and Drug Administration (FDA) anywhere outside of the United States.[32] According to a recent analysis by the UK Department for International Development (DFID),[33] China is now the 10th largest pharmaceutical market after Mexico (9th), and the second largest producer of pharmaceutical ingredients in the world. For penicillin, vitamin C, terramycin, doxycycline and cephalosporin, China is the largest producer in the world. The Serum Institute of India is now the largest manufacturer of diphtheria-pertussis-tetanus (DPT) vaccine in the world.

According to the DFID study, 60% of UNICEF's vaccine requirements for the Expanded Programme on Immunization (EPI) are produced in just four countries: India, Indonesia, Cuba and Brazil. Thailand obtains 90% of its antiretroviral (ARV) ingredients from India, while the three South African producers of ARVs obtain 100% of their raw materials from India.

"The Thai Public Health Ministry has clearly stated that their ambitious antiretroviral treatment programme would not exist without generic drugs, which would not have been possible without Indian [active pharmaceutical ingredient] supply. ...Similarly, data from the Brazilian firm, Farmanguinhos, which supplies approximately 40% of the total [Brazilian] Ministry of Health ARV demand, shows that approximately 74% of total ARV purchases in 2002 and 94% of total ARV purchases in 2003 were supplied by Indian, Chinese and Korean firms."[34]

A recent supplement of *Nature Biotechnology*[27], contains several papers emerging from a three-year seminal study by the Canadian Program on Genomic and Global Health at the University of Toronto.[27] The papers contain numerous examples of the growth of health innovation in developing countries. For example, the number of exhibitors from developing countries attending the US Biotechnology Industry Organization's annual conference grew from 2 in 2001 to 97 in 2004. In late 2003, the Chinese firm Shenzhen SiBono GenTech became the first in the world to obtain a license for a recombinant gene therapy product. South Africa's Council of Scientific and Industrial Research (CSIR) has isolated a hunger-suppressing steroidal glycoside (P57AS3) from an indigenous plant, *Hoodia gordonii*, and licensed the product to the British biotechnology firm, Phytopharm. The Synthetic Antigen Laboratory at the University of Havana played a leading role in developing the world's first human vaccine with a synthetic antigen. The vaccine protects against *Haemophilus influenzae* infection, which often leads to pneumonia and meningitis in children under the age of 5. Made with a chemically produced antigen instead of fermented bacterial culture, it is much cheaper to produce and safer than vaccines coming from living organisms.

Despite these impressive developments affecting innovation capabilities in developing countries, many impediments remain. *The Economist*,[35] reporting on the University of Toronto study, summarized some of specific problems in IDC health innovation systems:

"Brazil needs better links between academia and industry. Egypt's budding biotechnologists are short of cash from both government and private sources. India's regulatory system is slowing down product development. South Africa needs to do more to reverse its brain drain, and train more researchers to boost their ranks."

It is these impediments, and others, that an initiative focusing on innovation in developing countries will help to address. Networking among developing countries is needed to share information and good practices for better alignment of national innovation policies and national health priorities. Such an initiative will be essential if the growing health innovation capability of developing countries is to have an impact on public health.

Is Health Innovation in Developing Countries likely to Strengthen the Fight Against Diseases of the Poor?

There is as yet insufficient understanding of the detailed nature, dimensions, trajectory, and potential impact of the revolution of innovation in developing countries, of whether and how this revolution can best address the needs of the poor. Presumably, a significant portion of public sector investments by developing countries in health research is based on national health priorities. These financial allocations require more in depth analysis to understand how they are being used, but it is clear that these countries are allocating large and increasing sums thereby providing the opportunity to allocate increasing amounts to research on diseases of the poor.

As emphasized by a recent UN Commission,[36] the role of the private sector in IDCs will be critical to success. Will it be possible to obtain their commitment, to a meaningful extent, to working on diseases of the poor? Most of the PD PPPs referred to earlier collaborate with pharmaceutical companies in developed countries, but none of these companies have prioritized diseases of the poor.[37] The amount of in-house funds spent on diseases of the poor is insignificant compared to what is spent on their lead candidates—for cardiovascular, cancer, chronic diseases.[38] Prioritizing the disease and health concerns of lucrative markets, for patients in the developed world, is understandable given all companies' drive to maximize return-on-investment.[39, 40]

In one documented case, a major product development PPP, the Meningitis Vaccine Project—a collaboration between WHO and the Program for Appropriate Technology in Health (PATH)—was able to forge a collaboration with an IDC manufacturer to produce an affordable meningitis conjugate vaccine for sub-Saharan Africa.[41] After extensive consultations with African health officials, the Meningitis Vaccine Project sought to develop a product at a price not to exceed $1.00 per dose. Multinational manufacturers were not interested in participating in this project.

According to the previously cited Indian private biotechnology investment projections, the R&D based private sectors in IDCs (as opposed to generics and material manufacture) are growing rapidly. It is critical to recognize that all of these companies are driven to maximize a return on investment. It is not surprising, then, that recent studies show that many of these companies are according priority to "diseases of the rich," both locally and abroad.[37] For example, in the patent data cited above, for all IDCs in 2003 only 10 of 105 drug, vaccine, or pharmaceutical patents issued were for diseases that predominantly affect the poor (three antivirals, one anti-malarial, two antibiotics for drug-resistant bacteria, two vaccines, and one treatment for vaginal infections).

However, some IDC companies are considering business strategies that include diseases of the poor, and there are reasons to speculate that—given their apparent cost and location advantages—they might be better placed to turn diseases of the poor into profitable business opportunities.[42] For example, the offer noted above by the meningitis program made good business sense to an Indian manufacturer but not to multinational manufacturers. In addition, an Indian biotechnology company, Lupin, has formed a PPP with the Council for Scientific and Industrial Research to push forward a TB drug[43]. The University of Toronto study of health biotechnology innovation systems in seven developing countries found that health biotechnology in IDCs was often focused on local health needs, including import substitution (with lower cost products), manufacturing process improvements, and novel invention[27].

Many IDC firms are now forming joint ventures with major international companies. Examples include an R&D partnership between Ranbaxy Laboratories (India) and GlaxoSmithKline for product identification[44] and, in Latin America, partnerships between Biomanguinhos/FIOCRUZ (Brazil) and Glaxo SmithKline for the production of *Haemophilius influenzae* vaccine, the Instituto Butantan (Brazil) and Aventis Pasteur for influenza vaccine, and the Instituto Finlay (Cuba) and Glaxo SmithKline for meningococcal group B vaccine.[45]

The Study of Health Innovation Systems

Scholars who study innovation systems have, until very recently, paid little attention to health. However, Dhar and Rao have recently examined the development of the pharmaceutical industry in India.[46] Their analysis identified key determinants of innovation.

- *Support for R&D*. The government provided extensive subsidies for R&D including tax concessions, soft loans and exemptions from price controls. The government also provided extensive support of government research centers such as for the Council for Scientific and Industrial Research that actively engage in collaborative projects with private industry. Beginning in the 1990s, the government developed policies to stimulate local public-private R&D partnerships for product development[47].
- *Manufacture*. Until 1994, government policy required firms that were not using high technology in production of bulk drugs or formulations to limit their foreign holdings to 40 percent to be considered Indian firms.
- *Intellectual property*. The Indian system recognized only process patents, excluding product patents for pharmaceuticals and agricultural chemicals from IP monopoly protection.
- *Domestic markets and exports.* This system allowed manufacturers to reverse engineer products that had been developed in the North—both on and off patent—for the domestic market. Patented products could then enter international commerce as soon as the relevant patents had expired.

The University of Toronto study[27] identified the following main features of innovation.

- *Government policy:* Proactive role and long term support for targeted R&D. Establishment and management of policies on intellectual property rights and drug regulation. Establishment of policies for addressing brain drain problems, encouraging private sector development.
- *Public research institutes:* The growth of scientific institutions with highly trained staff, increasing number of paper published in international peer reviewed journals, capability to produce high quality products, formation of various close linkages and partnerships among themselves and with the health system and the private sector, and development of products.
- *Industry:* The growth of private enterprise as reflected by increasing number of biotechnology firms, percent of the domestic market supplied by local firms, size of the domestic market, number of patents, and active knowledge flow and partnerships with the other parts of the innovation system.
- *The general public:* The receptivity of and support by the public to modern biomedical research particularly with respect to R&D involving genetics.

