

SCIENCE'S NEXT FRONTIER: LOOKING BACKWARD TO SEE AHEAD

RETHINKING R&D POLICY FOR THE NEW CENTURY

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".... Can a historical analysis of the past 50 years really help us determine a sound policy for future? Don't we need more than an adjustment – don't we need a fundamental rethinking about who shall write an Endless Frontier for the next 50 years?"

Dr. Bernard Cole in "Science, An Endless Frontier as a Treatise"

THE FAMILIAR BACKDROP ...

The year was 1945. The world had just come out of years of conflict that had left hundreds of thousands of people dead and many more injured and displaced from their homes. Towns and cities around the world presented a picture of untold destruction and human suffering. The last few years had probably seen mankind, bitterly divided, and engaged in one of the fiercest and most internecine conflicts till date. While the events leading to end of the war brought death, destruction and humiliation to millions, they also signified a dawn of a new era for many others – an era that nations would someday term as the '*American Century*'.

American century it was, for many reasons. Not only did the coalition led by American forces managed to put an end to the world war in a comprehensive and shockingly swift manner but also it acquired a deciding advantage in the terms of defining the rules of the game that followed. The economic boost that came from the war time expansion did make America an unrivalled economic power – a feat, important in its own right though in our view not unique enough, as Japan grew at a much faster rate than the US in the post world war era to become secondly only to America in terms of economic prowess. What was definitely special and more fundamental about the period that followed was perhaps America's rise to the world's leadership in science and technology that in turn helped sustain its momentum both as an economic and a military

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power of unrivalled stature in the world². The ability of US science and technology establishment, both within the public and private sectors to push the horizons of scientific knowledge, and bring it to bear on society's most pressing problems in the form of new technologies, has very rightly been hailed as perhaps the most critical ingredient in the making of the American century.

America's rise to world's scientific and technological leadership was neither predestined nor a mere accident. Finishing the war in a position of power and dominance was neither a necessary nor sufficient condition for what was to follow. It is fairly easy to come up with counter examples to make a case that a victory in the second world war did not necessarily hardwire America's position in the world that followed. The gradual decline of the British Empire after the first world war and the rise to prominence of the 'defeated and demoralized' Japan after the second world war are the cases in question. The war, however, did aid in terms of providing an ideal set of initial conditions for United States to build upon but as argued earlier, nations have in the past, failed to capitalize on favorable initial conditions offered to them. What was really critical in the scheme of things was the realization, by those in the American policy circles (and public in general) that science and technology – the very factor that had paved way for a stunning end to the second world war – would continue to serve as a critical element of a future strategy for prosperity and continued military dominance. The seeds of the American science and technology revolution, therefore, were sown during the war itself³.

During the years preceding and leading up to the American involvement in the Second World War and its final culmination with the dropping of the atomic bombs in Hiroshima and Nagasaki, the involvement of American Science and Technology establishment in the war effort was significant, and instrumental to its outcome. A number of very important innovations, both hard (in terms of new technology fielded in the battlefield) and soft (in terms of methodology and doctrine), were developed and introduced, namely, the radar, atomic bomb, new and effective drugs for war related illnesses, operations research methodologies in combat modeling and simulation and game theoretic approaches to strategic military planning etc. Strongly influenced

² Ehlers, V., "Unlocking Our Future: Towards a New National Science Policy", House Committee on Science, Sept 24, 1998 states that *'The Scientific Enterprise in the United States represents our country's greatest strengths'*.

³ Stokes (1995) can be quoted as, "It would be difficult to exaggerate the degree to which the relationship between government and science was transformed by the second world war...Indeed in the period between the world wars, there was an active hostility on the part of scientific community to the acceptance of Federal support, stemming from unease about control that such support might bring. But this hostility was dramatically transformed by the war. It was a scientific war in large part, and that effort was led by enlightened scientists, with Vannevar Bush in the vanguard."

by these technological breakthroughs, the American victory in the second world war paved way for a strong realization of the important contribution of war-time research and development and became the basis for what can be termed as the a 'post-war' R&D policy in the US.

More than five decades since the end of the second world war, America has come a long way toward the realization of the '*nirvana*' – the scientists' promised land – so to speak. Following on the age old tradition of knowledge acquisition and innovation, that dates back to the American Constitution itself, but was further strengthened in the aftermath of the world war, firmly grounded policy of supporting scientific research and development (R&D) has been the critical ingredient of the *American Success Story*. While there have been minor adjustments and fine tuning, over time, in the overall policy environment governing research and development, the basic resolve of the nation's public, political and scientific establishment to make long term investments in basic and applied scientific knowledge and development has remained more or less unchanged⁴. What follows below is a review of what is often described as the landmark event in American science policy and an analysis of how it has affected the American science over the years. The idea is to identify the motivations and circumstances surrounding this event and the various ways in which it impacted the local policy science with a view to trying to elucidate as to how to go about thinking about a long-term policy for research and development? What form such a policy would take? What could be the key functions of such a policy (e.g. providing axial principles, creating requisite infrastructure, mobilizing professional opinion and support etc.)? But before we 'look back to see ahead', it would worthwhile to describe what we mean by R&D policy and planning as well as lay out a framework of thinking about long-term policy analysis.

