CLASS TWO: INNOVATION AT THE INSTITUTIONAL LEVEL – THE ORGANIZATION OF FEDERAL SCIENCE SUPPORT

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Seminar

FUNDAMENTALS OF SCIENCE AND TECHNOLOGY PUBLIC POLICY MAKING

Quick Summary of Class 1:

- CLASS ONE: GROWTH THEORY
  - Intro. to Growth economics –
  - Solow: "Technology and Related Innovation" is the key factor in economic growth – not capital supply, not labor supply
  - Romer: The driver behind technological innovation is "Human Capital Engaged in Research"
  - Direct Innovation Factors: R&D and Talent
- THE INNOVATION SYSTEM AND ITS ACTORS
  - Nelson – there are "national systems of innovation" – reviews the effectiveness of a "nation's innovation actors"
  - Indirect Innovation Factors - public and private sector
- BRANSCOMB AND AUERSWALD
  - The Valley of Death between R&D

PART ONE: Org. History of US R&D Innovation Actors:

- US SCIENCE ORG. IN WORLD WAR 2 AND THE EARLY POST WAR PERIOD:

David M. Hart, Forged Concensus- Science, Technology and Economic Policy in the U.S., 1921-1953 (Princeton Univ. Press 1998)

- 5 Visions of the Liberal state and Governance of Technological Innovation, 1921-53
- **1) CONSERVATISM:**
  - Saw need for state to provide for defense, including military technological innovation
  - Goal: keep this sphere isolated from domestic economy
  - Movement was reaction to the "excesses" of Wilson's WW1 mobilization – industrial controls

David Hart, Forged Concensus, Con't:

- **1) CONSERVATISM, con't:**
  - Frank Jewett – an exponent of this direction– Pres. of Bell Labs, head of Nat'l Academy, '38
    - Felt federal meddling with R&D and patents laws would slow growth of science advance
    - But: supported WW2 gov't role in science
    - Postwar – supported retrenchment of gov't role
  - Sen. Robert Taft – post-WW2 – military strategy was to control cost through limits on force size, therefore dependant on tech. innovation and nuclear arsenal
  - Summary – gov't's defense science role and needs should be isolated from domestic economy

David Hart, Forged Concensus, Con't:

- **2) ASSOCIATIONALISM:**
  - Exponent: Herbert Hoover – engineer, war relief organizer, Commerce Sec., President
  - Saw the power of state action
  - Felt unlimited economic competition inhibited tech. innovation – price competition prevented risk of innovation – competition blocked large scale R&D because it fragmented industry
  - Associationalism originated in WW1 war mobilization
  - FDR adopts Hoover's associational idea – but his NRA is an organizational disaster – then Vannevar Bush adopts this model for WW2 science and war mobilization

David Hart, Forged Concensus, Con't:

- **3) ASSOCIATIONALISM, con't:**
  - The government's role:
    - Disseminate best practices to rationalize industry continuously
    - Foster industry-wide R&D facilities run by trade association supported by gov't
    - Or: gov't service agencies run these R&D facilities
    - Must be close ties between industry R&D managers and bench scientists
    - Basic idea: gov't industry cooperation, pool resources together, avoid duplication
    - Example: Hoover's Dept. of Commerce – the Bureau of Standards:
      - to reorganize 'sick" industries with new technology
      - Build industry collaborative R&D
      - Tear down barriers that limit high growth industry

David Hart. Forged Concensus, Con't

- **3) REFORM LIBERALISM:**
  - Espoused after NRA failure in 1935 (exponent -Henry Wallace – Commerce Sec.)
  - Basic theory: reestablish markets by gov't regulation (ex., antitrust)
  - Saw gov't as an economic actor
  - Sought end of suppression of tech. innovation by cartels, monopolies
  - State could develop and commercialize new technology itself, or
  - Break bottlenecks that hold back innovation
  - WW2 mobilization by joint associative gov't-industry effort ended this movement
  - Post-WW2 – displaced by Keynesianism

David Hart, Forged Concensus, Con't:

- **4) KEYNESIANISM:**
  - Emerged in 40's – (J.M. Keynes econ. theory)
  - basic view: gov't spending to contribute liquidity to private markets, to spur demand
  - Debate over gov't S&T role – 2 views conflict:
    - Tech innovation is logical result of private investment, only gov't macro tools needed; vs.
    - Widespread market failures in provision of S&T – state should correct by S&T investment
  - Korean War – resolved conflict – Keynesians argue aggregate S&T spending, including defense R&D spending, benefits economy
    - Example: NSF R&D spending indicators – come from this macro orientation

