PERSPECTIVES ON THE ENVIRONMENT FOR INNOVATION

Rodney W. Nichols
President and CEO emeritus, New York Academy of Sciences
rod.nichols@verizon.net

CONFERENCE ON ECONOMIC DEVELOPMENT THROUGH SCIENCE AND TECHNOLOGY INNOVATION

ORGANIZED BY CRDF GLOBAL

The Royal Academy of the Kingdom of Morocco
Rabat, Morocco
June 16-17, 2011

Introduction

The first rank professionals at this conference have come together to rethink how best to reach the goals we share -- as we struggle with the choices we weigh. An anonymous sage – I bet she was an engineer – once said, "minds are like parachutes: they work best when they are open." Old, proven ideas often work, but we need new ones, too. This a central aim of CRDF Global: tap and extend best practices to frame even more effective programs.

I begin with a brief on history. Economics Nobel Prize winner Michael Spence reminds us that between 1750 and 1950:

> "average incomes in England, the US, Canada, Australia, and New Zealand rose about twenty times, from about $500 per year to over $10,000 per year and in the case of many industrialized countries much more than that. New growth was driven by the application of science and technology to production, logistics and communications, management and institutional innovation, and changes in governance and the ways in which politics and government interacted with the economy. It affected 15% of the world's population" [1]

This caused, in effect, a huge new "divergence" with respect to all other nations.

Spence goes on to argue, based upon the extensive work of the Commission on Growth and Development , that in the next 50-75 years, the “third century of the Industrial Revolution,” we will see “convergence. “ {2} This means the many nations catching up in the first half of this century will catch up quickly. That outcome is not guaranteed, but it is within reach. The world appears to well be in on its way toward higher standards of living for everyone, yes everyone. Although Spence sees major problems that could brake progress, he is optimistic. So am I.

The vital questions today boil down to these: how to accelerate this process of convergence, and what are the essential ingredients of the “environment” required to do so?

Today I will outline: (1) the dynamics of interactions between science and technology that affect development, along with the incentives and opportunities for entrepreneurs; (2) the broad range of timelines for participants that must be kept in mind; (3) the diverse purposes of varied participants; (4) the economic freedom needed to nurture a favorable overall environment; and (5) the metrics that are useful, if not definitive, for monitoring trends.

Dynamics

The phrase, “science and technology,” implies that “science” precedes, or is more important than, “technology.” That is mostly wrong. Yet Goethe nailed a dazzling pair of metaphors about what many do see as the bifurcation with his perceptive remark about science: “To one man it is the highest thing, a heavenly goddess; to another it is a productive cow who supplies them with butter”. {3}

In fact, virtually everyone who works in the research and development community knows that the dynamics are marvelously complicated. The diagram in figure 1 captures the main strands. {4}