THINKING ABOUT R&D POLICY – AN INTRODUCTORY FRAMEWORK

Many a times, and especially among the professionals in science and technology, the very idea of having an R&D policy is a considered a misnomer, partly because R&D is often concerned a highly uncertain process, and partly because of the general, often wrong, feeling that the worst thing one can do in order to improve innovation is to try to control it. If taken to heart in a strict sense, science and R&D policy seems like an oxymoron. The above description is, however, not true in its entirety. While there might be a fair degree of reality to the fact that R&D is an uncertain process, it does not preclude the possibility of long term planning and policy from affecting the outcomes of the scientific enterprise in a positive manner. The conduct of science

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and R&D policy, however, can at best be described as in its infancy. As Harvey Averch (1985) – a career science administrator-turned-science policy academic -- in an interesting commentary on the conduct of science policy in this country observes:

“Policy analysis for science and technology enterprise seemed to stand outside the mainstream ... there seemed to be no canons or even craft rules giving guidance on what constituted reasonable and legitimate analysis and advice to decision makers. In contrast to the doing of science, the doing of science and technology policy was casual. There were no standards for debate or argument. The most bizarre kinds of reasoning and the weakest kinds of evidence were offered in support of action recommendations. Scientists, engineers, and university administrators offered views and made assertions that could not pass the minimal standards of rigor, if one accepted the canons of policy analysis developed over the last twenty-five years. Yet action recommendations were seriously offered, passionately defended, and sometimes followed.”

Science policy proponents, Averch (1985) asserts, therefore often adopted a ‘kitchen sink’ mode of argumentation. It [Averch (1985)] characterizes the ‘mood’ of America’s innovation policy over the last five decades in four alternative strategies, namely, engineering strategy (in the tradition of a ‘can do’ technology push approach to R&D often held by S&T administrators in various administrations); market strategy (in the tradition of ‘market pull’ approach to R&D, mostly represented by OMB and public financial planners); public interest strategy (in the tradition of ‘competent communication’ and participatory policy making often held by citizen groups with social agendas); and finally, transformational strategy (that contends that the above three ‘marginalist’ strategies are flawed and that large scale policy and institutional reform with significantly improved intelligence capabilities are needed to manage the ‘exogenous’ technology). With such broad-based appeal to the logic, it is difficult to summarize, with definitional elegance, what all science and R&D policy is and is not. A number of academics have, however, tried to do the above.

Averch (1985) tries characterizing federal science policy in the following words:

“At heart, it [Science Policy] is about money and priorities and who gets them. The regulation and governance of the science and technology enterprise, we have been convinced should be left

⁴ Ehlers, V., “Unlocking Our Future: Towards a New National Science Policy”, House Committee on Science, Sept 24, 1998 states that ‘Because the scientific enterprise is a critical driver of Nation’s economy,

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to practitioners. Even though controversies over governance arise periodically, science and technology decision makers spend most of their time thinking about getting money and spending it in the right directions once it is obtained.... But awarding public resources to any enterprise raises questions about the effectiveness and absorptive capacity of the recipients..."

A 1997 report by Dr. William Boesman for the Congressional Research Service that analyzes 10 science and technology policy studies completed since 1991 describes three different types of adjustments (or purposes) of science policy studies and analyses. These include, major system restructuring; reactions to crises; and 'fine tuning' of the S&T system. While the report maintains that the various purposes are not mutually exclusive, they nonetheless form a useful way of characterizing the intent of science and R&D policy in the US in modern times. A more ambitious research effort sponsored by The Competitiveness Council at Kennedy School of Government identified six priority areas for a federal technology policy that called for encouraging private innovation, emphasizing basic technological research, making better use of available technologies, using a diverse set of policy tools (not just R&D support), leveraging globalization of innovation and improving government effectiveness and reliability as a long term research partner (Branscomb et.al. 1997).

The task of R&D policy making is essentially a complex one. Averch (1985) elucidates on this when it asserts that:

"First, policy analysis works best when the user is a single decision maker with significant control over resources and instruments. The S&T enterprise has multiple decision-makers, each of which individually has little control. Second, tools of policy analysis work best when the objective is to make existing markets, bureaucracies and institutions more efficient and effective. They provide less guidance on markets, agencies and institutions that need to be created to solve problems and little direction on how to create them."

Considering the challenge of incorporating the uncertainty of the unknown and the task of projecting outcomes over a long term future— an essential ingredient on the innovation process and therefore an R&D policy – *"the resolving power of available [policy] tools and models is discernibly weak"* (Averch, 1985). This makes R&D policy and planning an exercise in long term policy analysis.

investment in basic scientific research is a long term economic imperative"

A FRAMEWORK FOR THINKING ABOUT LONG TERM POLICY

Given, that developing an R&D policy, due to a number reasons (having to do with the unique characteristics of the endeavor) is essentially an exercise in long term policy analysis, it would be helpful to lay down a basic framework for analyzing the inputs, process, outputs and outcomes of such an exercise. However, we venture into that territory, it would be useful to establish what long-term policy means. For the purpose of the analytic methodology that follows, a long-term policy can be of three distinct flavors. *Firstly*, policy choices and actions that might be specifically undertaken with a view to having payoffs in medium to long term future (without much in terms of benefits in the short term) comprise the most strong form of long term policy. These policies, generally, are the most difficult of the long term policy choices as they compound the problem of 'de-coupling of benefits and costs' in the sense that present generation does not benefit from the cost they incur. Examples can be very long range R&D aimed at payoffs that fall well beyond the realistic horizon of the current generation. *Secondly*, making current policy choices to influence or avoid possible long-term futures, in the process drawing heavily on tools like forecasting, scenario building and alternate futures etc., comprises a second class of long term policy problems. These decisions, generally, have intermediate pay-offs in the sense that they gradually alter the course of society through a series of costs and benefits or insure against unfavorable long-term situations through present costs. Examples of these kinds of policies might include green house emissions policies etc. *Thirdly*, making policy choices in support of issues of interests today that also have long term repercussion, fallouts, unintended consequences etc. forms the third category of long term policy problems. Examples might include the creation of welfare program and health insurance etc. that were designed to serve present problems but had significant future consequences like increased liabilities and distorting incentives for participants etc.