These findings, as well as those of Da Motta e Albuquerque and Cassiolato[48], indicate that there are key determinants of health innovation systems in developing countries, and that strengthening these systems can help address national health priorities.

A Framework for understanding Health Innovation Systems

In order better to understand health innovation systems in developing countries,[10] and maximize their ability to address diseases of the poor, we propose a framework with six determinants.[9,49, 50, 51]

- Creating capacity for and undertaking R&D
- Creating and sustaining capabilities to manufacture products to appropriate standards
- Promoting and sustaining domestic markets
- Promoting and sustaining export markets
- Creating and implementing systems for IP management
- Creating and implementing systems for drug, vaccine, diagnostic and device regulation

Table 4 shows these six determinants in a framework that illustrates how developing countries can progress in innovation capability[52]. An essential aspect of this framework is that the six determinants are assumed to be dynamically linked such that progress in one is facilitated by and dependant upon progress in the others.[53] Similarly, the lack of progress in one can impede progress in the other five. Therefore, if a country wishes to improve its innovation capabilities, it must make coordinated, dynamic progress in all of the determinants.

For example, it will be difficult to create an export market without a satisfactory national drug regulatory system. Similarly, (and obviously) it will be difficult to develop new products from public or private R&D without a domestic ability for high quality manufacturing.

Publicly funded research also depends on sound public-private partnerships—which ideally protect the public interest—to translate academic findings into high quality products.[54, 55] Finally,

Table 4: *Stages of health innovation capabilities in developing countries by six determinants (Capabilities in developed countries are shown for comparison)*

	Manufacture	Domestic Market	Export Market	R&D	IP System	Drug Regulatory System
Stage 1	Assembly of imported components	Small market	Very little except as toll manufacturer	Very little	Very limited understanding of IP; no IP protection	Very limited
Stage 2	Production on license or by copy with significant cost-advantages over Northern products	Growing domestic market of increasing interest to foreign companies; some import substitution; significant share of imports come from other developing countries	Growing trade; companies learning how to establish export markets; significant share of exports go to other developing countries	Local government and foreign donor-funded R&D to understand technology either to produce on license or to copy	Patents allowed for local inventors, but foreign inventors and investors still not interested because of lack of markets and IP protection; few local public-private partnerships (PPPs)	Limited services without enforcement capabilities
Stage 3	Manufacture of domestically developed high technology products with significant cost-advantages over Northern products; growing source of outsourcing	Rapidly growing domestic market of interest to foreign companies	Increasing exports make significant contribution to GNP; significant share of exports go to other developing countries	Scientifically advanced; funded predominantly by local government, and carried out predominantly by local public research institutions; capable of innovation	Advanced IP system, but poorly enforced; moderate experience with technology management in local PPPs	Advanced capabilities but not at highest level because of need to strengthen capabilities as appropriate
Developed countries	*Most developed capabilities to produce high technology drugs, vaccines, and devices*	*Highly profitable market in both the public and private sectors generating profits to support, in part, advanced research*	*Global companies*	*Generous support for health research from basic to applied. Large research investment by private companies including large pharmaceutical manufacturers and biotechnology companies*	*Established system of IP protection, and management of technology in local PPPs (e.g., university-industry R&D agreements)*	*A dedicated agency overseeing regulatory approvals of drugs/vaccines. In addition, the government oversees clinical trials & production facilities and enforces rules and regulations.*

IDCs need to develop intellectual property systems that can attract private investment and through ethical stewardship can address public health needs.

Experience from non-profit product development partnerships shows that IP rights can be used by the public sector to help attract private sector interest, mobilize the necessary funds, and ensure affordability and access to essential new health products. There is therefore a need for special care in the development of national IP systems. The most appropriate IP system for IDCs at different stages of development, particularly when viewed with a focus on diseases of the poor, remains an open question for policy research. This point has been raised by many commentators, perhaps most notably by the UK Commission on Intellectual Property Rights[56] and a recent major study by the World Bank[57]. On 1 January 2005 the Agreement on Trade Related Aspects of Intellectual Property Rights (TRIPS) went into effect for most developing countries. The impact of TRIPS on innovation is a matter of great debate and there is a need to study this impact especially with respect to innovation of health products needed by the poor.

A Network to Strengthen Developing Country Capabilities

In the complex field of new health product innovation, national governments, public and private sector product development efforts, and other related initiatives need to develop a coherent strategy for product development by addressing each of the determinants discussed above. Some IDCs may be able to address, and will address, all the determinants themselves. However, in other cases strategies involving coordination and learning among countries may be the best route. South-South information exchanges could help countries learn from one another to maximize the effectiveness of their health innovation systems to both achieve economic development and to address national health priorities, including diseases of the poor.

Developing countries with innovation capabilities could take on an important role of leading the global advocacy for health product innovation by sharing experiences, shaping priorities, developing workable strategies, conducting collaborative programs, and facilitating public-private collaborations. Such efforts would complement other initiatives including the PD PPPs which are primarily headquartered in developed countries (with numerous collaborative relationships in IDCs).[58]

A South-South based initiative could help to promote research on health innovation systems (a heretofore neglected field), support the dissemination of information about effective innovations system policies among IDCs, promote the conduct of demonstration projects of innovation system policies concerning one or more of the determinants, and provide a forum for IDCs to exchange information about health innovation systems. There is a need to mobilize relevant institutions in developing countries that are concerned with health innovation including R&D centers, technology and IP management centers, drug and vaccine manufacturers, sources of financing, regulatory bodies, and government institutions and non-governmental organizations that are concerned with access to health products and services.

As a mechanism to help strengthen health innovation systems in developing countries, this is consistent with key recommendations of previous studies that have examined the potential role of developing countries in health product innovation. The Evans Commission of 1990 highlighted that, in addition to addressing their own health needs, developing countries could contribute to the solution of global health problems.[59] The UK Commission on Intellectual Property Rights has examined the issue of the participation of developing countries in health product innovation.[60] The Commission's report notes,

"[Of important promise] might be a network of the public-private partnerships in developing countries, taking advantage of the concentration of research resources in

public sector institutions but also the opportunity to build research capacity in the private sector." It then goes on to recommend:

"Public funding for research on health problems in developing countries should be increased. This additional funding should seek to exploit and develop existing capacities in developing countries for this kind of research, and promote new capacity, both in the public and private sectors."

There are efforts underway to link and mobilize innovation in developing countries. For example, the Global Forum for Health Research supports an annual meeting to bring together key individuals and organizations concerned with research on priority health problems in developing countries[61] while the WHO-hosted Tropical Disease Research Special Programme has been a leader in this effort, and an 'incubator' of PD-PPPs.[62] The Global Research Alliance (GRA), composed of nine research institutes in developed and developing countries, seeks to facilitate and promote research in a number of development areas including health.[63] The Research Agency Collaborative for Global Health (REACH) is an emerging initiative to facilitate coordination and collaboration among national medical research agencies in both developed and developing countries.[64] This year, the WHO, along with nine developing countries, created and launched the National Regulatory Network for Vaccines. The participating countries are Brazil, China, Cuba, India, Indonesia, Russia, South Africa, South Korea and Thailand.

Some new efforts have been created for, and led exclusively by, developing countries themselves. Each of these could be an important contributor to an international network promoting health product innovation in developing countries:

- The Asia Pacific Economic Cooperation (APEC) is developing a comprehensive Strategic Plan for its Life Sciences Innovation Forum that addresses the issues raised in this paper.[65]
- India-Brazil-South Africa Dialogue Forum (IBSA), established in June 2003, includes a focus on intellectual property and access to medicine, traditional medicine, and research and development of vaccines and pharmaceutical products to address national health priorities.
- Technology Network for HIV/AIDS, announced during the 2004 Bangkok meeting on HIV/AIDS, includes Brazil, China, Nigeria, Russia, Thailand and Ukraine (and possibly South Africa and India in the near future). The Network will support research and South-South technology transfer on antiretroviral drugs and drug formulations, and the development of an HIV vaccine.
- Developing Country Vaccine Manufacturers' Association, established in 2000.[66]
- The Third World Academy of Sciences, whose goal is "to promote scientific capacity and excellence for sustainable development in the South."

However, based on the analysis presented here, something more comprehensive seems to be needed. The new initiative for health innovation systems in developing countries could help promote:

- research on health innovation systems;
- information sharing among IDCs;
- information dissemination on effective policies and practices;
- demonstration projects; and
- capacity building to support all the above points.

A major goal would be to help formulate policies in several areas including financing, capacity building in each of the determinants, and the formulation of laws and government regulations to promote health innovation.