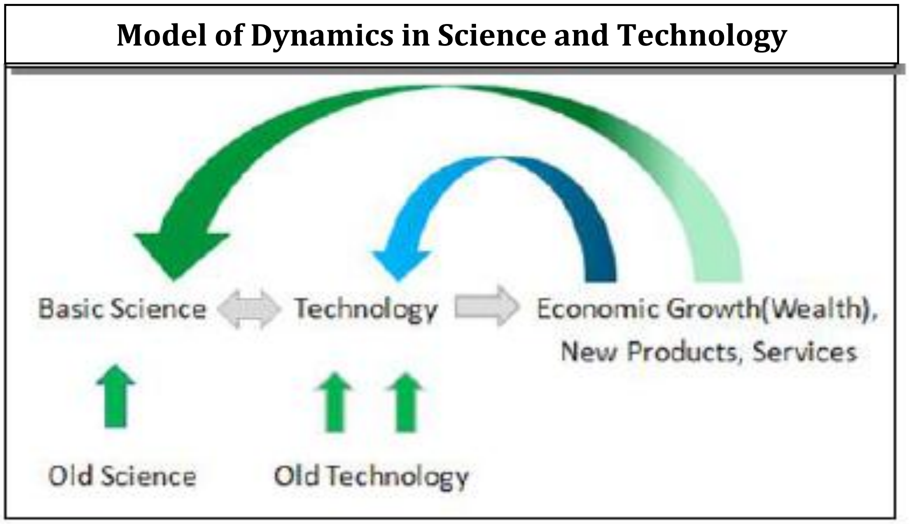


Figure 1

This portrays what Pasteur wisely asserted: “There is only one science and the application of science, and these two activities are linked as the fruit is to the tree.” At the same time, science and technology are also in many ways autonomous, each building on itself.

“Old science” -- on the left --is the base for research on the frontier. But the point is subtle. Older work often illuminated crucial questions that could not be attacked with the earlier tools available for research; hence those old questions must be revaluated. For instance, the early, shrewd conjectures about the components in the interior of a cell could be investigated and brightly revealed only after the electron microscope came to the laboratory.

Further, “old science” is the irreducible base for the technical education that students and teachers must master in every stage of economic development and industrialization. Taiwan opened technical and vocational schools long before it could move up the value chain in education and tech-heavy activities. (See K.T. Li in ref in note #9.)

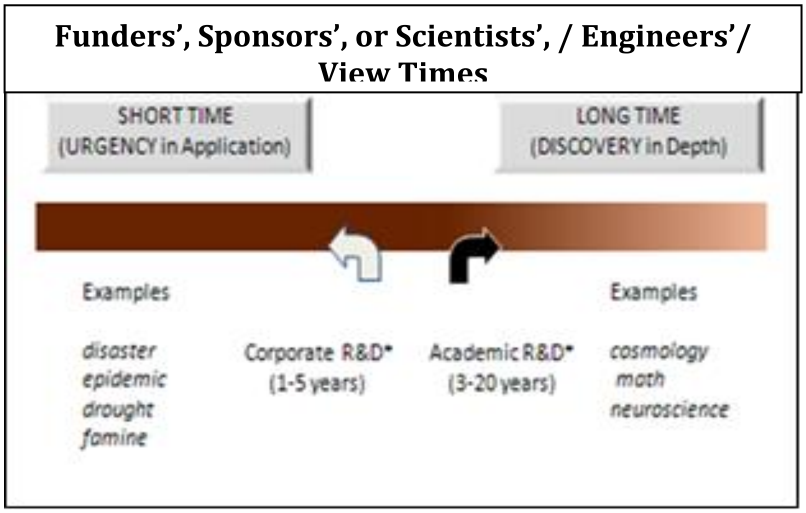
To take another example from this diagram, “old technology” is typically the baseline for “new technology” in a large fraction of the powerful incremental improvements in manufacturing. Ultimately, these increments are cost-saving and/or performance-enhancing for most products and services. Engineers add productivity and value one brick at a time, with imagination and craftsmanship, like building a bridge or a home.

I will not dwell on further examples of how these dynamics play out. But each of the feedback loops carries a story, and catalyzes possibilities, that must be studied carefully to build the environment for innovation.

Finally and perhaps most importantly, I must emphasize the obvious driver of the entire dynamics: these feedbacks only buzz, and soar, when savings and investments – wealth – are available to entrepreneurs, researchers, and developers at every stage in the patterns of invention, innovation, and diffusion of technologies.

Timelines

Fig 2 outlines, in bare form, the range in timelines for R&D -- seen from the viewpoints of both sponsors and investigators. This picture covers any strategy for funding R&D, not only at the national and global levels, but also for smaller geographical contexts. (5)



Funders', Sponsors', or Scientists', / Engineers'/ View Times

*The time frames for much of both academic and especially corporate research have shortened during recent years. Government support encompasses the entire time spectrum, but the vast majority of government funding goes to "development" (D), not "research" (R).