Making long terms decisions is often a complex task that involves significant amount of analysis as well as trade-offs etc. if done right for many reasons. Firstly, long term policy choices suffer from a curious mismatch between those who benefit and those who incur the costs. This problem is further complicated by the fact that these two parties of the decision are often removed far enough in time or even not adequately represented at the time to the decision to allow any feasible sharing contract to be written and executed. Secondly, long-term policy decisions are often based on assumptions about constancy of value-systems that might prevail between the two

instances in time. Thirdly, long term policy decisions are often made under circumstances of great uncertainty and imperfect information. These uncertainties might arise from a number of sources, namely, political, technological and social (although it is often argued in literature that social processes, once set in motion, are more or less predictable) as well as the combination of these factors and the non-linearities of the overall system.

THE LONG TERM POLICY PARADIGM	
<i>The Process (Short Term Policy Analysis)</i>	<i>The Motivation (Short Term Policy Analysis)</i>
<ol style="list-style-type: none"> 1. Establish the Context 2. Define the Problem 3. Identify Alternatives 4. Evaluate Consequences 5. Make a Decision 	<ol style="list-style-type: none"> 1. Change the rhetoric or vocabulary about an issue 2. Usefully “complexify” an oversimplified debate 3. Usefully simplify or summarize 4. Provide a common factual basis for debate 5. Can change the analytical question
<i>The Process (Long Term Policy Analysis)</i>	<i>The Motivation (Long Term Policy Analysis)</i>
<ol style="list-style-type: none"> 1. Motivating and Building a Vision 2. Defining the Problem 3. Identifying Axial Principles 4. Identifying Alternatives-Policy Space 5. Determining Values 6. Evaluating Options-Consequences 7. Outlining and Creating Mechanisms-Institutions-Axial Structures 	<ol style="list-style-type: none"> 1. Stimulate and stretch imagination, improve perspective 2. Clarify, name, define, expound and argue major issues 3. Design and study alternative policy packages/contexts 4. Create propaedeutic and heuristic expositions, methodologies, paradigms, and frameworks 5. Improve intellectual communication and cooperation 6. Increase the ability to identify new patterns and crises 7. Furnish specific knowledge and generate/document conclusions, recommendations, suggestions 8. Clarify currently realistic policy choices 9. Improve "administrative" ability to decision-makers and staffs to react to new/unfamiliar 10. Shaping institutions (for stability, balance, adaptability) 11. Help develop a systemic view 12. Creating options 13. Help identify key future events/thresholds 14. Help identify appropriate values and identities 15. Help change the rhetoric 16. Help change the model 17. Providing databases 18. Creating a process to help gain other voices 19. "Structuring the unstructured" 20. Implicit training/education of decision-makers & staffs and the policy analysts themselves 21. Identifying contingency decisions

All of the above, necessitates a structured approach to tackling long term policy problems. One way of imposing some structure on the long-term policy decisions is to develop a step-wise approach to long-term policy analysis, as often argued, in the case of short-term policies. We represent this paradigm of long-term policy analysis in the form of a 2x2 matrix⁵ of that defines the short-term policy paradigm as a point of departure for thinking about long-term policy analysis.

SCIENCE: THE ENDLESS FRONTIER -- AS A BENCHMARK FOR LONG TERM R&D POLICY

In keeping with the general principles identified above, it would be interesting to look at at least one of the efforts that is generally conceived to have an influential impact on the shaping of America's science and technology policy in the post-war era. Looking back in time through the lens of a science and technology policy analyst, one event stands out, perhaps, marking the beginning of a major effort to harness the power of science and technology in the American national interests. This was the release of the report called "*Science: The Endless Frontier*" in 1945 by Dr. Vannevar Bush who had served as the Director of Office of Scientific Research and Development (OSRD) that was the locus of scientific R&D during the second world war.

In November 1944, with Allied forces within sight of victory in the war, President Franklin D. Roosevelt, while acknowledging the role of the science and technology establishment in war effort, asked Dr. Bush, the then Director of OSRD, to submit a report that drew upon the experience of the war and made recommendations on how to organize *American Science Establishment* so as to enable it to continue to serve national interests during peace-times⁶. President Roosevelt's letter to Dr. Bush put forward the following challenge for American Science:

⁵ The Long Term Policy Analysis Matrix draws upon a number of efforts. The most significant of these was a Research Seminar in Long Term Policy Analysis conducted at the RAND Graduate School (Spring 2001) by Profs. Robert Klitgaard and James Dewar. The short term policy analysis model, of which this is an extension, draws upon a number of sources as well. The canonical 5-steps come from a number of texts in policy analysis and is quite well-established in its spirit, although might vary slightly. The Motivations for short term policy was basically derived from a Course in Policy Analysis at the RAND Graduate School taught by Profs. Charles Wolf Jr. and Robert Klitgaard. The matrix was developed as a result of discussions among participants of the above research seminar and drawing from a number of sources like Herman Kahn and Anthony J. Weiner, "The Year 2000 (A Framework for Speculation on the next Thirty-Three Years", New York, MacMillan, 1967.