Innovation systems research

There is a real need to encourage studies focusing on diseases of the poor. There is a need for innovation system theorists and global health practitioners to develop a more sophisticated literature on health innovation in developing countries. Methodologies for country, product and company case studies, derived from innovation systems theory, need to be applied to health innovation. This work would evaluate best policies and practices for consideration by IDCs. Another important product of this work would be the development of sustainable and consistent networks for information collection, analysis and sharing.

Information dissemination

There is a need to ensure the widest possible dissemination of best practices and polices identified through research and forum activities (see below) by, for example, codifying the output of innovation research into briefs for policy makers and practitioners.

Demonstration projects

There is a need to support demonstration projects to test implementation of proposed policies and practices in real life situations, and to determine how best practices and policies may vary depending on local conditions.

A Forum for IDCs

These activities could be addressed to improve the efficiency and effectiveness of health innovation systems in IDCs through a forum that would bring together diverse institutions and individuals, including scientists, policy makers, and leaders from international development and the private sector. Forum participants would:

- discuss specific innovation determinants and share experiences related to innovation in health products, drawing on the health innovation research activities;
- develop consensus on best practices and policies; and
- advance policy initiatives to improve the efficiency and effectiveness of health product innovation.

In 2003, The WHO Commission on Macroeconomics and Health called for an expanded outlay in 2007 of approximately $1.5 billion per year in R&D through a new Global Health Research Fund (GHRF).[59] These funds would be in addition to those already allocated to existing channels such as the WHO-based research programs on tropical diseases and human reproduction, and the PD PPPs. The report states, "A key goal of the GHRF would be to build long-term research capacity in developing countries themselves. The GHRF would provide vital funding for research groups in low-income countries."[59] Unfortunately, developed countries have not implemented this recommendation perhaps, in part, due to a lack of appreciation of how rapidly capabilities for innovation in developing countries are growing.

Arguably, those closest to the needs of the poor are the communities, scientists, policy makers, and institutions—public and private—in the countries where the challenges of poverty reside. As persuasively argued by Lucas,[67] it is essential to devise ways in which programs in developed countries can become better integrated with the scientific and technological institutions in developing countries that have been rapidly expanding their ability to undertake health innovation and are becoming part of the global knowledge economy.

Solutions depend on sophisticated global partnerships and collaborations to share knowledge and good practices in innovation policies to enable developing countries to drive and own agendas and harness their available capabilities to achieve the most effective ends including the improved health for the poor, and the generation of wealth.

Conclusions

To address global health disparities, the global community must harness the potential of national and regional health innovation systems throughout the world, with a particular focus on the development of technologies and techniques that are relevant to developing countries.[68] This means making full use of abilities, energy and resources in both developed and developing countries. IDCs should assume a leadership position in health innovation, both because of their increasing capacity to address global health problems, and because they are literally closer to the legitimate voices of those living in poverty. A new focus on health innovation systems in developing countries should capture the imagination of those in leadership positions and many others who share the belief that all people, especially the disadvantaged, should be able to share equitably in the benefits of modern health innovation.

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Nation Building through Science and Technology: A Developing World Perspective

10th Zuckerman Lecture, *The Royal Society*, London

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The invitation to deliver the 10th Zuckerman Lecture is one of the greatest honors of my life. I want to thank the Office of Science and Technology and Lord Sainsbury for doing me this honor. It is also a very special privilege to pay a tribute through this lecture to Lord Zuckerman, who was one of the most distinguished scientists of the 20th Century. He left such a huge imprint on science in this great nation. I feel overwhelmed when I look at my nine predecessors; all of them were men of such great eminence. I must also add that last year, when I was sitting in the audience in the front row listening to Sir David King, who gave the 9th Zuckerman Lecture, little did I realize that we would be swapping places this evening! Sir David's brilliant and stimulating lecture is still very vivid in my memory. He brought such a wonderful new perspective to this vital issue of the science of climate change. His will be a very hard act to follow but I'll do my very best. I do hope my best will be good enough for this evening.

The topic that I have chosen for the tenth Zuckerman Lecture is "Nation Building through Science & Technology: A Developing World Perspective." I come from a developing country, namely India. India's civilization is one of the world's oldest, with very rich traditions in science and technology. India's contributions to astronomy, to mathematics, to medicine, and other scientific fields in millennia gone by have been truly phenomenal. Science in India was always very closely intertwined with culture and philosophy, and it was also tempered with very unusual wisdom.

Today we look at the modern India that was built after independence. We must give credit to Pandit Jawaharlal Nehru, our first Prime Minister, who had such a deep faith in science and technology as a powerful tool of socio- economic transformation. He helped us take the first definitive steps in nation building. His deep commitment to science and tech-

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nology appears in his famous statement that "it is an inherent obligation of a great country like India, with its traditions of scholarship, original thinking, and great cultural heritage, to participate fully in the march of science, which is probably mankind's greatest enterprise today." India has benefited immensely from this enthusiastic participation in "the march of science." Sustained investments made in higher education and science and technology have helped build a new nation, which now aspires to reach developed country status by 2020. Drawing from the Indian experience, I would like to share with you my own perspective on how the nation building process in the developing world can be accelerated through the powerful tool of science and technology.

Positioning the Developing World in a Global Landscape

Let me begin by looking at the global landscape and the position of the developing world in it. We can, in a simple-minded way, position all the countries in a single diagram in terms of their relative economic strength and indigenous capacity in science and technology (Table 1). In the top right-hand corner are such developed nations as the USA, Japan, countries in Europe, etc. They have a very high indigenous science and technology capacity and a very high economic strength. In contrast, in the lowermost left-hand quadrant are the least developed countries, including those in sub-Saharan Africa, where indigenous science and technology capacity as well as economic strength are low. In the top left-hand quadrant are countries that have attained very high economic strength by the strength of their natural resources (such as the oil rich Middle East countries). But these do not have any significant indigenous science and technology capacity.

The most interesting quadrant is the lower right-hand area. These countries have high indigenous science and technology capacity but relatively low economic strength. They include India, China, Brazil, Argentina, Chile, South Africa, etc. Of course, the positions of developing nations in this diagram are not static. Different countries in different times of history occupied different positions on this map. For instance, not too long ago, Korea belonged to the lower right- hand quadrant. But they moved upwards to attain the status that OCED countries enjoy today. After all, Korean companies like LG and Samsung dominate global markets and compete with the best in the world today, a phenomenon unknown thirty years ago!

There is an interesting equilibrium between countries in these different quadrants. For instance, countries like India and China provide huge human capital to the USA. However, these countries are becoming global research and design development centers today. Leading industrial enterprises from the USA and Europe are physically setting up their research and development centers in these countries, something that was not occurring a decade ago. Because of the strength of these scientifically advanced developing countries, a subtle but definite tension is also created. For example, the capacity of these countries to create cheaper versions of generic drugs, or indeed to copy new molecules in a protected intellectual property regime (as has happened in India), has recently led to fierce intellectual property rights (IPR) debates. When multinational companies offered a year's treat-

Table 1: *Relative economic strength and indigenous capacity in science and technology of different countries*

Economic Strength	Oil Rich Middle Eastern Countries	USA Europe Japan
	Sub-Saharan Africa	Brazil China India
	Indigenous S&T Capacity	

ment of an anti-retroviral cocktail of HIV/AIDS drugs for US $10,000 in South Africa, it was CIPLA, an Indian pharmaceutical company, that offered it for a mere $350. This case created a major public debate. The issue of TRIPS and public health was brought forward in the Doha Declaration. This in turn awakened many to the difficulties surrounding access to medicines for the poor and the rights and obligations of the big pharmaceutical companies.

New dynamics of cooperation and competition have also arisen amongst these countries positioned in different quadrants. Take, for instance, the issue of the recent outbreak of SARS in China. When this happened, research on SARS started not only in China and Hong Kong but also in the USA, Canada, and Germany. In the race to sequence the SARS genome, Canada won. We thus have a new equilibrium in this new global setting, one that drives cooperation and competition in unexpected and peculiar ways.

Benefits of Investment in Science and Technology in the Developing World

It is well known that the success of today's advanced industrialized countries is due to their history of innovation along different dimensions, including the creative use of science and technology to add value to their natural resources (physical as well as human), combined with strong institutions, trade, and organization. Many, however, many ask whether the scarce resources of a poor developing nation should be invested in science and technology. It is important to realize that investments in science and technology are investments in the future. Furthermore, it has been shown time and again that a dollar invested in a developing country may go very far. It can create international competitiveness as well as socio-economic development.