Figure 2

The far left of this diagram reminds us that in any emergency, technical specialists –- from firms, campuses, and governmental agencies –- will be called upon to give immediate diagnosis. Then, whether for a flood or a famine, for an epidemic or an airplane crash, the crisis must elicit technology-based aid. Such situations often also create opportunities for conducting research, testing new products, and showing new angles about longer term technological needs. This was the case, for example, in the recent large oil spill in the Gulf of Mexico.

In the center of this figure appear the 1-5 year time frames that characterize much corporate R&D as well as most university-industry partnerships. For the pharmaceutical and semiconductor sectors, R&D continues for much longer periods, upgrading products as well as exploiting new findings from discoveries in the related scientific fields. But even for multi-year strategies, most firms stick stringently to imposing goals with tight milestones and then cutting off projects that do not meet those markers. Increasingly, firms in the US have tightened up virtually all of their investments in science and technology so that it is rare to see any of the distant time horizons that were common a generation ago.

R&D on campuses –- supported primarily by the government in most countries – can be and often is structured to resemble corporate R&D. Tight limits are imposed on the time periods for grants and contracts. While a corporate sponsor's support may be extended if progress is steady and impressive, every three years or so proposals must be submitted and reviewed.

Campuses host almost all of the authentically long-range scientific inquiry, as highlighted on the far right of the diagram. In studies of the cosmos, in mathematics, and across the neurosciences, for example, entire careers will be devoted to trying to crack a tough problem. That emphatically does not mean that quality controls should not be brought to bear. Funds are too scarce to waste on mediocre programs led by obsolescent leaders. The trick is deciding about how important is the effort, how imaginative is the leader, and what opportunity costs a sponsor is willing to bear. Many American entrepreneurs stay in touch with these long horizon academic groups, partly for recruiting talent, partly for scouting possible breakthrough ideas.

The pivot for considering these timelines – and the reason for reviewing this rudimentary perspective – is, simply, that too often people forget where and why they are on this spectrum. Notions of crash programs, or hopes for quick payoffs from venturesome investments, often ignore the demand to systematically clarify the time to fulfill the goals of the project.

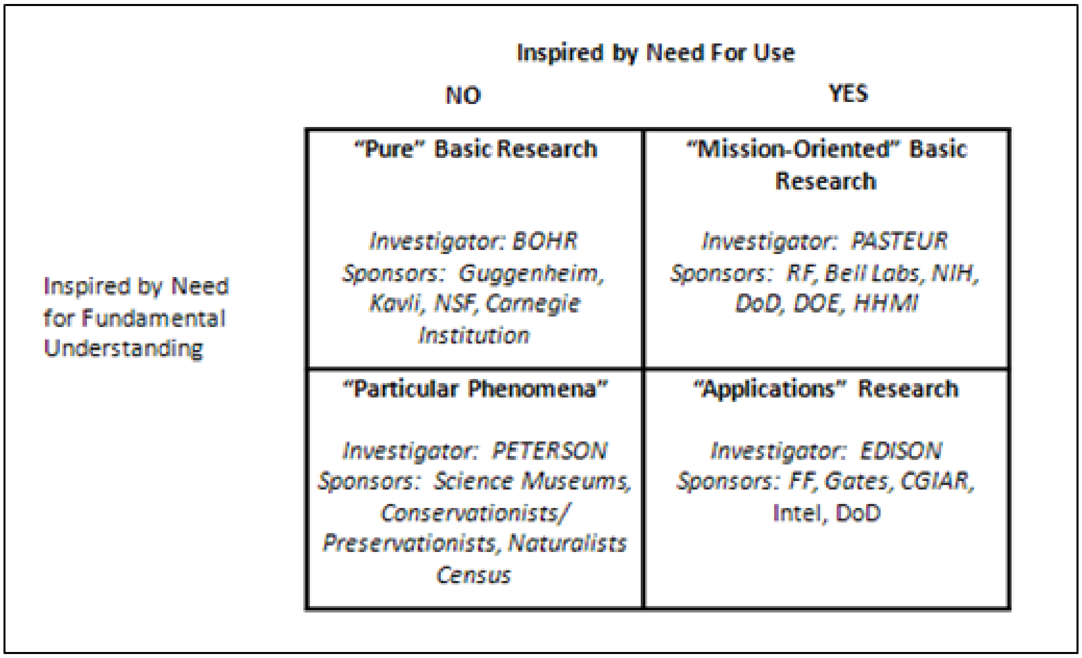
For instance, stem cell therapies have enormous potential, but will not be an immediate clinical answer. Safe and effective widespread results are probably 10-20 years away. But some philanthropists, venture investors, and governmental units seem to misread the time periods. Yes, stem cell research is, in many ways, profoundly deepening our knowledge of biology. And it is "urgent" medically speaking for many traumatic injuries and tragic diseases. So potent incentives are there for science, and long-range incentives are there for investors. But banking on early medical or commercial returns is unwise.