David Hart, Forged Concensus, Con't

- **5) NATIONAL SECURITY STATE:**
  - Emerged in WW2 and Cold War
  - Use any means/any model necessary to reach S&T leadership for defense needs
  - WW2 – associative state and national security state merge
  - Led by Vannevar Bush in WW2
  - During the Cold War –
    - Congressional Repub. - Conservatives – wanted high tech force (Air Force) – cheaper than mass force
    - Dem. Keynesians – military R&D was still R&D – contributed to aggregate R&D spending
      - Were they right???
      - Examples: aerospace, computing, electronics were results

David Hart, Forged Concensus, Con't:

- REALITY: HYBRID GOV'T S&T MODELS DOMINATE THE LAST 50 YEARS, THROUGH THE END OF THE COLD WAR:
- We have a blend of different visions of the state role
- The underlying conflict between positions goes unresolved; pragmatism reigns as usual; mix of:
- Conservative – gov't domestic R&D role – defense only; separate sectors; private sector should play domestic economy S&T role
- Nat'l Security – use any model for S&T to gain military leadership
- Associative – Hoover, FDR, Vannever Bush – latest: Clinton's public-private partnerships
- Keynesian – aggregate R&D spending is key, defense and private sector adequate

Jennet Conant, Tuxedo Park
(bio of Alfred L. Loomis) (Simon & Shuster 2002)

- Alfred L. Loomis – 1887-1975
  - Father deserted family, Loomis is forced to law and Wall St., despite love of science, to support family
  - Made fortune in emerging electrical utility industry – sold out before ’29 crash
  - Experimented in physics of ultrasound in 20’s-30’s
  - Authored 29 science papers before 1939
  - Set up his own R&D lab in his Tuxedo Park mansion north of NYC in 30’s
  - Brought in greatest science physics talent in the world for “summer studies” – informal management
  - MIT’s RAD Lab was a scale-up of this model
  - Loomis’ cousin Henry Stimson, FDR’s Sec. of War, is a surrogate father

Alfred Lee Loomis – “the last of the great amateurs of science” – Luis Alvarez

Jennet Conant, Tuxedo Park, Con't

- MICROWAVE RADAR
  - Loomis had invented 10cm doppler radar system
  - British invent "resonant cavity magnetron" microwave source (inventors: John Randall, Henry Boot)
  - Britain lacks the industrial capacity to do engineering dev. and mass production – US is world's leading mfg. power
  - [Note: relationship between mfg. and technology leadership – unified whole]
  - British had to reach out to mass production capacity of US economy even though US not yet in war – so Tizard Mission
  - US military reluctant to trade secrets with British
    - Stimson/Marshall – Army - more open
    - Ernest King – Anglophobe – distrustful, delay
  - Loomis himself is inventor – family ties to Stimson, and to US science leadership that he has been funding, esp. Ernest Lawrence of Berkeley, the leading US physicist
  - Vannevar Bush heads FDR's Nat'l Def. Res. Comm. – NDRC
  - Loomis is a radar experimenter, heads NDRC's microwave committee – is a Bush ally
  - 9/28/40 – Loomis develops British trust – see value of microwave radar magnetron immediately

Jennet Conant, Tuxedo Park, Con't

- LOOMIS INVENTS THE "FFRDC"
  - The day after seeing the magnetron, Loomis invents the idea of a civilian scientist-run lab with contract to DOD – later called "Federally Funded R&D Center"
  - Loomis sees incredible promise of microwave radar – England is being night-bombed, has no defense, U-boats on verge of starving Eng. – microwave radar can be mounted on a plane and defend against both
  - Immediately proposes a large central microwave lab
  - Civilian scientist controlled, not military controlled
  - To take scientists from both Univ's and industry
    - Draws on British lab model
  - Loomis knows the value of tech leadership – "the boat ahead gets the new breeze first, just because it is ahead and thereby increases its lead."
  - Loomis immediately moves to set up this lab – gets approvals from the NDRC Microwave Comm, Sec. Stimson and Gen. Marshall the next day

Jennet Conant, Tuxedo Park, Con't

- LOOMIS INVENTS THE FFRDC, Con't:
  - Loomis immediately invents the 3 major R&D tasks for the new lab –
    - Airborne interception (AI)
    - Gun-laying for antiaircraft weapons (GL)
    - Long range aircraft navigation (becomes Loran)
  - Loomis the next day recruits Ernest Lawrence (Loomis has been funding his Berkelye accelerator experiments) to start up the lab and hire the finest physics talent in the US
  - Loomis, not even a gov't 'ee, authorizes contracts for magnetron by the end of the weekend
  - By Oct. – finest US physics talent joins the new lab
  - INCREDIBLE SPEED OF DEVELOPMENT