One can cite many examples from around the world to illustrate the point. Because of my greater familiarity with the Indian scenario, I will cite examples from India. The generic lessons drawn from these examples, however, are valid across the globe.

Take as a specific example the Indian space research program. The research and development budget for this program was $450 million in 2002. The R&D budget for General Motors in the same year was around $7 billion. What has India's space program achieved with such a small budget, one equivalent to 7% of a single company in the USA? Today, India has developed a strong capacity to design, develop, test, and fabricate its own launch vehicles and satellites. India has moved from one sophisticated launch vehicle to another—that is from SLV to ASLV to PSLV to GSLV. It has done this without any help from anyone, since for love or for money, no one was willing to provide the technology in these strategic sectors. India has launched 35 satellites so far, of which 17 are Indian launches, 23 are in orbit, and 14 are geostationary. India has also launched satellites of foreign customers, including Germany and Korea.

India has also achieved international competitiveness in remote sensing with these small investments. Tina Cory, the Director of Application and Training of Eosat, which is a US based satellite imagery marketing firm, recently said that the "Indian Remote Sensing (IRS) series of remote sensing satellites is a ‘jewel in the crown.’" It is predicted that India's IRS series may actually capture 30% of the global market in remote sensing.

The real impact of the Indian space program has been in terms of nation building through accelerated socio-economic development, which has addressed problems ranging from education to drinking water. Thanks to India's progress in space research, one is able to “reach the unreached” in distant villages, valleys, hilly areas, and so on. Just as there was a “green revolution,” today India is witnessing a “connectivity revolution” that is bringing this vast nation together. Primary, secondary, and tertiary education is reaching vast masses through the use of distance learning devices as well as remote access to diverse educational resources.

Space research is also impacting on other human needs, such as drinking water. This problem is acute in India. I still remember Rajiv Gandhi telling us something striking in one of our meetings of the Science Advisory Council to the Prime Minister (SAC-PM). He said that John Kennedy had a dream to land a man on the moon; his equivalent dream was to take drinking water to 180,000 villages that had no access to it. India's space program has been able to draw hydro-geomorphological maps across the country. This scientific source-finding approach has meant that the success rate for groundwater targeting has improved from 45% to more than 90%. Around 160,000 villages with drinking water problem have benefited from this.

Lives of poor fishermen have been impacted too. Through the satellite IRS P-4, potential fishing zones were identified. Information on the locations of these zones is communicated to the fishermen through radio and Internet. The catch in potential fishing zones is higher than the normal catch by approximately 100% to 500%! Lack of cyclone warnings in the coastal regions of Andhra Pradesh used to wipe out entire villages in the aftermath of a cyclone. Early warning systems now ensure that this no longer happens. Clearly, for both poor nations and rich nations, investment in science and technology plays a key role in nation building.

Making Technology Work for the Poor

Developing nations are besieged with several burning problems. Let us look at some disturbing figures in the year 2000. Look at education. There were 854 million illiterates in the world. 325 million children end school at the primary/secondary level. There were 968 million people who had no access to drinking water. 2.4 billion people lived without access to basic sanitation. There were 2.8 billion people living on less than $2 per day. Can technology help make a difference and change these statistics, both quantitatively and qualitatively? Again the answer is a positive one, but only if the technology is directed appropriately on problem solving for the poor.

Consider illiteracy. In India, we have about 200 million adults who cannot read or write. There are not enough trained teachers, and using conventional methods of learning requires 200 hours of instruction. This leads to many dropouts. India's illiteracy rate today is being reduced only at the rate of 1.3% per annum. At this rate, India will need 20 years to attain a literacy level of 95%. Can we do it in less than 5 years by using technology?

The great doyen of India's IT industry, F.C Kohli, believes that this can be accomplished through his recent breakthrough. He has developed a unique Computer-based Functional Literacy (CBFL) method based on theories of cognition, language, and communication. In this method, scripted graphic patterns, icons, and images are recognized through a combination of auditory and visual experiences by using computers. The method emphasizes learning words rather than alphabets. While it focuses on reading, it also acts as a trigger for people to learn to write on their own.

Based on this method, Kohli's team has developed innovative methodologies using IT and computers to improve reading capabilities among adult illiterates. This experiment was first conducted in Medak village near Hyderabad. Without a trained teacher, the women started reading the newspaper in Telugu in 8 to 10 weeks. Thereafter, Kohli's team carried out more experiments in 5 states and in 5 languages. 40,000 people have been made literate in these pilot experiments so far.

Kohli is an engineer. He believes in pragmatic and affordable solutions. His team ran these lessons on Intel 486s and earlier versions of Pentium PCs modified to display multimedia. There are around 200 million such "obsolete" PCs in the world that have been discarded and can be made available free of cost. By using these PCs, the cost of making one person literate would be less than Rs.100, slightly over one British pound. With CBFL, Kohli claims he can increase literacy in India to 90-95% within 3 to 5 years instead of 20 years.

Kohli was invited in South Africa to demonstrate the power of CBFL. He dealt with a group whose ages varied from eighteen to eighty. All of them started reading a newspaper in eight to ten weeks. Kohli told me that one of the participants said, "I used to go to the church every Sunday morning. I used to hold the Bible in my hand—pretending to read but not understanding a word of it. Today I understand what I am reading." How touching! Kohli's CBFL can help 854 million illiterates in the world—such is the power of this technology.

Technology is a many splendored endeavor. There is low technology and high technology. Both can be used to solve the problems of the poor. The prestigious medical research journal *Lancet* referred to the greatest medical breakthrough of the 20th Century. That breakthrough was a simple oral dehydration therapy. Tens of thousands of children from the developing world used to die in the laps of their mothers because the mothers did not know how to treat diarrhea. The normal treatment through intravenous injections costs $50 per child, which is impossible for some one who earns less than $2 a day! A simple sugar and salt solution in the right proportion was found to increase the intake factor by twenty-five. This saved millions of children. But this was a simple technology. What about the use of advanced technology? 11 million children around the world die before reaching their fifth birthday. The major causes of infant mortality are such infectious diseases as pneumonia, measles, and malaria. Molecular diagnostics involving rapid DNA-based diagnostic methods present a powerful set of tools to arrest child mortality. Can we make it cheap enough so that it benefits the poor? The answer is yes, provided we make an effort.

Sometimes scientific advances will create solutions, but adopting them to conditions in the developing world can pose a challenge. Vaccines for killer diseases such as measles, whooping cough, diphtheria, and tetanus were developed because the antigens to tackle these diseases were known for a long time. But they required sterile conditions and reliable cold chains. Transporting them to village health centers thousands of miles away was a challenge. Technological advances leading to freeze dried and more heat-stable vaccines that do not require refrigeration made a big difference.

These advances and solutions can be developed by developing countries. How does one set up a telephone exchange in a village in the Rajasthan desert in India, where temperatures go beyond 50°C and the sand storms create unmanageable dusty conditions? It was the Centre for the Development of Telecommunications (C-DOT) in India that designed the rural exchanges that could withstand these aggressive conditions.

Our real challenge seems to be to get the "best minds" around the world to engage themselves in providing solutions to the problems that can make a difference to humanity. Every thirty seconds, a child somewhere dies of malaria. Can you imagine the impact if we had a good vaccine for malaria? HIV/AIDS is ravaging nations today. Can you imagine what impact a new vaccine on HIV/AIDS will have? Electric power generation and grid delivery were first developed in 1831 but they are still not available to a third of the world's people. Can you imagine what impact a breakthrough on low cost fuel cells and photovoltaics for decentralized power supply will have? We must find ways and means for the best scientific minds in the world to be first ignited and then united to tackle these challenges. Maybe we need a high profile and massively funded "Millennium Challenge Initiative" funded through a Global Science Fund.

While new technological solutions can solve the problems of the poor, public concerns about the risk of new science and technology also need to be handled with care. The challenge before many poor countries with vast populations is simply to get "more from less." That means more food production from less arable land per capita, less water per capita, and less environmentally damaging inputs in agriculture. This requires the judicious use of such emerging technologies as information technology, space technology, and biotechnology. When it comes to biotechnology, the risk assessment of genetically modified crops immediately emerges as a key issue. Different nations have adopted different approaches that are promotional, protective, precautionary, or totally preventive. Obviously we need to adopt a precautionary but promotional effort, one based on sound and transparent scientific methods of evaluation with full public participation. If this does not happen, then the benefits of technological revolutions such as these will bypass precisely those parts of humanity that can most benefit from them.