Similarly, after decades, or centuries, of work in chemistry, metallurgy, ceramics, and the materials sciences crossing many disciplines, the famous "Moore's Law" -- projecting correctly the spectacular gains in information technology hardware -- was born a generation ago. It is going strong today. The engines of this success tracked parallel paths encompassing several of the timelines I have mapped: urgent projects as well as long-range explorations. Physicists around the word, and the inventors and builders at firms such as Intel and Texas Instruments, can testify to the complexity and endurance required. The fortunes that have been made emerged from following roadmaps that were brutally realistic about the technological challenges and costs.

Purposes

With this in mind, consider Fig 3, an evocative summary of the distinct purposes – or better, the motives – of sponsors and investigators. Here the emphasis is on research per se, not on the later stages of development and not on the feedback loops embedded
in Fig 2.

ILLUSTRATIONS OF MOTIVES AND SPONSORS AND INVESTIGATORS FOR RESEARCH



	Inspired by Need For Use	
	NO	YES
Inspired by Need for Fundamental Understanding	"Pure" Basic Research *Investigator: BOHR* *Sponsors: Guggenheim, Kavli, NSF, Carnegie Institution*	"Mission-Oriented" Basic Research *Investigator: PASTEUR* *Sponsors: RF, Bell Labs, NIH, DoD, DOE, HHMI*
	"Particular Phenomena" *Investigator: PETERSON* *Sponsors: Science Museums, Conservationists/ Preservationists, Naturalists Census*	"Applications" Research *Investigator: EDISON* *Sponsors: FF, Gates, CGIAR,* Intel, DoD

Figure 3

This matrix was conceived by Donald Stokes. {6} I have modified it to add illustrations of the participants. The basic distinction is between whether a project is "inspired" by the desire for "fundamental understanding," or "inspired" by the need for "use."

In the left upper quadrant, the great Danish physicist Niels Bohr epitomizes a person conducting "basic" research. In his theoretical studies, he pioneered the deepest intricacies of atomic structure. While the 20th century saw hundreds of useful applications flowing later from research by Bohr and by other giants, their aim was always fundamental understanding. None of the subsequent consequences of the knowledge -- neither the nuclear bomb nor the NMR technology used in medical diagnosis -- was their original purpose. Sponsors such as the Guggenheim, Kavli, the US National Science Foundation, and the Carnegie Institution in Washington DC are, for example, representatives of this quadrant's allies and sponsors. Few, if any, entrepreneurs touch this zone for business objectives. But many business people keep a close eye on it.

Diagonally down and across on the right, the "Edisonian" quadrant highlights situations in which the dominant purpose is to clinch new applications with incremental advances. That is: do whatever it takes to improve an existing technology (say, increasing fuel economy) or to meet a stated need (say, pushing down costs) by relentlessly running through all the alternatives. It is research. The leaders must be technically expert and they deserve lucrative patent protection. This domain pushes the envelope of "innovation" after the initial commercial vistas have been seen. But the process is not animated by the goal of deep understanding. Much of the Ford Foundation, the Gates Foundation's work on vaccines, the Consultative Group on International Agricultural Research, some of Intel's R&D, and most of the US Department of Defense's "6.2 Applied Research" funding has this character. Often such efforts turn out to reveal the need for a return to "basic research." Many biotech firms might be characterized as being in this quadrant; and their university links frequently connect to other quadrants.