Jennet Conant, Tuxedo Park, Con't

- Loomis Invents the FFRDC, Con't
  - Bell Labs' Frank Jewett tries to locate at his co. – Loomis, with MIT's Compton and V.Bush, outmaneuvers him and locates at MIT
  - Becomes "Rad Lab" – Radiation Lab – cover name since atomic research viewed as long term and not war-relevant
  - Loomis sets up **unprecedented partnership**: between gov't.-univ.-industry
  - 11/11/40 – first meeting of Rad Lab researchers at MIT
  - Farmed out separate component mfg. to industry and all deadlines met as of 11/11/40, so could focus on integrating a system

Jennet Conant, Tuxedo Park, Con't

- CHARACTERISTICS OF RAD LAB - Model for the Postwar FFRDC:
- GREAT TALENT
  - 10 Nobel prizes go to Rad Lab scientists
- FLEXIBLE FUNDING:
  - Loomis himself advances the funds for start-up
  - Contracting with industry is non- bid; Loomis just awards – there's a war on
- LOOSE, INFORMAL ORGANIZATIONAL MODEL
  - Non-bureaucratic org., loose, interacting groups teams Leadership based solely on talent
  - "easy comraderie"; casual tone; interactive
  - "long hours"
  - Almost all scientists – few in support staff – at first, 36 scientists, 1 secretary
- ABILITY OF LAB HEAD TO GO TOP
  - Loomis heads Rad Lab – reports officially to V. Bush of NDRC
  - BUT- frequently goes directly to War Sec. Stimson
  - Loomis forces slow military bureaucracy to adopt new technology
  - SO: another key to Rad Lab – access to top decisionmakers

Jennet Conant, Tuxedo Park, Con't

- MANHATTAN PROJECT
  - "Uranium Comm." had been set up after Einstein to FDR– not progressing – viewed as long term project, post-war realization
  - Ernest Lawrence sees possibility of atomic weapon; all fear German science
  - Lawrence goes to Loomis, he persuades Stimson and V.Bush to expedite and reorganize effort – FDR immediately approves
  - Manhattan project set up on same org. model as Rad Lab - 11 Rad Lab'ers go to Los Alamos to help Oppenheimer set it up
    - Military tried to put it into military bureaucracy – put scientists into uniform
    - Based on success of Rad Lab precedent, approach rejected

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- THE RAD LAB DOES DEVELOPMENT
  - Loomis moves Rad Lab into the continuum from fundamental science base to applied science, at the outset
  - By 8/42 Loomis works to force collaboration with Army so that technology becomes tied to Army's "operational framework" – forces movement of invention into doctrine
    - Classic problem that haunts all defense R&D
  - Loomis adds engineering design, design form mfg., and mfg. prototyping to role of Rad Lab
  - INVENTS: integrated science lab R&D model

Jennet Conant, Tuxedo Park, Con't

- POSTWAR: RAD LAB'S INTEGRATED MODEL ENDS
  - Loomis, even though he achieves the "Associationalist" (see Hart) model of gov't-industry-academic partnership for brilliant and fast R&D development, with V. Bush, dismantles it
  - In postwar he is a Conservative (see Hart) – suspicious of the Associationalist model
  - Shuts down Rad Lab shortly after the end of the war
    - Decides it won't work without war pressure
    - Retains deep faith in private enterprise
  - V. Bush shares his view
    - Bush fights to retain gov't role in basic research

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- LOOMIS' ACCOMPLISHMENTS:
  - As a technologist:
    - LORAN long range radar beam based navigation (originally named after him – he rejects title)
    - Blind landing system for aircraft (ground controlled radar based approach)
    - Re: both Rad Lab and Manhattan Project – he forces both projects into rapid development – critical to the two leading tech developments of the war
  - MORE IMPT: As a science organizer:
    - Development of the FFRDC model is a critical organizational step for US science
    - Also implements the model for integrated science and technology at the Rad Lab – fundamental research through prototyping, eng. design, and initial stage mfg. – this model still not repeated

Vannevar Bush, "Science, The Endless Frontier" (at nsf.gov, 1945)

- 11/17/44 – FDR writes Bush (did Bush draft it for him?)
  - 1) How to diffuse science knowledge gained from the war?
  - 2) How to organize "war against disease"?
  - 3) gov't role in supporting public and private sector research?
  - 4) gov't role in developing science talent?
- FDR's "new frontiers of the mind"
  - Grasps V.L. Parrington's concept of the role of the frontier in American life
  - Proposes new science frontier as next American frontier

Vannevar Bush, 1890-1974

Vannevar Bush, Science the Endless Frontier, Con't:

- BACKGROUND:
  - V. Bush's paper comes out in July 1945 after FDR's death – it is the most influential policy paper ever written on US science organization
  - V.Bush is thinking through the postwar model for US science, thinking about the gov't's future role
  - The "Associationalist" model dominates WW2
  - V.Bush dis-agregates science away from this model
    - Probably convinced politics will dismantle the WW2 model of integrated research and development
    - Wants to salvage basic research for a gov't role
    - Concerned that applied science dominated WW2 – sees need to restore basic science