⁶ This was a mutual concern and Vannevar Bush was himself challenged by this question as he expressed in his 'other' famous essay titled 'As We May Think' (The Atlantic Monthly, July 1945) in the following words, "It has been exhilarating to work in an effective partnership. Now for many, this appears to be approaching an end. What are the scientists to do next?"

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“New frontiers of mind are before us, and if they are pioneered with the same vision, boldness, and drive with which we have waged this war we can create a fuller and more fruitful employment and a fuller and more fruitful life.”

Specifically, the letter addressed four basic questions, namely:

- What can be done, consistent with national security needs, regarding dissemination of war-time research conducted in various federal laboratories so that private sector might benefit with the fruits of war time science and technology with spillovers in terms of jobs, employment, growth and other improvements in national well-being?
- How can the war-time research in disease prevention and medicine be continued so as to improve the health of American population?
- What would be the role of the Government in the post-war era in terms of aid to research and development both in the public as well as private sectors?
- How can an effective program of workforce development be instituted to attract American youth towards careers in science and technology so that a continuing future effort in these domains be sustained as had been during the war?

In essence, the President's letter was pondering over some tough questions of science and technology policy dealing with issues like federal priorities, the science-technology-economy connect, privatization of public research, public-private partnerships in the area of technology development, creation of the right environment and incentives for workforce development etc. These fit well into the general framework of thinking about a long-term science and technology policy as identified in the previous section.

In response to the President's request, Dr. Vannevar Bush led a research effort in formulating America's response to some the challenges identified above. Four different committees, consisting of about 50 eminent scientists and researchers, were formed, one looking at possible answers to each of the above questions. These committees came up with their recommendations which were then compiled and integrated into Dr. Bush's final report to the President named ***“Science: The Endless Frontier”***. This report remains today of special interest and value not simply as an influential historical document but as Allan T. Waterman, the first Director of the National Science Foundation puts it, *‘a classic expression of desirable relationships between*

Government and science in United States". Following are some of the salient recommendations of the report that originated as a result of this exercise:

- ***The primacy/centrality of scientific endeavors for American society*** – The report pondered over the question whether scientific progress is essential for society in the sense that it needs to be a priority of the government and not merely left to private interests. It came up with a resounding 'yes'. Drawing from the contribution of science and technology in the second world war, not only in terms of the outcome of the war but also in the simultaneous expansion in industrial activity and creation of new science-based industries like radio, rayon, plastics, air-conditioning etc. and their derivative impact on employment creation and economic growth, the report asserted that it is essential to maintain a continuous and substantial flow of new scientific knowledge to ensure future benefits. It placed advancement of science and its application as one of the three the key reasons of American prosperity with the other two being free play of initiative under democracy and a heritage of natural wealth. On the issue of government role in science, the report put forth the argument that since health, economy and national security are the proper concerns of the government, by virtue of its intricate link with all of the three, scientific progress 'must' be of vital interest to the government. The report also suggested the famous 'Bush's Linear Model' of scientific development where investment in basic research at one end of the spectrum resulted in benefits out of the other end from development of useful technologies. The report, therefore, pushed for government support of research of more fundamental and basic nature where incentives for private laboratories for investment were especially weak. It also identified certain areas of research like military, agriculture, housing, public health, medicine etc. as especially worthy of active government support because of the above incentive problems.
- ***Government's Role/Policy on Medical Research*** – The committee chaired by Dr. W. W. Palmer submitted that the wartime improvements in disease prevention management that had resulted in an order of magnitude decrease in disease-related casualties had been possible due to some very fundamental research done years before and leading the second world war. Continuing improvements in medicine and health of American population would continue to require an expanding body of scientific research to draw upon. While a larger medical infrastructure in quantitative sense might be essential to a response, qualitative improvements in terms of better knowledge of the human organism might be essential to exploit it. Medical science draws from a number of 'pure' underlying sciences like biology, physiology,

chemistry, bacteriology, pathology etc. that need to be explored and need government's support in terms of research funding. In addition government can aid in the commercialization of medical technology by coordination and support. The report asserted that the right place for medical research was the medical school supplemented by laboratories in the Army, Navy and the Public Health Service. The report strongly emphasized on preserving and providing an environment that would lead to 'free, untrammelled study of nature, in directions and methods suggested by interests, curiosity and imagination [of the researchers]'. In order to maintain the pace of progress in medicine achieved during prior 25 years, the report recommended, that the government should extend financial support to basic medical research in medical schools and in universities, through grants for research and fellowships.

- ***Government's Role/Policy on Science-driven Welfare*** – The committee chaired by Dr. Isaiah Bowman built an argument for science-driven welfare by highlighting the role of science in the areas of both 'national security' and 'economic prosperity'. It quoted the joint letter from the Secretaries of War and the Navy to the National Academy of sciences in support of the contributions of science to national security. The letter read, "*The war emphasizes three facts of supreme importance for national security: 1) Powerful new tactics of defense and offense are developed around new weapons created by scientific and engineering research; 2) the competitive time element in developing those weapons and tactics maybe decisive; and 3) war is increasingly 'total war' in which the armed services must be supplemented by active participation of every element of the civilian population...to insure continued preparedness along farsighted technical lines, the research scientists of this country must be called upon to continue in peacetime some substantial portion of those types of contribution to national security which they have made effectively during the stress of the present war*". The report called for a continuing partnership between civilian science and defense community. On the 'economic prosperity' front. The report observed that in order to reach the goal of full employment, it is essential to release the full and creative energies of the American people. International competitiveness depends on developing new and innovative products and services that could command premium prices in the marketplace. A stream of investments in scientific knowledge must '*turn the wheels of private and public enterprise*'. The report stressed upon the critical linkage of basic 'unfettered' research with no practical ends in mind to economic development. While acknowledging the importance of applied research, aimed at developing products and providing complete answers to society's