The Millennium Development Goals seek to eradicate extreme poverty and hunger, achieve universal primary education, promote gender equality and empower women, reduce child mortality, improve maternal health, combat HIV/AIDS, malaria, and other diseases, and ensure environmental sustainability. Judicious investments in science and technology and the consequent development of indigenous technological capacity can help us reach each of these goals, possibly even before 2015. But we can do this only if we build technological capacity in developing nations. How can we achieve this?

Building Indigenous Technological Capacity

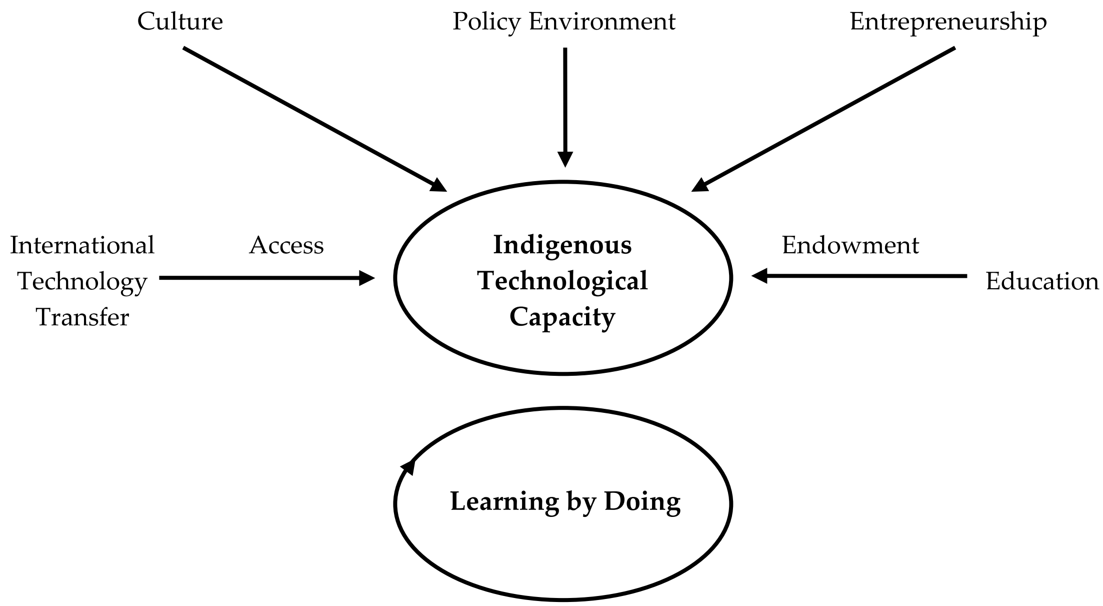
The critical factors that help to build indigenous technological capacity are shown schematically in Figure 1. These factors include a conducive policy environment, entrepreneurship, promotion of a culture of innovation, access to technology through international technology transfer, an educated and skilled work force, and finally an emphasis on indigenous efforts involving "learning by doing." The critical role paid by many of these factors is too obvious to need further elaboration. However, the importance of a conducive policy environment is not so obvious. Let me illustrate its importance.

A policy environment influences the innovative capacity of firms, the society, and indeed that of the nation as a whole. Let me illustrate this with a striking example from India. As I stand here in London, I am reminded of the way the car industry has changed in India. In the last fifty years, the wheel has turned full circle. It was the British Morris Oxford that sold as an Indian Ambassador on Indian roads some fifty years ago. Today it is an Indica, an Indian car, designed and built in India, that is being sold as the City Rover on London roads!

This transformation was entirely due to a policy change. I remember the legendary Indian industry leader JRD Tata saying in desperation in February 1978 that Telco, which was his company, was not allowed to develop a car. It was only in July 1991 that India liberalized its industrial policy and opened up. It was in 1993 that Ratan Tata, who succeeded JRD Tata, was allowed to make a car. He gave this challenge to 700 engineers who had never designed a car before in their life. Spending only one tenth of what major auto manufacturers would have invested, he and his team designed and developed a new Indian car, Indica, that was world class. The creative ability of his 700 engineers from Telco was always there for all to see, but it got "expressed" only when the government policy changed through opening up and liberalization.

Creativity gets nurtured in a flexible, competitive, and dynamic economic environment. In a developing country context, this means building on reforms that emphasize openness to new ideas, new products, and new investments. For example, telecommunication laws that favor government monopolies will isolate countries from the global network and retard growth.

Figure 1: *Critical factors required in the building of indigenous technological capacity*



The recent experience in India has shown that competition among providers of information and communications technology has led to increased investment, increased connectivity, and better service. It has also heralded the age of new technological breakthroughs.

But open markets and competition alone will not be enough. Expanding human skills to meet the challenge of relentless technological change becomes critical. Advanced skills developed in secondary and tertiary schools become increasingly important. As do vocational and on-the-job training. For firms to remain productive and competitive, they will have to make massive investments in building the quality of human capital. Only then can the indigenous technological capacity be sustained at adequate levels.

Consider the impact of international technology transfer on indigenous technological capacity as shown in Figure 1 above. Facilitating the access of third world countries to the technologies they require is key to accelerating the pace of their economic and social development. Such access is generally the result of licenses and technology transfer agreements. The prospective technology seekers in developing countries, however, face serious difficulties in their commercial dealings with technology holders in developed countries. These difficulties arise for a variety of reasons. Some arise from the imperfections of the market for technology. Some are due to the relative lack of experience and skill in developing countries of enterprises and institutions to conclude adequate legal arrangements to acquire the technology. Other difficulties stem from government practices, both legislative and administrative, in both developed and developing countries, that influence the implementation of national policies and procedures designed to encourage the acquisition of technology by developing countries.

Concrete examples show that technology transfers to the developing world have not taken place when most needed. The 1990 Montreal Protocol on Substances that Deplete the Ozone Layer ran into conflicts over commitments to ensure fair and favourable access for developing countries to chlorofluorocarbon (CFC) substitutes protected by IPRs. The 1992 Convention on Biological Diversity aims to ensure fair and equitable use of genetic resources partly through technology cooperation, but its technological provisions have received little attention. The 1994 TRIPS agreement calls for technology transfer to the least developed countries, yet that provision has scarcely been translated into action.

There are additional difficulties. Scientifically advanced developing nations are not necessarily considered as an endless source of demand by firms in the developed world. Technology buyers from such countries are beginning to be seen as potential competitors in the world market. Technology sales are therefore conditioned with marketing territory restrictions. The age of straightforward technology licensing agreements is also over. It is giving way to technology-cum-market, technology-cum-stakeholding, and technology-cum-product swap. Technology is available to a buyer only if it fits in with the supplier's global scheme.

Figure 1 also shows that the most important factor in developing indigenous technological capacity is that of "learning by doing." This requires investment in local research and development. Some developing nations have remained mere "assemblers" instead of becoming "smart assimilators." Japan is a classic case in point. It invested heavily in international technology transfer, but then moved forward aggressively through strong local research and development to create globally competitive products. Cleverly designed national policies do stimulate this drive towards "learning by doing." Innovative ways of linking universities and industry, creating fiscal incentives to promote research and development by private firms, and venture capital financing are just some of the proven ways to promote this process.

Bridging the Development Divide

The development gaps between rich and poor nations today are truly striking. The richest 1% of the world's people received as much income as the poorest 57%. In 1998, 29 OECD countries spent $520 billion on research and development—more than the combined economic output of the world's 30 poorest countries. These countries had 91% of the share of the new patents issued in 1998, which means that the remaining 81% of the people had only 9% of the share. Can we ever dream of bridging this divide? What needs to be done?

As an example, let us consider just one sector: Information and Communications Technology (ICT). The revolution in ICT can provide powerful new tools for a major socio-economic transformation of people in poor countries. But can they really benefit from this revolution? Think about the huge asymmetries in ICT infrastructure! Whereas one in two Americans is on-line, only one in 250 Africans is on-line. More strikingly, one out of two citizens in this world has never had the luxury of making a telephone call! The whole of Africa has only 14 million telephone lines, which is less than those in Manhattan alone. 15% of the people in the world do 90% of the global spending on IT. An average OECD country has 40 times more personal computers, 110 times more mobile phones, and 1600 times more Internet connectivity than a country in Africa.