Vannevar Bush, "Science, The Endless Frontier", Con't:

- V. Bush's Report Defines the Future Direction of US Science Progress:
  - Bush announces new popular causes for US Science
  - Science is to be "part of a team" for "health, security, prosperity" –
  - separates science as a separate player from other innovation actors – against integrated model for science
  - Announces 3 goal areas for science:
- 1) "War Against Disease" Direction:
  - Bush and FDR saw huge medical gains in WW2
  - Antibiotics key – reduced disease, cut death from disease in WW2 to .6/1000, from WW1 of 14,1/1000
  - Health provides new public purpose for science

Vannevar Bush, "Science, The Endless Frontier", Con't:

- 2) National Security Direction:
  - Pre-Cold War, but argues military research in peacetime vital for US security, can't rely on allies (lesson of WW2 preparedness)
  - But insists on Loomis' Rad Lab approach – must be civilian control of defense science, with "close liaison" to military
  - Because NSF is not formed until after Cold War starts, NSF never assigned defense R&D
- 3) "Public Welfare" Direction:
  - Goal is "full employment" – big postwar anxiety
  - Proposes idea that "basic research is public capital"
  - science role is to add capital, value to innovation system, not to dominate it or be integrated into it
- 4) Nurture "Talent" Direction:
  - Bush envisions gov't role in educating science talent

Vannevar Bush, "Science, the Endless Frontier", Con't:

- Bush has a "pipeline" theory of innovation:
  - Science with gov't backing will contribute basic research, not applied
  - Industry will apply it to practical problems
  - Gov't role is to increase "scientific capital" by supporting academic research
    - This form of research is removed form "pressure for immediate tangible results"
  - Bush's idea: remove science from the fray – protect it, put it back into the ivory tower
    - Is that a good idea?

Vannevar Bush, "Science, The Endless Frontier", Con't:

- Bush's Vision of Postwar Gov't Role in Science"
  - Sharply limited from WW2 role he oversaw
  - Support for science talent development
  - Offer industry an R&D tax deduction
  - Reform the patent system
  - Gov't should also develop mechanisms to disseminate science advances to industries outside the reach of science
  - Notes that a big backlog of APPLIED science advance from WW2 efforts are available to solve practical problems
    - Gov't should "lift the lid" and enable industry to access
  - Opening "new frontiers" is historical US gov't role – extends concept for opening frontiers to justify gov't science role – but limited and controlled role

Vannevar Bush, "Science, The Endless Frontier", Con't:

- Bush call for a "New Agency" to carry out the directions he proposes for US science:
  - 1)new agency to support "basic science"
    - Research direction and control will remain in academia, with gov't providing funding and minimal supervision
  - 2) new agency will support science "talent" education
  - Bush argues that US science requires " long range research programs" which will be based on "stable funding" – hence agency at arms' length from gov't
  - His model agency becomes NSF –
    - It's delayed for 5 years, and meanwhile defense R&D, AEC and NIH move out ahead and separately – therefore there is no unified science funding agency as he envisioned – US science is fragmented because of the delay

Summary of PART ONE Readings:

- DAVID HART: STORY ONE:
  - Explains the political currents behind defining the gov't role in support for science/R&D
  - Associationalist theory still battling with Conservative/National Security movements
- LOOMIS AND V.BUSH: STORY TWO – WW2 LEADS TO NEW MODEL
  - Bush and Loomis unify US Science R&D under Bush's NRDC and its successor OSRD
  - Even though they are funded by the military, they react against the military's WW1 role and create a new civilian controlled model

Summary of PART ONE, Con't

- STORY 2, Con't - Loomis sets of the Rad Lab R&D center outside not just Defense but outside the gov't, at MIT
- "FFRDC" – Loomis invents this model and it is a key to how US science will evolve post-WW2 – civilian scientist control, flexible org.
- organized in loose teams, fast and flexible R&D contracting, great talent, non-bureaucratic
- Bush unifies US science under a central directorate (ie, Bush); Loomis unifies basic and applied research in the non-gov't FFRDC R&D center

Summary of PART ONE, Con't

- STORY THREE: POSTWAR SHATTERS THE UNITY
  - The immediate postwar shatters the unified science organization that Bush and Loomis created
  - Bush himself dismantles it – that's one message in his famous manifesto "Science, The Endless Frontier" - Bush decides that Gov't should only support basic research – walks away from the applied/basic mix he and Loomis set up at Rad Lab and Manhattan Proj.
  - He tries to unify science research at NSF but his fight with Truman stalls it
  - SO: by the early cold war – unity of science research is broken and the unity of basic and applied science research is broken