Now consider "Pasteur's Quadrant," in the upper right. As he solved everyday problems of breweries and milk suppliers, Pasteur aimed for depth as well as utility -- and discovered the "germ theory of disease." "Mission-oriented" (basic) research is the core idea. The problem cannot be solved until deeper understanding is reached. When the Rockefeller Foundation laid the groundwork for the "Green Revolution," the goals were long range, the tools for the research were comparatively undeveloped, and the funding was assured (more or less) until the problem was solved. Norman Borlaug and his team, like Pasteur, had to probe, invent, discover, the answers. Similarly, the Bell Laboratories in the mid-20th century, the "6.1 Research" in the US Defense Dept., the high energy physics related to fusion in the Department of Energy, and the Howard Hughes Medical Institute – all have "needs" in mind, but achieving those goals demands novel insight and instrumental power beyond current technology. Hence, fundamental studies with a clear focus. Some of these sponsors also are in Bohr's quadrant. Some venture capitalists used to be in Pasteur's pasture, but few graze there now.

To complete the matrix, the bottom left quadrant points to the painstaking efforts required to classify enormous numbers or ranges of objects – as in Peterson's Guide to Birds. Another example is the conduct of a census; these data underpin significant demographic and epidemiological work, but rarely create or enrich an original conceptual framework. Although the goals in this quadrant relate to a "need," such as a curatorial study in a science museum, work is organized to document particular phenomena in complete and scrupulous detail. Neither deep understanding nor a pressing social or economic/technological need is the driver.

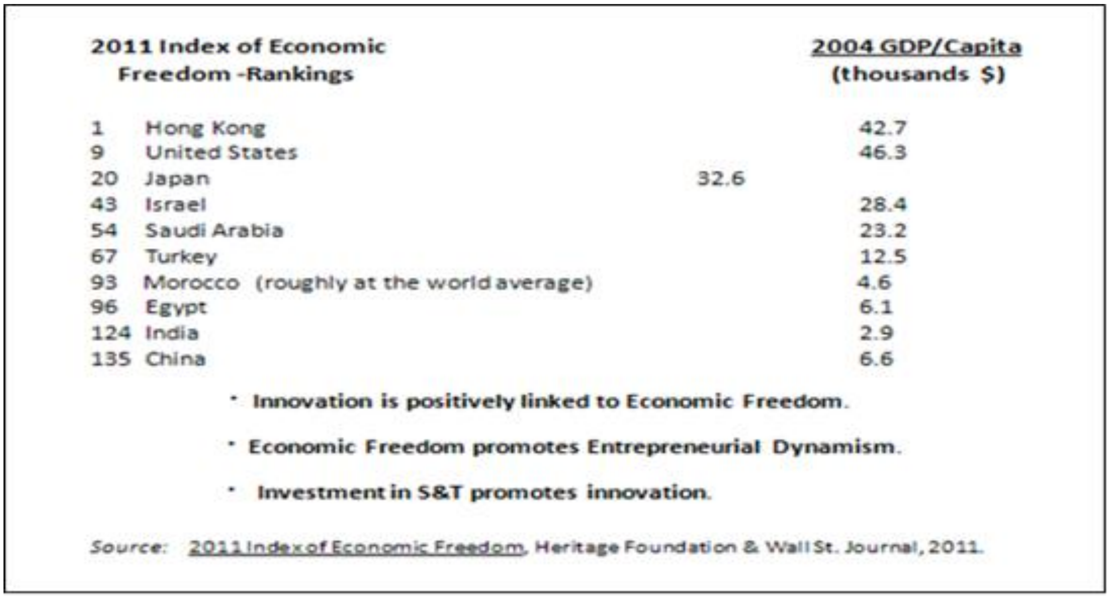
Sponsors of research – governmental units and all private funders, including entrepreneurs and philanthropists – must be crystal clear about the technical state of the art as they consider commitments in each of the quadrants.