However, there is good news. Rapid advances in technology are bringing costs down dramatically, with an attendant increase in speed and quantity. Transatlantic cable was laid in the late 1950's. The cost of one minute of voice communication was then $2.44. Today it has plummeted to less than one cent. The processing power of a computer by 2010 is expected to be 10 million times more than that in 1975. The prices for providing bandwidth are crashing due to fiber optic network technologies.

We need to take advantage of these breathtaking advances to provide the poor with access to these new technologies. We also need to focus more on creating technologies that are specially suited to the poor. As an example, consider the Indian development of the "simputer" by the Indian Institute of Science (IISc) in Bangalore. A handheld internet appliance based on the Linux open source operating system costs less than $200. The intellectual property rights have been transferred for free to the non-profit Simputer Trust, which is licensing the technology to manufacturers at a nominal fee. Simputer provides Internet and e-mail access in local languages with touch-screen functions and micro-banking applications. Speech recognition and text to speech software for illiterate users have been provided. This is clearly a technological advance that can reduce the divide between developed and developing countries.

The Indian Institute of Technology in Madras offers another heartening example. It has created a low-cost internet access system that needs no modem and eliminates expensive copper lines. The technology is based on a wireless local system, which is ideal for providing access to low-income communities throughout India and beyond. Licensed to manufacturers in India, Brazil, China, and France, the technology is already in use internationally in Fiji, Yemen, Nigeria, Tunisia, and elsewhere.

We can draw two lessons from these examples. The first is that both these initiatives were supported by public funding and incentives. The second is that they came from two of India's most elite institutions: the Indian Institute of Science and the Indian Institute of Technology. Scientists in such institutions are often accused of working on problems that will fetch them peer recognition from western scientists, rather than on problems that can make a difference to their country. These brilliant exceptions prove that with proper support and encouragement, we can change the direction of people and institutions to eventually benefit humanity at large. Clearly, hope calls us to bridge the great, inhumane divide between rich and poor countries.

Creating Wealth through Traditional Knowledge

Many developing countries are described as rich countries that poor people leave. Their richness lies in their traditional knowledge, biodiversity, and other untapped sources of wealth. This traditional knowledge relates to such diverse domains as geology, ecology, botany, agriculture, physiology, and health. There is a great potential to create wealth through such traditional knowledge, but this opportunity so far has remained largely untapped.

One of the concerns of the developing world is that the process of globalization is threatening to appropriate elements of these societies' collective knowledge into proprietary knowledge for the commercial profit of a few. They seek to protect these knowledge systems through national policies and an international understanding linked to international property rights. At the same time, they seek to provide for the development and proper use of this knowledge for the benefit of its natural possessors. To encourage communities, it is necessary to scout, support, spawn, and scale-up this green, grass-root innovation. Linking innovation, enterprise, and investment is particularly important.

New experiments on benefit sharing models for indigenous innovation are beginning to emerge. Again, an experience in India is worth sharing. It relates to a medicine that is based on the active ingredient of a plant, *Trichopus zeylanicus*, found in the tropical forests of southwestern India and collected by the Kani tribal people. While on an expedition with the Kani in 1987, scientists at the Tropical Botanic Garden and Research Institute (TBGRI) in Kerala learned of the plant, which is claimed to bolster the immune system and provide additional energy. These scientists isolated and tested the ingredient and incorporated it into a compound that they christened "Jeevani," the giver of life. The tonic is now being manufactured by a major Ayurvedic drug company in Kerala. In 1995, an agreement was reached to share the license fee and 2% of the sales of the product as royalty that is receivable by TBGRI and will be shared on a fifty-fifty basis with the tribe. This marks perhaps the first time that intellectual property held by a tribe has provided compensation in the form of cash benefits directly to the IP holders.

The granting of patents for non-original innovations based on the developing world's traditional knowledge has caused great concern in the developing world. It was CSIR from India that challenged a US patent granted for turmeric's wound healing properties. In a landmark judgment, the US Patent Office revoked this patent in 1997, having ascertained that there was no novelty because the findings had been known by innovators in India for centuries.

Yet another case of revocation followed in May 2000. A patent granted to W.R. Grace Company and the US Department of Agriculture on Neem by the European Patent Office was squashed again on the same grounds that its use was already known in India. In yet another case, India filed a reexamination request for a patent on Basmati rice lines and grains granted by the US Patent and Trademark Office in 2000. In response, the Ricetec Company of Texas decided to withdraw the specific claims challenged by India as well as some additional claims. In a further action, the examiner decided to disallow seventeen of the twenty claims.

To mitigate this persistent problem, the Indian Government took steps to create a Traditional Knowledge Digital Library (TKDL) on traditional medicinal plants and systems. This will also lead to a Traditional Knowledge Resource Classification (TKRC). Linking this to the internationally accepted International Patent Classification System (IPC) will mean building a bridge between the knowledge contained in an old Sanskrit Shloka and the computer screen of a patent examiner in Washington DC! This will eliminate the problem of incorrectly granting patents since the Indian rights to that knowledge will be known to the examiner.

Eventually, the creation of the TKDL in the developing world would serve a bigger purpose in providing and enhancing its innovation capacity. It could integrate widely scattered and distributed references about traditional knowledge systems of the developing world in a retrievable form. It could also bridge traditional and modern knowledge systems. Moreover, the availability of this knowledge in a retrievable form in many languages will give a major impetus to modern research in the developing world. The TKDL can then get involved in innovative research to add further value to this traditional knowledge, such as the development of an allopathic medicine based on a traditional plant based therapeutic. Sustained efforts to modernize the traditional knowledge systems of the developing world will create higher awareness of its potential both nationally and internationally, as well as establish a scientific approach that will ensure higher acceptability of these systems by practitioners of modern systems and the general public.

Intellectual Property Rights and Development

An ideal regime of intellectual property right strikes a balance between private incentives for innovators and maximizing access to the fruits of innovation for the public interest. This balance is reflected in article 27 of the 1948 Universal Declaration of Human Rights, which recognizes both that "Everyone has the right to the protection of the moral and material interest resulting from any scientific, literacy or artistic production of which he is the author" and that "Everyone has the right ... to share in scientific advancement and its benefits." The burning question seems to be how to optimally balance the interest of the inventor and the interest of society.

Intellectual property rights are being harmonized worldwide. As per the obligation under the Trade Related Intellectual Property Systems (TRIPS) agreement, developing countries are now implementing national systems of IPRs following an agreed set of minimum standards, including such items as twenty years of patent protection. The least developed countries have yet to fully implement

TRIPS, and one of the developing world's concerns is that while a fully harmonized IPR system is now being advocated, today's advanced economies had refused to grant patents throughout the 19th and early 20th Centuries. They formalized the enforced intellectual property rights gradually as they shifted from being net users of intellectual property to being net producers. Indeed, France, Germany, and Switzerland, who are leading developed countries today, completed "standard protection" only in the 1960s and 1970s.

In the developing world, the impact of TRIPS will vary according to each country's economic and technological development. Middle-income countries like Brazil and Malaysia are likely to benefit from the spur to local innovation. Countries like India and China, which have a large intellectual infrastructure, can gain in the long-term by stronger IPR protection. But least developed countries, where formal innovation is minimal, are likely to face higher costs without the offsetting benefits.

I was privileged to be a member of the UK Commission on Intellectual Property Rights. The Report of the Commission addressed the issue of IPRs and development as it pertained to public health and access to food, information, education, and other important items. The sum and substance of the report can be briefly summarized as follows. For too long, IPRs have been regarded as food for rich countries and poison for poor countries. It is not as simple as that. Rich countries can get indigestion from overindulgence. And poor countries may find them a useful dietary supplement, provided that they are accommodated to suit local palates and are not force-fed. The appropriate diet for each developing country needs to be decided on the basis of what is best for its development. This is the guiding principle that should help national governments and the international community to arrive at rational decisions that can help integrate intellectual property rights into a balanced development policy. Reaching that balance, however, requires a real understanding between the global players. The sooner we reach it, the better it will be for mankind.

"Technoglobalism" and the Developing World

Trade globalization is growing at a rapid pace, and so is the globalization of research and technology. A new term, "Technoglobalism," has recently been coined to describe this phenomenon. The term "Technoglobalism" means a strong interaction between the internationalization of technology and the globalization of the economy. Technoglobalism has created a widening cross-border interdependence between individual technology-based firms as well as economic sectors. Technoglobalism provides both challenges and opportunities for the developing world, especially scientifically advanced developing nations.