Summary of PART ONE, Con't

- STORY THREE CON'T:
  - ONR gets stood up buy Adm. Bowen
  - Also – NIH, and AEC/DOE gets Manhattan Proj.
  - ONR is the model, and provides leaders, for NSF
- Meanwhile, William Golden stands up OSTP/Presidential Science Advisor
  - Weak coordinating entity in the White House – lacks budget power to be meaningful

PART TWO: Org. History of US R&D Innovation Actors:

- THE COLD WAR AND THE EVOLUTION OF US SCIENCE ORGANIZATION:

George Mazuzan,"NSF, A Brief History (1950-1985)"(nsf.gov 7/15/1994)

- The 5 year battle over the form of administrative control for NSF between V.Bush and Truman allowed other science agencies to arise to fill the void.
- Atomic Energy Commission – AEC acquired the Manhattan Project and its scientists at Los Alamos, Sandia, and Lawrence-Livermore – this made AEC, and its later successor, the Dept. of Energy, the automatic leader in atomic physics
- National Institute(s) of Health – the Public Health Service had earlier established a science branch to support its missions. When NSF failed to materialize, the Nat'l Institute (there was only one then) expanded its own intramural labs
  - Then NIH added an extramural grant program for basic research in universities that built geographic support. Congress provided sizable funding to serve an enduring political constituency.
  - Because of the basic research biology science missions it was assigned, and its isolation from the rest of science, it failed to develop cross-disciplinary connections with the rest of science

Mazuzan, NSF, A Brief History, Con't

- Office of Naval Research – was the 3rd major agency stood up – this was a basic science agency, with a uniformed officer in command but civilian scientist deputies – it pioneered the approaches NSF would take, from peer review to flexible contracts, and it's staff transferred to NSF to run it in its early years
- National Academy of Sciences – gov't science advice agency, not research agency. Founded in 1863, and its gov't advisory arm, the Nat'l Research Council in 1863

Mazuzan, NSF, A Brief History, Con't

- NSF's authorizing legislation enabled it to serve as a supervisory, coordinating science agency, but it rejected this role despite pressure from BoB to do so
- NSF was slow to startup; it's first budget was not until FY '52 and was only $3.5m
- Organizational elements:
  - Modelled on ONR's processes
  - Offered flexible research grants, that covered direct costs as well as 15% of indirect costs
  - Grants went to the univ. not specific researchers
  - Program managers led in science areas
  - Peer review system set up to review grant applications
  - science merit was critical grant award criteria, so concern from Congress on geographical distribution
  - Other mission was science education – fellowships for grad ed
  - "Big Science" – large part of budget was consumed in major facilites (optical astronomy, atmospheric research, Antarctica)
  - Social sciences allowed as "other sciences" under statute – not funded until 1958

Mazuzan, NSF, A Brief History, Con't

- SPUTNIK - 1957:
- Leads to Golden Age of US Science
- Sputnik transformed NSF from a small agency; tripled funding to $134m in '59 and grew to $500m in '68
- NASA – Sputnik also led to founding of NASA – had portfolio of space mission applied science, but also related basic science
  - Continued US trend of specialized science agencies
- Sputnik also forced Cong. reforms – strong science Committee for space and general science formed in the House; weaker Committee in the Senate (later merged into Sen. Commerce)
- Sputnik also forced major science education reforms in K-12 education
- NSF also began supporting science facilities and equipment in Univ's.

Mazuzan, NSF, A Brief History, Con't

- APPLIED SCIENCE AT NSF:
- Daddario-Kennedy bill in '68 reauthorized NSF authorized applied as well as basic research by NSF
- Lyndon Johnson, a great leveler and egalitarian democrat, pushed applied science agenda
- NSF stood up an applied agenda – focused on science resources for major social problems like environment, energy, transportation, social problems
  - Attempted to link industry with Univ's.
  - Bitter revolt against this by basic research scientists, NSF staff, other agencies
- Carter and Reagan Administrations both supported NSF, but while Carter, an engineer, supported applied, initially Reagan opposed

Mazuzan, NSF, A Brief History, Con't

- ERICH BLOCH ERA AT NSF:
  - Pres. Reagan brought him in from technology development career at IBM – a computing engineer who won Nat'l Medal of Tech for Systems 360 work
    - First and only NSF head from industry
  - He brought engineering to a new status in the agency, pushing the "engineering centers" program
    - Represented a break from small basic research grant history of NSF
    - Linked univ's and industry
    - Centers sponsored work in sign. Tech breakthrough areas
  - Bloch was able to get add'l funding for NSF so his engineering focus didn't conflict with basic research portfolio
  - Built computer science dept.'s and computing centers at Univ's.