In certain cases, the most highly productive investments are at the early stage of establishing an innovation. For example, the Alliance For Global Good is taking advantage of early results – from Pasteur's Quadrant – in bringing newer technological assets to social goals such as de-worming in villages in Ethiopia, improving solar panels in the Middle East, and evaluating extremely low-cost baby incubators – all trying to evaluate the potential for cost-effectively scaling up. (7) Commercial activities may follow such demonstrations.

Environment

Every country has “defects” or “imperfections” that undercut or constrain its environment for innovation. And each country has unique assets and cultural factors that frame its potential. For example in the US, our deteriorating systems of elementary and secondary education, especially in science and math, weaken the national capacity for sparking innovations.

One trend, documented around the world, is that economic freedom tends to promote entrepreneurial dynamism and innovation. Fig 4 shows a recent ranking of selected countries in terms of ten aspects of “economic freedom.” The rankings are based on indices such as business and trade freedom, property rights, freedom from corruption, and labor freedom. {8}



2011 Index of Economic Freedom -Rankings		2004 GDP/Capita (thousands $)
1	Hong Kong	42.7
9	United States	46.3
20	Japan	32.6
43	Israel	28.4
54	Saudi Arabia	23.2
67	Turkey	12.5
93	Morocco (roughly at the world average)	4.6
96	Egypt	6.1
124	India	2.9
135	China	6.6

- **Innovation is positively linked to Economic Freedom.**
- **Economic Freedom promotes Entrepreneurial Dynamism.**
- **Investment in S&T promotes innovation.**

Source: 2011 Index of Economic Freedom, Heritage Foundation & Wall St. Journal, 2011.

Figure 4

Roughly speaking, the freer the country, the richer the country, as measured by gross national production per capita, as shown on the right hand column. Exceptions such as Saudi Arabia occur because of its oil revenues. Notice that Hong Kong and Israel have had such strong education and such vigorous R&D, enabling so many successful start-up firms, that their GDP/capita outstrips Saudi. {9} China is lower on measured economic freedom, but it has a surging science and technology base, ample investments from both domestic and foreign sources, and comparatively low labor costs. So China's GDP/capita rose quickly, is high now, more than double India's income level, despite India's higher rank on the freedom indices. (10)

Given the enormous range of local circumstances and traditions – not to speak of differences in governance -- this perspective does not produce instant prescriptions. Nonetheless, it suggests apparently reliable domestic guidelines: make it easy for a firm in a tech sector to form, to raise capital, to protect its property rights, and to hire and fire staff. Thinking globally, other guidelines are: open markets to the bracing effects of global competition – that spurs domestic innovation -- and open educational systems to international exchanges --that draws on the international reservoirs of know-how and know-why. Yet another is to insist on quality controls for S&T investments, including rigorous competitive reviews by experts inside and outside the country.

To follow such guidelines, combinations of the private and public sectors are increasingly appealing. Irwin Feller reminds us how Kenneth Arrow showed long ago why "a free enterprise economy (will) under invest in invention and research…because it is risky and because the product can be appropriated only to a limited extent, and this underinvestment will be greater for more basic research." (11) Thus, it is all the more important that national capitols assure prudent funding for basic research. In every nation, government has become the indispensable partner, neither silent nor patient, with the private sector. This has been at the core of America's post-WWII strategy for Federal appropriations for science. Nonetheless, as political scientists Harvey Sapolsky and Mark Zachary Taylor cogently argue, it is the "politics of specific missions," not any insightful reasoning, that "determines the rate and direction of investments." {12}A "war on cancer," or a war on malaria, is usually more compelling than a voyage of discovery.