India, for example, is rapidly becoming a global research and development hub. More than one hundred major companies around the world have set up their R&D centers in India just during the last five years. The biggest would be the R&D centre of General Electric (GE) at Bangalore. Its current size of 1600 employees will increase to around 2400 employees, making it GE's second largest R&D centre in the world. This is not happening in India alone. Similar phenomena are occurring in China, Korea, Singapore, Taiwan, and elsewhere. Specialized clusters are coming into existence in the Philippines and Malaysia, and many leading enterprises around the world are building innovation platforms by multi-sourcing innovations.

Why has the multi-sourcing of innovations gained such prominence? Primarily because there is increasing pressure to shorten international market penetration times for new products, to shorten the period of R&D, and to decrease the market lifetimes for new products. Thus innovations are beginning to have multiple geographical and organizational sources of technology, with increasingly differentiated and innovation specific patterns of diffusion. R&D in high-technology industries such as biotechnology, microelectronics, pharmaceuticals, information technology, and new materials has become highly science-based. The costs of R&D are thus also increasing phenomenally, which also drives multi-sourcing.

The strategic position of corporate central laboratories within large firms has been progressively weakening. These firms around the world are becoming very selective, with internal developments focused on critical products and processes. They complement their internal efforts by acquiring external technology from around the globe.

The creation of seamless laboratories around the world is also being helped by the evolution of global information networks. Indeed, these networks allow for the real-time management and operation of laboratories in any part of the world. Companies gain a competitive advantage by using the global knowledge resource and working with a global time clock. The trend is also being fuelled by the shortage of R&D personnel in some emerging high technology areas in industrialized countries. Companies bridge that demand-supply gap in skills with external outsourcing. Obtaining access to high-quality scientists, engineers, and designers is at the top of the agenda now for many major companies.

An example from the European Union (EU) reveals the severity of the shortage of R&D personnel. For the EU to meet the goal set at the Barcelona Summit of raising R&D spending as a share of GDP to 3% by 2010 will require 700,000 new researchers. Obviously, there will be a great demand—a supply gap. Not surprisingly, there will be a greater draw on "third world researchers," as one EU representative put it recently.

The demographic shift in the developed world means that developing countries with relatively favorable demographic profiles (those with a large proportion of working and talented young people) can become global innovation hubs. Companies from the developed world will not only outsource innovation to these countries but will also set up R&D based innovation centers. This progressive shifting of the R&D location from developed to scientifically advanced developing nations is likely to have strong social, cultural, political, economic, and strategic implications. Increased local demand for high quality science and scientists will result as competition develops between local institutions and industry on the one hand and foreign R&D enterprises on the other. Clearly, access to superior human capital will be a key driver of change. Shifting the "center of gravity" of knowledge production to these scientifically advanced developing nations will have strategic implications in the long run. Such shifts will also lead to a gradual reversal of brain drain due to the increased opportunities in one's native country.

Brain Drain to Brain Gain

Indeed, let us place the brain issue drain in a broader context. Why does brain drain take place? I found the answer one day. I was involved in the process of interviewing for the Chief Innovation Officer of the National Innovation Foundation in India. I found that the individual that we were interviewing was an expert in branding a product. I said, "I want to brand India. How would you do that?" He was puzzled. He had branded a soap and a refrigerator, but he wondered how he could brand a nation. I said, "I will make it easy for you. Let me tell you how other nations brand themselves. For instance, the US brands itself as a land of opportunity." He immediately replied, 'I will brand India as a land of ideas." Now here is the problem. India is a land of ideas but the USA is a land of opportunities. That is why young people with aspirations go to the USA, which provides them with an opportunity to reach their own potential.

I believe that for young people it is not the "physical income" but the "psychic income" that matters most. The incentives are not just financial. The fun of creation, the admiration received from their peers, the excitement and glory of taking part in the process of building something new and exciting matters to them much more. That is why a computer engineer in India works on the challenge of the Param computer in the Centre for Development of Advanced Computation (C-DAC) in India on a salary that is a small fraction of what he would get from IBM in India. That is why a space scientist in the Indian Space Research Organisation works on the indigenous satellite-launching vehicle GSLV rather than for NASA. That is why I came back to India in 1976 on a princely salary equivalent to 140 British pounds per month, and so did many of my colleagues. The problem is that our number is still a small fraction.

Brain drain is not just a developing world phenomenon. It exists in the developed world too. The Italian scientist Riardo Giacconi, a Nobel Laureate in Physics, summed it up beautifully when he said, "A scientist is like a painter. Michael Angelo became a great artist, because he had been given a wall to paint. My wall was given to me by the United States." Italian, English, and German scientists have also migrated to the United States, as have Japanese scientists. A recent US National Science Foundation report (2002) shows that the percentage of Japanese Ph.D.s who remained in the USA increased from about 35% in 1995 to over 70% in 1999. However, the damage that brain drain does to the developing world is far greater than in the developed world. Let me provide an analytical perspective to this argument.

The ecology of the intellectual process places outstanding scientists and inventors in a pyramidal structure of power-law fashions. The distribution of scientific productivity was analyzed by A.J. Lotka of the Metropolitan Life Insurance Company in 1926. The result of Lotka's investigation [Journal of the Washington Academy of Sciences, 16, (1926) 317-323] was an inverse square law of productivity, which states that the number of people producing n papers is inversely proportional to n^2. This means that for every 100 authors who produce one paper in a given period of time, there are approximately $100/2^2$, or 25, who produce two papers. Simultaneously, there will be $100/(10^2)$ or one, who will produce ten papers, and so on. Interestingly, the same law applies to patents too. Francis Narin and Anthony Breitzman [Research Policy, 24 (1995) 507-510)] analyzed the data on patents in semiconductor technology and showed that Lotka's law was also applicable here.

It certainly appears that scientific and technological creativity and productivity lie in the minds and abilities of a relatively small number of highly talented individuals. The developing world continues to lose them to the developed world. For example, the cream of the cream from Indian IITs, which are India's premier institutions, leaves the Indian shores year after year. India comforted itself by saying that it did not really matter if it lost a small number. After all, it is a country with a population of one billion. But India did not realize the implications of Lotka’s law, that it was these few individuals who made such a huge difference to those economies abroad. India did not realize that when it lost 1% of its top talent, it also lost 90% of its intellectual energy. A recent UNDP report estimates that 100,000 Indian professionals leave the country every year to take up jobs in the United States. It estimates a resource loss of $2 billion per year for India. However, looking at the potential economic gains that these exceptionally talented people could have made in India, one realizes that the losses are even higher!

Different developing nations have used different means to handle this issue of brain drain at various times in their history. The strategies of Taiwan, Korea, China, and India, for example, have been distinctly different. Indeed, I saw somewhere a compendium of 110 different initiatives that have been taken. Taiwan set up a National Youth Commission to encourage return. Korea upgraded its research institutions and offered salaries competitive with overseas incomes. Both Korea and Taiwan succeeded. Africa set up The Return of the Qualified African Nationals Program, which is run by the International Organisation for Migration. Over the past twenty years, around 100 persons per year returned. Considering the high level of brain drain in Africa, this is negligible. On the other hand, India’s recent experience is striking. The data collected by NASSCOM in India shows that over 25,000 professionals have returned over the past three years. These first faint signs of the reversal of brain drain in India are due to increased opportunities in the IT sector and the new multinational R&D centers. Reversal of brain drain will only take place when there are improved opportunities in one's chosen field and improved economic conditions—this is true universally.

Global Knowledge Pool for Global Good through Global Funding

Are we doing enough to fund those areas of research that will benefit the poor? I am afraid not. Let me illustrate this by considering just the issue of diseases of the poor. Today there is a problem about creating the drugs for treating the diseases of the poor. For instance, in 1998, the global spending on health research was $70 billion, but just $300 million was dedicated to vaccines for HIV/AIDS and about $100 million to malaria research. Of the 1,223 new drugs marketed worldwide between 1975 and 1996, only 13 were developed to treat tropical diseases and only 4 were the direct result of pharmaceutical industry research.

It is obvious that there is a pressure on large drugs and pharmaceutical companies to provide the maximum value to their shareholders. Their research portfolio is obviously heavily slanted towards drugs that bring in maximum profits to the firms and not towards drugs needed by the poor. Incidentally, this is true of the pharmaceutical companies in India too! Despite an orphan drug law, the developed world does not have an incentive to work on diseases that do not affect at least some part of their own population. There is no substitute, therefore, for creating new drugs for the poor through public funding (national as well as international) and meaningful public private partnerships.