needs, 'further progress of industrial development', the report observed, 'would eventually stagnate if basic research were long neglected'. Breakthroughs in basic research, in other words, acted like a 'pacemaker of technological progress' which cannot be left to other countries as has been in the past. The report charged the responsibility of doing basic research to colleges and universities and endowed research institutions because of a number of characteristics like researcher freedom, access to quality researchers, spillover affects arising in terms of training of graduate students and young research apprentices etc. Consequently, the responsibility of applied research falls on industrial research labs that are closer to the marketplace and hence better suited to the right incentives for undertaking such endeavors and government laboratories for unique mission-specific applied research like national defense and health etc. In the realm of industrial research, the report asserted that the best role for the government was to support basic research, develop scientific manpower and create incentives for businesses to innovate. The report called for a number of measures to strengthen and align this delicate balance of research portfolios across the entire spectrum of public and private sector actors. These included:

- Providing public support for basic research conducted in research centers in colleges, universities and endowed institutions
 - Forming a permanent Science Advisory Board to consult various scientific bureaus, agencies and research establishments within the government to align and coordinate scientific activities within the public sector.
 - Developing favorable income tax regimes that support research and development by private enterprises; rectify and improve the operation of patent laws to create incentives for innovation etc.
 - Assuming a leading-active role in promoting international flow and transfer of scientific knowledge
- ***Government's Role in the Renewal of Scientific Talent*** – The committee headed by Mr. Henry Allen Moe deliberated on ways to ensure adequate scientific talent for the wellbeing of the scientific enterprise. The general conclusion of the committee was that the number of people engaged in R&D was perhaps the only limiting factor in the health of the system and therefore the impetus must come from upstream i.e. the education system. The report, however, observed that promoting hard science at the expense of other branches of knowledge like social sciences and humanities etc. would be folly and hence detrimental to

the national wellbeing. It therefore cautioned against siphoning in money into science and technology from other public educational programs and investments. The report observed that *'there is never enough ability at high levels to satisfy all the needs of the nation; we would not seek to draw into science any more than science's proportionate share'* The report, however, suggested steps to undo the deficit of scientific talent resulting from enrollment of young men and women into armed forces during the war. It estimated this number at bachelor's degree level to be 150,000 and at advanced degree level in hard sciences to be around 17,000. It recommended drawing from a larger base of scientific talent by allowing the opportunity to pursue science to *'all kinds and conditions of men [and women]'* – in keeping with the *'American way'* – *'to those who show themselves worthy of further opportunity...and by giving most opportunity to those who show themselves continually developing.'* The report called for removing the barriers to higher education like income and access etc. It also stressed upon the need to salvage scientific talent from the generation in uniform by requiring the Armed services to make proper arrangements to allow those who want to pursue scientific education to do it in the US or abroad. Among the various recommendations of the committee were a program of undergraduate scholarships, graduate fellowships, fellowships for advanced training and research, and the creation of the National Science Reserve comprising those who benefited from these.

- ***The Problem of Scientific Reconversion*** – The committee chaired by Dr. Irwin Stewart looked at the problem of scientific reconversion i.e. utilization of wartime research for peacetime objectives. The committee noted that while the involvement of scientific community in wartime research had paid handsomely in terms of the final outcome of war as well as advancing the date of victory, it had essentially diverted the attention of the research community away from their true objectives i.e. unfettered research. This exercise, however, has also led to the creation of new scientific knowledge during the war and closely tied to the mission of the agencies sponsoring it like medical research and other weapons related scientific advancements. The committee observed that it is important to broadly disseminate this *'closely guarded'* research to the scientific community so as to allow its use in the pursuance of other national objectives like the economy, health and even national security. It stressed that a policy of broad dissemination would be more beneficial in the longer run than one of restriction. The report also stressed that the continued ability of the US to dominate militarily lies not in maintaining its existing scientific lead but rather on continual scientific advancements. The committee called for a coordinated effort on the part of various agencies

with wartime scientific arms to release this information in a manner consistent with national security objectives and those of the allies.

- ***The Final Recommendations*** – In sum, the report stressed for a greater role and responsibility by the Federal Government in pursuance of scientific means to national ends. It emphasized financial support of basic research and manpower development, even at the risk of driving out funds from local governments, foundations and private donors. The report proposed the formation of a new agency specifically designed for the purpose of coordinating Federal role in scientific progress, over and above the roles played by the operating agencies. The report stressed upon ‘five principles’ as the basis of Federal support for scientific research and development:

- Whatever the extent of support maybe, there must be the stability of funds over a period of years so that long range programs maybe undertaken
- The agency to administer such funds should be composed of citizens selected only on the basis of their interest in and capacity to promote the work of the agency. They should be persons of broad interest in and understanding of peculiarities of scientific research and education
- The agency should promote research through contracts and grants to organizations outside the Federal Government and it should not operate any laboratories of its own.
- Support of basic research in public, private colleges and universities and research institutes must leave the internal control of policy, personnel and the method and scope of research to the institutions themselves.
- While assuring complete independence and freedom for the nature, scope, methodology of research carried on in the institutions receiving public funds, and while retaining discretion in allocating funds among such institutions, the foundation proposed herein, much be responsible to the President and the Congress.

In addition to the proposed ‘National Research Foundation’, the report also recommended appropriate mechanisms of public support to continue the linkage between mission-sensitive national security agencies and the civilian scientific enterprise.