Donald E. Stokes, "Pasteur's Quadrant, Basic Science and Technological Innovation" (Brookings 1997)

- The relationship between science and gov't was transformed by WW2
  - US prewar had some federal science entities – USGS, agriculture experiment station – pursued agency missions
  - Had nascent research Univ's on the Germon model
  - During interwar years, Univ. science concerned it might lose its "autonomy"
- V. Bush's OSRD (Office of Scientific Research and Dev. – successor to NDRC) "was the nearest thing to a true central science org. in all of American history"
  - Unparalled flow of funding into basic as well as applied science - esp. nuclear physics, electronics

Prof. Donald Stokes, 1928-1997

Dean of the Woodrow Wilson School at Princeton; died of Leukemia shortly after finishing “Pasteur’s Quadrant”

Donald Stokes, Pasteur's Quadrant, Con't

- STOKES ARGUES BUSH'S BASIC RESEARCH CANNON HAS TWO PARTS:
- "IT IS PERFORMED WITHOUT THOUGHT OF PRACTICAL ENDS"
  - DESIGNED TO PERSUADE COUNTRY THAT ATTEMPTS TO CONSTRAIN FREE CREATIVITY OF THE BASIC SCIENTIST WOULD BE INHERENTLY SELF-DEFEATING
- "BASIC RESEARCH IS THE PACEMAKER OF TECHNOLOGICAL IMPROVEMENT"
  - DESIGNED TO PERSUADE THE POLICY COMMUNITY THAT INVESTMENT IN BASIC SCIENCE WOULD YIELD THE TECHNOLOGY TO SOLVE A BROAD SPECTRUM OF NATIONAL NEEDS

Donald Stokes, Pasteur's Quadrant, Con't

- V. Bush's OSRD:
  - V. Bush's OSRD appealed to FDR's love of creating initiatives outside of regular gov't
  - Bush and allies Compton, Loomis, Conant grasped that the war would be technology and science-based conflict in significant part
  - Bush worked with FDR through his legendary aide Harry Hopkins - had access to the Pres.
  - OSRD part of the exec Office of the President
  - OSRD contracted for science work, didn't set up own labs
  - Leadership from the scientific elite and elite science institutions

Donald Stokes, Pasteur's Quadrant, Con't

- POSTWAR SCIENCE:
- Sen. Harley Kilgore (W.Va.) sponsored first bill for postwar science organization in '42 – science didn't have the leading voice in his agency
- Bush's goals – federal support of basic science, but curtail gov't control of the performance of that research
- Bush aimed to create an entity with cross-science authority as broad as OSRD's in WW2
- Director would be chosen by a board of scientists, not named by Pres. and Senate-confirmed

Donald Stokes, Pasteur's Quadrant, Con't

- BUSH'S ORGANIZATIONAL PLAN IS DEFEATED
  - Truman rejects scientist control of NSF – insist on Pres. Appointment, general control
    - Congress, completely geography protective, suspicious of elitist funding distribution
  - The 5-year delay fragments the overall science portfolio Bush envisions for NSF
    - ONR, AEC stood up; NIH gets OSRD's medical research contracts
- BUT: BUSH'S BASIC SCIENCE IDEALOGY TRIUMPHS

Donald Stokes, Pasteur's Quadrant, Con't

- WHY BUSH'S BASIC SCIENCE IDEALOGY TRIUMPHS
  - Bush's Postwar Bargain – if gov't funds basic science, I promise you technological progress
  - NSF's Univ. constituents love the idea that pure research is "the font of technological progress" – enables them to provide social rationale for basic research to justify federal funding
  - Sputnik proves how deeply Bush's ideology spread – the American answer to Sputnik is not only an applied science space race, but huge new investments in basic science
  - DOD: "Project Hindsight": 1 in 100 defense basic research projects result in weapons system advance
  - NSF – its whole rationale is challenged – showed the antecedents of 5 selected technological innovations were basic science-based

Donald Stokes, Pasteur's Quadrant, Con't

- BUT – NSF WAS JUST SHOWING WHAT COULD BE TRUE – TECH. ADVANCE COULD COME FROM BASIC RESEARCH
- BOTH DOD AND NSF CONTINUE TO THINK IN LINEAR MODEL
  - DOD: ALL THAT MATTERED IS LINEAR SEGMENT OF: APPLIED TO DEV TO PRODUCITON
  - NSF: ALL THAT MATTERS IS LINEAR - BASIC TO APPLIED TO DEV. TO PRODUCTION
- THE IDEAL OF PURE INQUIRY UNDER BUSH'S CANNONS DATES FROM CLASSICAL GREEK SCIENCE
- BUSH PARADIGM OF THE LINEAR RELATION BETWEEN SCIENCE AND TECH STOKES ARGUES BEARS NO RELATIONSHIP TO THEIR TRUE CONNECTION