Can public funding effectively develop new drugs? Two issues arise here. First, the track record of the government in commercializing research is generally poor. Secondly, the governments of the developing countries do not have adequate R&D budgets of their own to support research for diseases of the poor, especially tropical diseases. These problems can be circumvented by imitating the successful models used in agriculture. Research in agriculture was supported through public funding and has provided immense benefits to developing countries, heralding a green revolution in several of them.

The solution is to create a **global knowledge pool** for **global good** through **global funding**. The global fund should be created and managed by an international body. The funding should be for creating new knowledge and products for identified diseases of concern to the poor. This body would also set the research agenda and monitor the programs. The norms for sharing the intellectual property arising out of this endeavor could be decided in such a way that access at affordable prices to the poor is ensured.

There are three ways to fund. The first is to create new world-class R&D centers in countries that have the intellectual capacity to deliver results. These centers could be specially fenced, structured, and managed. The second is to fund already existing public institutions in developing countries. They would have to have a successful track record with a performance that could be bolstered with additional, directed funding. The third way is to create a global knowledge network with partnerships between the public and the private (e.g., Medicines for Malaria Venture (MMV) or International AIDS vaccine Initiative).

It has been repeatedly demonstrated that supporting R&D for the poor in developing nations can bring rich benefits. For example, India's Central Drug Research Institute produced a drug to treat cerebral malaria. Themis, an Indian pharmaceutical company, sells it under the brand name E-Mal to 48 countries at affordable prices. These include poor nations in Africa. India's Shantna Biotech came out with a recombinant DNA vaccine (Shanvac) for Hepatitis B. This vaccine was being sold for $15 per dose. Thanks to the entry of Shanvac, the prices of the vaccine kept on tumbling till they came to less than a dollar per dose. Today Shanvac is supplied to UNICEF for 50 cents!

The message is that strengthening the manufacturing capacity for science and technology in the developing world can benefit the poor of the whole world. Global funds directed towards this goal can accelerate the process of providing access to medicine for the poor.

Global Funding for Global Public Goods

How can global funding for creating global public goods be created? UNDP's Human Development Report (2001) on "Making New Technologies work for Human Development" provides some striking statistics. It suggests that developed nations should take seriously the agreed standards for official development assistance of 0.7% of GNP. Doing so in 1999 would have increased official development assistance from $56 billion to $164 billion. Dedicating just 10% of that to technology would have generated more than $16 billion.

In 2000, the official debt service payments by developing countries amounted to $78 billion. A swap of just 1.3% of this debt service for technology research and development would have raised over $1 billion.

A handful of foundations (THE Welcome Trust, The Bill and Melinda Gates Foundation, the Rockefeller Foundation, and the Ford Foundation) have made exemplary commitments to investing in long-term research. Through its Industrial Technology Development Programs (ITDP), the World Bank over the past twenty years has invested over $4 billion to improve the intellectual infrastructure in such developing countries as Korea, India, Philippines, Turkey, Chile, and others. These efforts are laudable but not fully adequate. It is estimated that an input of at least $10 billion per year is required to push the R&D agenda on public good creation.

While help can be sought from around the world, can developing countries help themselves? In 1999, the governments of sub-Saharan Africa dedicated $7 billion to military spending. Diverting just 10% of this would have raised $700 million, more than enough to support the HIV/AIDS vaccine research program.

It is also not the case that only the developed world has billionaires. The developing world has these too. In 2000, Brazil had 9 billionaires with a collective worth of $20 billion, India also had 9 worth $23 billion, Malaysia had 5 worth $12 billion, Mexico had 13 worth $25 billion, and Saudi Arabia had 5 worth $41 billion. Foundations set up by such billionaires from the developing world could make important contributions to regionally relevant research agendas. Will they respond to these calls?

With its financial, intellectual, and research resources, industry could make an invaluable contribution by committing a portion of profits to research on non-commercial products. In the pharmaceutical industry alone, if the top nine Fortune 500 companies had dedicated just 1% of their profit to such research in 1999, they would have raised $275 million. In this context, it is refreshing to see the setting up of Novartis' Institute for Tropical Diseases (NITD) in Singapore or the Astra Zeneca Research Centre in Bangalore, India, for tuberculosis research. We need to multiply these efforts several fold.

Lifting the Submerged Past of the Iceberg

Let me end the lecture by sharing a recent experiment done by one of our laboratories, the Central Salt & Marine Research Institute (CSMCRI) in Bhavnagar in India. In Kutch in Gujarat, we had a major earthquake. There was no electricity and no drinking water for those poor people in the villages. CSMCRI had developed reverse osmosis technology for drinking water, but to operate this technology required a pressure of around twenty atmospheres. Without electricity, how would one generate such pressure? The villages had no electricity but they did have bullocks. So, the scientists made the bullocks go around and, using a cleverly designed helical gear system, generated the required pressure to run the reverse osmosis device. A village with around 300 families got drinking water. The Intermediate Technology Group in Rugby, England, was so impressed with this feat that it featured it in the *New Scientist* (10 May 2003). Applauding this feat, the article noted that "the device holds a great promise for 1.2 billion people, who lack electricity and clean water, but who have plenty of oxen."

I see both good and bad news here. The good news is that the compassionate Indian scientists, touched by the sorry plight of the poor villagers, created an "appropriate technology" by using the odd combination of motion by bullocks and the high technology of reverse osmosis. The bad news is that the remarks in the *New Scientist* article imply that we will still assume that 1.2 billion people in the world will continue to be without electricity and drinking water! This is simply not acceptable. Continuing with such disparities will cause a global fracture.

The substantial disparities between the developing and the developed world are a major cause of concern for us today. They also exist, however, within the developing world. For example, large nations like Brazil and India suffer poverty on a national scale, but they also have large sub-regional variations in social and economic fortunes. East and Southeast Asia have huge regional crests and troughs. Myanmar, Laos, and Cambodia have not enjoyed the same economic growth as other East Asian Countries.

The same situation persists in India. Today, 50% of Indian children go to school, 30% of these reach the 10th standard, and 40% of those pass. Multiply these percentages and you will find that 6% of the children pass the 10th standard—as opposed to 65-70% in Korea. Yet India is projected to be an emerging IT Superpower. 600,000 software professionals with an average age of around twenty-six generated 20% of our exports last year. By 2008, they will generate 35% of our exports and contribute to 7% of our GDP. But 600,000 professionals constitute only 0.06% of our population. This is the tip of an iceberg. For this tip of the iceberg that is shining, there is a huge part of the submerged iceberg, which constitutes the "have-nots" and the "underprivileged" that is in the dark. What worries me is how we are going to lift that iceberg.

It is rather strange that I am delivering the 10th Zuckerman Lecture here in London. I belonged to that submerged part of the iceberg in India. I was born in a very poor family. My father died when I was six. My mother, who was uneducated, did menial work to bring me up. I went barefoot till I was twelve. I studied under streetlights. I remember that after I took my Secondary School Certificate Examination in 1960 and had secured the eleventh rank among 135,000 students in the state, I was about to leave the school. My mother could not fund my college education. And I remember Sir Dorab Tata Trust coming in with a scholarship of 60 rupees per month. They supported me until my graduation. This support was less than one British pound per month. Those 60 rupees added so much value to my life, but it did not subtract any value from the Tatas.

What are the lessons that I draw from my own life? There are three factors that helped me. First, I was given an opportunity to study in a municipal school that was run through Government funding. This education was free. Second, there was the philanthropy of the house of Tatas. This unique public-private partnership, if you like, made it possible for Mashelkar to complete his education. Third, as a young man in my early thirties, I was invited back to India and given all that I needed to do my research in polymer science and engineering. This invitation was a part of a special initiative by the then Prime Minister to reverse the brain drain. I was given an opportunity to rise to my own potential. But for that one Mashelkar, who is standing here, there are millions of

Mashelkars around the developing world who need to be helped. If they get this help, then they will not remain confined in that submerged part of the iceberg. They will themselves rise to become a part of that shining tip of the iceberg, and they will also help lift that submerged part of the iceberg. Ladies and gentlemen, I'd like to conclude by saying that we must do everything to lift this iceberg. As I have repeatedly demonstrated in this lecture, science and technology have the power to lift that iceberg.

We can all do it **together** and make a better tomorrow—not just for a lucky and privileged few but for all humanity.

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