EVALUATING ‘SCIENCE: THE ENDLESS FRONTIER’ AS A LONG TERM POLICY DOCUMENT

Vannevar Bush’s historic document has had a profound impact on the US science and technology establishment in a number of significant ways that can be systematically analyzed on the long-

term policy template that we laid out in an earlier section. Although, some of the recommendations of the Bush Report were not adopted in their entirety, and as it later turned out, for a good reason, especially the formation of centralized basic research funding organization that Bush proposed, many of the recommendation were indeed adopted and did shape the American scientific establishment.

'SCIENCE: THE ENDLESS FRONTIER' AS A LONG TERM POLICY DOCUMENT	
THE PROCESS LENS	
<i>Generic Process Steps for LTPA</i>	<i>The 'STEF' Process</i>
Motivating and Building a Vision	Using the example of the Science's role in WW2 to motivate future role
Defining the Problem	Transition from war effort to peace, danger of losing science's contribution in other societal problems/needs
Identifying Axial Principles	The linear model of R&D Research Autonomy Basic R&D spillovers to other sectors of society
Identifying Alternatives-Policy Space	Public (Federal) support for basic research
Determining Values	National security, economic wellbeing and health as important societal values
Evaluating Options-Consequences	Strong emphasis against continuing status quo, need for bridging the deficit of manpower etc.
Outlining and Creating Mechanisms-Institutions-Axial Structures	Public funding of R&D in autonomous organizations, creation of NRF, scholarships, fellowships-grants etc.

Applying our above-mentioned template of the Long-Term Policy Analysis model to 'Science: The Endless Frontier' leads to some very interesting insights vis-à-vis both the process and the motivation aspects of the Bush Report. Looking through the 'Process Lens' we can place the various actions-impacts of the Bush report in the 7 broad categories, namely, motivating and building a vision, defining the problem, identifying axial principles, identifying alternatives-

policy space, determining values, evaluating options-consequences, outlining and creating mechanisms-institutions-axial structures⁷. Similarly, with the benefit of the hindsight, one can also attempt to identify the various ways through which the Bush Report helped aid and motivate the long-term policy agenda of its time. These tables reflect a synthesis of this analysis.

A number of interesting comments are warranted. The Bush report, while perfectly following the 'process template', did show some variance in terms of how well it was able to satisfy the requirements of each of the steps. While the report did quite well on the first three steps, namely, motivating the vision, defining the problem and identifying axial principles, It did quite poorly on some of the later steps.

The overarching 'alternative' presented by the Bush Report was federal support for scientific research, partly predetermined by the mandate of the report and partly owing to a weakness in terms of implementing the policy analysis process. Barfield (1997), for example, maintains that the Bush Report '*gave the private sector short shrift*' as well as "*erred in not paying greater attention to broader government policies...which exert strong influence on private development of technology in the United States*". In effect, the Bush Report only considered a limited number of policy alternatives and therefore made the error of not evaluating the entire policy space that could have enlightened the issue even further and perhaps led to better policy choices.

In terms of determining values, the Bush Report managed to get the national priorities right but failed to foresee the tension around the debate of whether government should support research and development or should it be left to the private sector alone. This question has been debated widely between different professional communities in the US since the release of the report along with issues like what constitutes basic research and whether government needs to be involved in applied research for the sake of developing international competitiveness as well? Whether or not this was a deliberate 'omission' on the part of the Bush Report is a task for the historian, but it did affect one of the central process steps of the long term policy analysis and might have had some effect on the its outcome.

⁷ A closely related concept to mechanisms and institutions is 'Axial Structures' as described by Daniel Bell in his Year 2000 Work.

'SCIENCE: THE ENDLESS FRONTIER' AS A LONG TERM POLICY DOCUMENT

THE MOTIVATION LENS

<i>Generic Motivating Factors for LTPA</i>	<i>The 'STEF' Motivating Factors</i>
Clarify, name, define, expound and argue major issues	Starting from President Roosevelt's 4 questions, it elaborated upon each to drive home the role of science in each of the contexts
Create propaedeutic and heuristic expositions, methodologies, paradigms, and frameworks	Laid out and popularized a framework of thinking about public support for R&D based on linear-model of R&D
Furnish specific knowledge and generate/ document conclusions, recommendations, suggestions	Provided advice to the President by convening several committees of eminent scientists and science related professionals
Clarify currently realistic policy choices	Adopted an approach of gradually building up to its lofty goals, by suggesting realistic level of initial funding and preliminary infrastructure
Shaping institutions (for stability, balance, adaptability)	Made recommendations about institutions like National Research Foundation, with provisions to allow long-term and stable commitments
Help develop a systemic view	Elucidated how basic scientific research was inter-linked with other worthy objectives of societal wellbeing
Help identify appropriate values and identities	Identified national security, economic prosperity and health as societal values. Also hinted at research autonomy and opportunity.
Help change the rhetoric	Changed the antagonism of the research community and rhetoric towards public support of research by suggesting some steps/ CBMs
Help change the model	Proposed a new way of looking at public support of R&D i.e. through the linear model
Creating a process to help gain other voices	Made specific recommendations for developing structures that would allow the voice of scientific community in policy making

With reference to the penultimate step i.e. evaluating options and consequences, once again one can see a fundamental weakness in terms of a lack of analysis that is apparent from at-least the report itself and the accompanying documentation. One can try to discount that with essentially two arguments. Firstly, the omissions of the Bush Report can be seen with reference to the naïveté of the analytic community at that time, a fact alluded to in Stokes (1995) that states that perhaps “*in 1945, and even later, there just was no good history of science and technology available in large enough measure to make good judgements there.*” Secondly, it might be reasonable to assume that the bulk of the recommendations of the Bush Report were indeed not based on explicit analysis of policy options as is the norm today but rather on the implicit and ‘tacit’ judgement of the 50-odd experts on the various committees gained over hundreds of man-years of experience in research and policy domains.