Returning to my first remark about Michael Spence's review of the early global "divergence" during the industrial revolution, and thinking historically again, Nathan Rosenberg and L.E. Birdzell framed this conclusion about how the West grew rich: " The key elements of the system were the wide diffusion of the authority and resources necessary to experiment; an absence of more than rudimentary political and religious restrictions on experiment; and incentives which combined ample rewards for success, defined as the widespread use of the results of experiment, with a risk of severe penalties for failing to experiment." {13} Fulfilling this formula is challenging in every country, no matter what the degree of economic freedom. The Council on Foreign Relations has just started a new program, led by Isobel Coleman, that will explore in depth the intersections of Civil Society, Markets, and Democracy, i.e., precisely the environment likely to foster economic development. {14}

Metrics

Finally, consider the questions of metrics. Begin with one central puzzle: how much to invest in science and technology? Based upon global economic results of the last half of the 20th century, it appears that nations should stretch to bring national S&T spending budgets to a level of about 3% of GDP. This is an educated guess, merely an observation of what the most developed countries actually did; it is a crudely empirical number, not derived from convincing models.

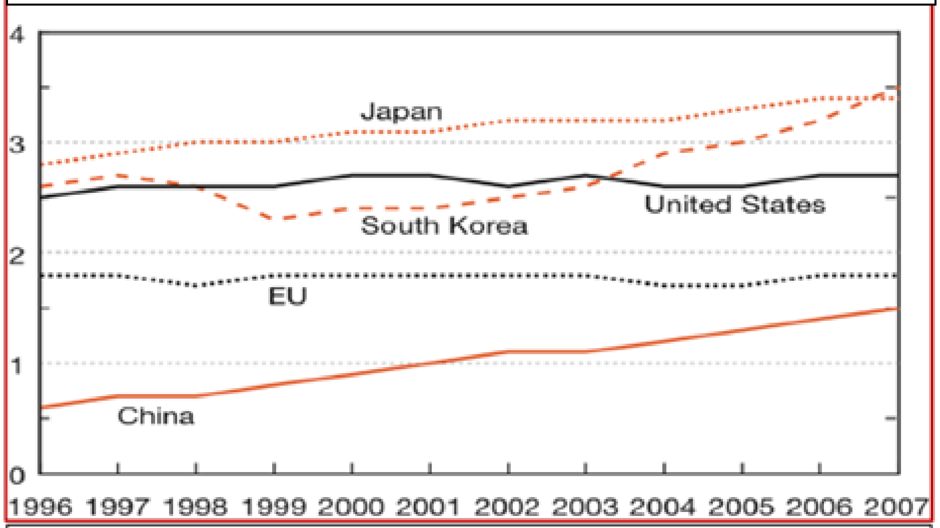
In fact, for the US, during a candid 2005 speech, John Marburger, former Presidential Science and Technology Adviser, exposed one of the worst kept secrets of the Washington science policy community: there is no compelling quantitative rationale for how much the US government – and, I believe he would agree, any nation --should spend on research and development in the aggregate, nor how best to distribute funds across specific areas of interest. [15] He called for disciplined study.

After a few years the National Science Foundation opened a competitive grants program (SciSIP) that is creating a "community" of investigators who are committed to framing more confident estimates of the outcomes from public support. It aims to collect international data. This initiative, long needed, also led to the recent publication of "THE SCIENCE OF SCIENCE POLICY: A Handbook". {16} This is a first-of-its-kind volume. With assessments by the editors and 23 experts, it will spark debate – by advocates and skeptics alike – and will push the envelope of responsible analysis across all fields of science, engineering, and mathematics – and across all of the technically based programs designed to advance national missions from energy to health and agriculture.