Donald Stokes, Pasteur's Quadrant, Con't

- BUT: THE TIES BETWEEN SCIENCE AND TECHNOLOGY AREN'T LINEAR, THEY ARE INTERACTIVE
- USE-INSPIRED SCIENCE YIELDS BOTH BASIC AND APPLIED RESULTS
- BUSH'S EFFORT ON BEHALF OF THE SCIENCE COMMUNITY TO PRESERVE THE AUTONOMY OF PUBLICALLY-FUNDED SCIENCE LED HIM TO DECRY EFFORTS TO CONSTRAIN THE CREATIVITY OF BASIC RESEARCH
  - BUT IT IS EVENTUALLY SELF-DEFEATING BECAUSE IT'S NOT THE RIGHT MODEL
- CHALLENGES TO BUSH'S IDEALOGY GREW INSISTENT AS US NEEDS SHIFTED FROM THE MILITARY TO ECONOMIC SPHERE

Stokes - The Problem with V. Bush's Pipeline Model:

- **Vannevar Bush's model for gov't funded undirected basic research, post WW2, was a STATIC model, although he argued it would be "the pacemaker for technological progress"**
- **basic research investment would capture the gain of tech progress**
- **Bush paradigm found deep resonance in Western classical philosophy of science as reason, and its other tradition, Francis Bacon's marriage of science with the practical arts**
- **Bush short-circuited basic research from consideration of use**
- **His linear model was one-dimensional**

Stokes: The Problem, Con't

- Bush belief: understanding and use are conflicting goals, so basic and applied research must be separated
- "applied research drives out pure"-V.Bush
- No wonder US has had historic trouble converting its leadership in technology inventions into products – Bush made this a suspect activity
- Bush's segmented linear/pipeline model:

Basic-->applied--> development--> production & operations

Stokes: the Pasteur Model

- Stokes' Test Case: Pasteur – the rise of microbiology
- Pasteur sought a fundamental understanding, via microbiology, of the process of disease
- But he sought this through applied goals of preventing spoilage in various substances including milk, then pursuing anthrax in sheep, cholera in chickens, rabies in animals and humans
- As Pasteur's scientific studies became more fundamental, his inquiry became more applied

Stokes' PASTEUR'S QUADRANT:

- Consideration of Use?

Search for fundamental under-standing	No	Yes
Yes	Pure basic research – Ex- Nils Bohr	Use inspired basic research – Ex- Louis Pasteur
No	Review of the particulars not the general -- early Darwin	Pure applied research – Ex-Thomas Edison

Stokes: The Problem. Con't -

- **The deepest flaw in the V. Bush paradigm is that technology development flows one way, from science to technology**
- **BUT: there is a reverse flow – from technology to science**
- **Science is interactive – it is a whole, not segregated**
- **There is a growing amount of technology that flows from science, but the other way is strong:**
- **For example - Semiconductors – fundamental research that is technology based - built from atomic layer to atomic layer**
- **Who reaps the technological harvest from science? U.S. reached technological leadership LONG BEFORE it reached science leadership**