Finally, more often than not, the end product of a long-term policy exercise is the creation of long-lasting institutions and mechanisms that carry forward the implementation of its recommendations. The most significant institution that Bush Report aimed to establish was “National Research Foundation” – that was later modified and formed as the National Science Foundation – as the federal government agency with the charter and sole responsibility for funding basic research. Again there were some glitches in the Bush Report – that with the benefit of the hindsight – seem like glaring omissions on the part of Vannevar Bush and his men.

The picture through the ‘motivations lens’ is a lot more consistent with the canonical long-term policy analysis framework. The release of the Bush Report did make some very interesting contributions to the debate on the long-term science policy in the United States. Out of the 21 factors, we can easily identify at-least 10 (listed and illustrated below) on which STEF contributed significantly.

ASSESSING THE LONG TERM IMPACT OF ‘STEF’

Ever since its release in 1945, the Bush Report has had a fair degree of impact not only in terms of implementation (at least partially) of many of its recommendations but also in terms of shaping the debate in American science policy circles. Stokes (1995) identifies the contribution of Bush Report to the scientific establishment in the US on a number of levels. Firstly, it asserts that the Bush Report provided the nation with a general way of thinking about science, a ‘*paradigmatic view*’ that was later employed more and more by those who wanted to achieve similar objectives. This ‘paradigmatic view’, in the words of Stokes, was contained in two ‘aphorisms’ in the Bush

Report. The first of these emphasized that *'basic science is performed without thought of practical ends'* that according to Stokes (1995) acquired a 'definition-like' usage later. The second of the aphorisms was that *'basic research is the pacemaker of technological improvement'*. While whether these are valid today, to the same degree as they were at the time of the release of the report, is subject to debate, but this new way of thinking about scientific progress did serve a very important political purpose at that time. Firstly, it paved way for public support of research without endangering the autonomy and objectivity of the process itself and was thus like music to the ears of the scientific community. Secondly, it established a plausible linkage between public investment in the scientific enterprise and its returns to the society thus providing credence to the pro-science lobby in the government. Thus, in essence, it served the purpose of bridging the gap between the scientific community that could use government support but was skeptical of the restrictions that would come with it and those in the ranks of power who had seen the benefits of scientific research during the second world war and were eager to capture the same for the society in the times of peace that were to follow.

While the general principles of STEF were widely accepted, cited and acknowledged, some of the more specific recommendations were not. The organizational plan of the Bush Report was defeated right from the very onset. It took 5 years from 1945 to 1950 for National Science Foundation to be established – the real world equivalent of Bush's National Research Foundation. Also, when it did come into existence, it was severely limited in terms of its scope and authority than originally envisioned by Bush. The political process took its toll on many counts. Between 1945 and 1950, a number of organizations were charged with the responsibility of conducting basic research that had the effect of diluting the centrality of NSF. These organizations included Atomic Energy Commission (AEC) for nuclear-related research, Department of Defense (DOD) for military research, National Institutes of Health (NIH) for medical research etc. With the benefit of the hindsight, many scholars have in fact shown apprehensions about what would have been a centralized research funding mechanism had Bush's organizational model been implemented. Stokes (1995) writes *"...defeat of the [Bush Report's] organizational plan made it more likely that the ideological view would triumph...Indeed only after the organizational responsibilities for science were shattered and fragmented could the DOD use the Bush outlook to cement its relationship with the universities..."*

Stokes (1995) also cites Gerald Holton as stating a number of other 'glaring omissions' of the Bush Report, namely, neglect of the social sciences and humanities, the concept of a single national research foundation for all fields, the ignorance of the way future would turn out as well

as its omission of federal support for basic technological research etc. Another important pillar of the Bush Report, namely, the linear model of R&D has also come under increasing criticism from many. Barfield (1997) describes the linear model as *'the most fundamental flaw in Bush Report'*. Whether, that is true in its entirety is a subject to debate. Our feeling (and hypothesis, though unproven) is that Bush Linear Model might have been more true in 1945 than it seems today in the sense that increasing technological complexity in the modern times makes it necessarily to assume a much more complex and interlinked relationship between various components of the national innovation system. This was clearly not the case in 1945 when the Bush Model itself was a significant improvement from the existing paradigm of the time that depended on relatively under funded research and development. Today the more widely accepted 'general' wisdom is that the world of research has come a long way from Bush's linear model where basic and applied research were actually competing and that there is a broad based acknowledgement of a much more intimate and complex relationship between various elements of the research and development continuum.

Another interesting comment that to our mind raises some doubts about the validity of the analytic underpinnings of the Bush Report, but not necessarily its efficacy as a long term policy document, comprises Bush's admission that he in fact engineered the entire set of circumstances that led to not only the writing of the report but also its commissioning through a letter by President Roosevelt. Stokes (1995) cites Dr. Bernard Cohen as saying ... *"I conducted an oral-history interview with Vannevar Bush a few years before his death. I asked him straight out, just as we were leaving, whose idea was it to commission such a report? Who had written the letter? He looked at me in the eye, and without a moment's hesitation said that the idea was his. He turned his head a little bit to one side as was his habit, smiled, and stated unequivocally, "I wrote the letter." ..."* While this might not be unsettling for anyone who was looking at the impact of Bush Report on American Science in the post world war era without regards to the counterfactual, it is somewhat disturbing for a policy analyst who might be interested in STEF as an 'objective' document of long term science policy separate from Vannevar Bush's predisposition to a particular type of interventions. Seen in this light, it is hard not to resist the temptation of discounting the glorious STEF as an advocacy piece or at-least something lesser than a fine example of long term science policy. The question that then arises is how many of the known long term policy exercises can be judged in isolation with the motivations and predisposition of their initiators to which our answer is: very few.