Since setting goals and plans can't wait for further calculations and historical collections of data, what can we say today about investment in S&T as a percentage of GDP? For the US, the combined public and private spending is now about $400 billion, roughly 2.6 % of GDP. The Federal government's share is about 25%, and private industry invests about two-thirds of the total. All of the funding has been under pressure because of deficit cutting, even as the country sees a need to increase innovation as a way to increase jobs and growth.

Fig 5 shows key trends in R&D expenditure in several countries over the past decade through 2007. And Fig 6 is shows the extraordinary commitments to S&T by several Asian countries. (17)

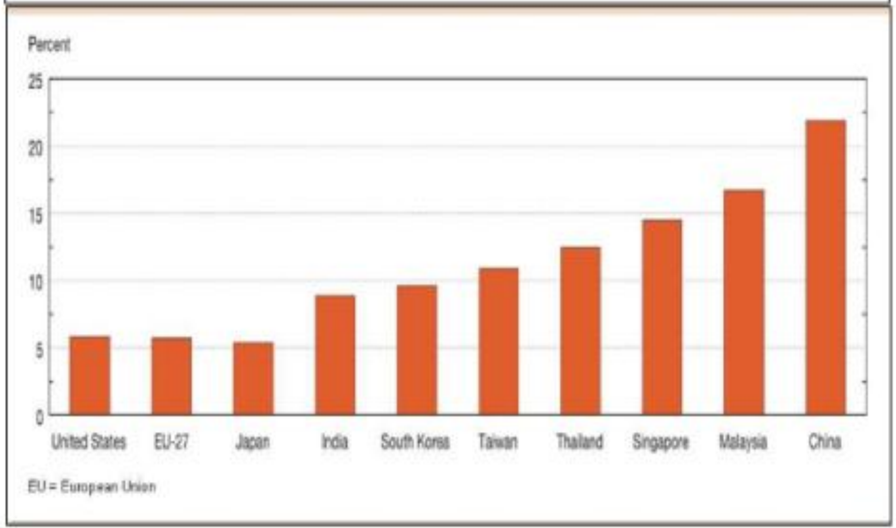
R & D expenditures as share of economic output of selected countries: 1996-2007



Source: Organization for Economic Co-operation and Development. Science and Technology Indicators (2009/1 and previous years).

Figure 5

Average annual growth of R & D expenditures for United States, #U-27, and selected Asia-8 economies: 1996-2007



Source: Organization for Economic Co-operation and Development. Science Technology Indicators (2009/1 and previous years).

Figure 6

Yet innovation is not just about total spending. It also inevitably depends upon the "balances" struck across S&T investments in different domains. How much for health vis-à-vis defense, energy, infrastructure? How much for chemistry or information technology or biomedical sciences? Should the "basic research" component be 10-15% of the total?

Closely related issues arise. For example, how quickly can higher education be expanded? Egypt and India, for instance, have experienced severe problems with their expansion of universities, especially in the absence of a resolutely enforced "merit-based culture." {18}

Cutting through all of these choices about how to build human capital is the increasing recognition that there must be an imperative to "empower women as scientists and engineers, support girls' education, and value women as builders of economic development." {19} There is no action more important than charting incentives to bring the talents of women into the system. Nations need all their talent, freely educated and openly employed. Moreover, recent studies confirm new and powerful ways for technology to advance women economically.

Finally, the S&T community in each country must consider external measures of its own performance. How competitive is the quality of internal research? What impact, if any, does it have globally? Are there invited participants in "big science" facilities, solicited co-authors of publications in leading journals, and aggressive licensing of patents? These are among the familiar ways to count what can be counted. Disciplined self-evaluations of quality are critical, even if any one of these indicators cannot possibly be definitive.

Concluding Note

In thinking about the environment for innovation, recall the aphorism:

> "National economies are like 10-speed bicycles; most of them have gears that never get used."

At the risk of pressing this metaphor too far, I believe this conference aims to recognize all the gears we have, to oil them well, and to learn how to use them regularly and reliably. (20)

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