TOWARDS AN R&D POLICY FOR THE NEW CENTURY

The world of scientific research and development has come a long way since Vannevar Bush's founding vision of 'federally-supported' American science. Over the last five decades, while the degree of federal support to science, and the mechanisms and institutions that provided it have varied (e.g. very generous during the Kennedy administration to less so during Nixon's), the basic principles have remained more or less the same as dished out by Vannevar Bush. Even today, the basic questions in the science and R&D policy debate remain more or less the same as was the case five decades ago. Stokes (1995) points out that "*In 1945, this opinion of how scientists should directed was widespread. And we know that half-a-century later, the same kind of battle is being fought.*" There is, however, a fair bit of newness to this debate as well. While all four 'strategies' as identified by Averch (1985) and discussed above, had different flavors in which they make an appeal for support to the scientific enterprise, they generally agreed with the basic aphorisms of the Bush Report. Not any more.

There is a growing sense within the scientific and policy communities that the Bush's Linear Model needs a major overhaul, that the very nature of the processes of research and development has changed in such a manner that its about time that science and R&D policy be rethought as well and that the changed circumstances and motivations of the American nation also mandate a reconsideration of what the role of government needs to be. There is a general awareness among the academic community that R&D is becoming a more and more multi-disciplinary, dispersed, resource intensive and complex activity. The linear model proposed by Bush Report is entirely out of sync with the general wisdom of the day that looks at R&D as a complex process with multiple interactions between various participants and a number of fruitful avenues of policy interventions not just funding of basic research. Michael Crow (1997) asserts that "*My premise is that Vannevar Bush's design is not flawed in any serious way. Rather, it is so seriously outdated that it appears completely flawed*", there are a number of related problems that have come up over the years that need a major overhaul of the Bush Model. Crow (1997) identifies these in terms of 'design principles' that need to be taken into account when a new model for the future (perhaps, next 50 years) is built. These include, rethinking the concept of political autonomy and replacing it with a institutional mechanism for forecasting long term science and technology needs and set research priorities accordingly; developing mechanisms for internal discipline of the scientific community; paying more emphasis on applied research ("*science for science's sake*

as well as for problem solving”, as he puts it); a acknowledging and supporting a greater role for team-based research; general accountability; and broad-based funding of scientific endeavors etc.

All this raises new questions (and challenges) and calls for a new vision for government support of R&D. The increasing complexity of the scientific and technological endeavors and the society in general and policy apparatus in particular have led to the notion of ‘adaptive policy making’. Averch (1985) calls for such a policy regime when he asserts that “*Faced with true ignorance of where science and technology is taking the nation, the preferred policy mode may have to be one of search and learn, of acquiring information as one goes, and judging actions sequentially. The policy problem in this case is designing public or private institutions that are ‘light on their feet’, can carry out rapid reconnaissance, process information quickly and correctly, and take rapid action*”. Rycroft et.al. (1999) quotes Brian Arthur as describing this new adaptive policy expertise as a skillful navigation of a paper boat when he asserts, “*Actually you’re just the captain of the paper boat drifting down the river. If you try to resist, you’re not going to get anywhere. On the other hand, if you quietly observe the flow, realizing that you’re part of it, realizing that the flow is ever changing and always leading to new complexities, then every so often you can stick an oar into the river and punt yourself from one eddy to another... You just observe, And where you can make an effective move, you make a move*”

This provides us with an agenda and accompanying institutions radically different than the ones presently in place. Writing of a new vision is perhaps in order. Analyzing “*Science: The Endless Frontier*” as a long term policy documents provides us some guideposts to aim for and important considerations to take into account. If the contributions of the Bush Report can be described in three words, they would be, axial principles, community participation (in this case scientific and policy communities) and shaping institutions. A new vision of public involvement in science would have to essentially do a good job at all three of them and preferably many of the 21 long-term policy motivations identified above to be successful. In some sense the task is already underway. One example, among many others, of that is NSF’s move towards experimenting with and encouraging ‘*partnerships for innovation*’ between various stakeholders in the scientific enterprise. This concept essentially experiments with the new and emerging axial principles that deal with changing nature of the R&D enterprise (e.g. multi-disciplinarity, dispersed and team-based) as well as a more adaptive and fine-tuned involvement of public policy; community involvement by bringing together the various participants in the research enterprise (e.g. universities, businesses and government in a win-win partnership for innovation); and new institutions as in a more proactive and supportive National Science Foundation.

Science's Next Frontier: Looking Backward To See Ahead

If the NSF gets it right, this might as well be the beginning of another era of science in the United States in which case NSF would rightly deserve the title that Dr. Neal Lane once alluded to in his speech on ‘The Future of the National Science Foundation’ in the following words, “*This building is a magic place. We are making tomorrow*”; or this might just be another one of the experiments to try to get it right; or this might as well be the NSF of the future, always adaptive and changing, like Brian Arthur’s mythical boatsman. History will be the best judge.

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