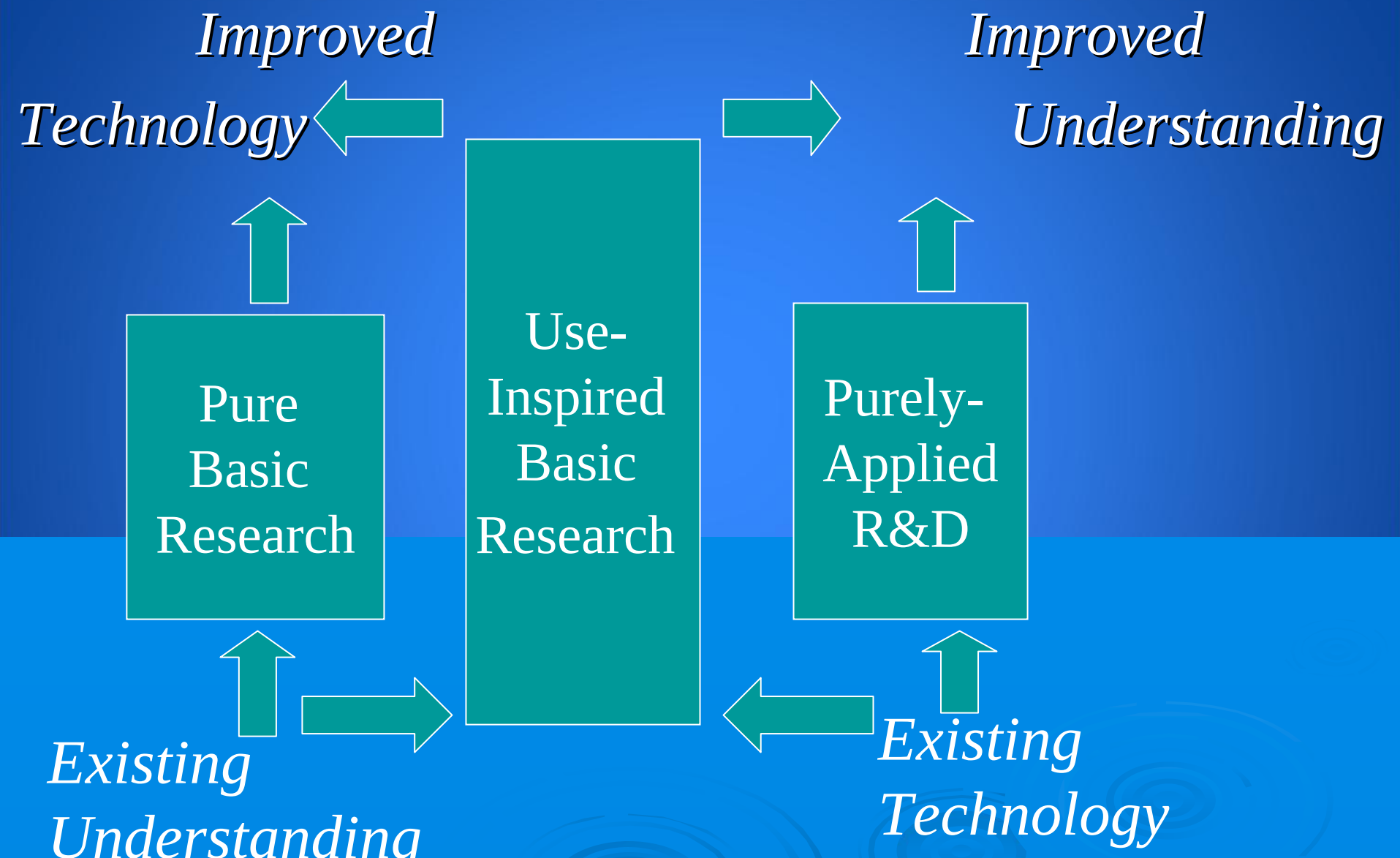
Stokes: The Problem, Con't -

- **The greatest strides in productive technology can be made by nations that lack science leadership – the US in the 20's, Japan in the 70's-80's**
- **V.Bush's manifesto presents "a paradox in the history of ideas" – history of science presents so many cases of interactive applied and basic science, how did it become believed that these were in tension?**
- **James B. Conant, Pres., Harvard – Bush Ally in WW2, first head of Truman's Nat'l Sci. Bd.: "No one can draw a sharp line between basic and applied research…we might do well to discard altogether the phrases…in their place I should put the words 'programatic research' and 'uncommitted research'. It would be safe to say all so-called applied research is programatic, but so, too, is much that is often labeled fundamental." - 1950**

Stokes: The Problem, Con't -

- The U.S., which owes so much for Bush's stunning science organizational work in WW2, to his vision of how science could be mobilized and energized, lost so much from the postwar narrowness of his view of science -- perhaps due to his fear of the power FDR's industrial state [or reaction to militarization of science or to the atomic bomb, or to worry about where the funding was to come from in post war peace]
- Deborah Shapley & Rustum Roy: "What was lost, in a word, was the importance of applied science and engineering, and something else we shall call *pur-positive basic research*…"

Stokes' "Dynamic Model"



Stokes: the Problem, Con't -

- **Eventually, Erich Bloch comes to NSF and is able to bring computing and sci/tech and engineering centers – but the "Upstairs-Downstairs" damage to science had been done**
- **How much was revulsion against what the Manhattan Project did to physics?**
- **Block (and David Cheney): "Technology that remains in the lab provides almost no economic benefits. Technology that is applied only to gov't markets such as defense, provides much smaller economic benefits than technologies that contribute to success in the much larger commercial markets, and especially to the ever more important global markets."**

Stokes' Closing Manifesto

- "A clearer understanding by the scientific and policy communities of the role of use-inspired basic research can help renew the compact between science and government, a compact that must also provide support for pure basic research.
- "Agendas of use-inspired basic research can be built only by bringing together informed judgments of research promise and societal need."

Vernon W. Ruttan, is War Necessary for Economic Growth? (2006)

RUTTAN, CON'T

- **INTERCHANGEABLE MACHINE MADE PARTS - CHAPT. 2**
  - Mfg. goes from 10% of US commodity production in 1800 to 50% by 1900
  - "The American System" is key
  - 1797 War Dept. bought arms from private contractors - Washington substituted arsenals - esp. Springfield, Mass. and Harpers Ferry, W.Va
  - Mfg. was a handicraft process; armies had logistic tails of blacksmiths and armorer trains
  - Eli Whitney story - 1798
    - - bogged down in patent litigation over his cotton gin, turns to War Dept. musket contract - early industrial bailout
    - - proposes interchangeable machined parts
    - - invents cost plus contracts and massive cost overrun
    - - right idea but doesn't have the machine tools yet
    - takes 11 years to deliver - and not interchangeable parts

RUTTAN, CON'T

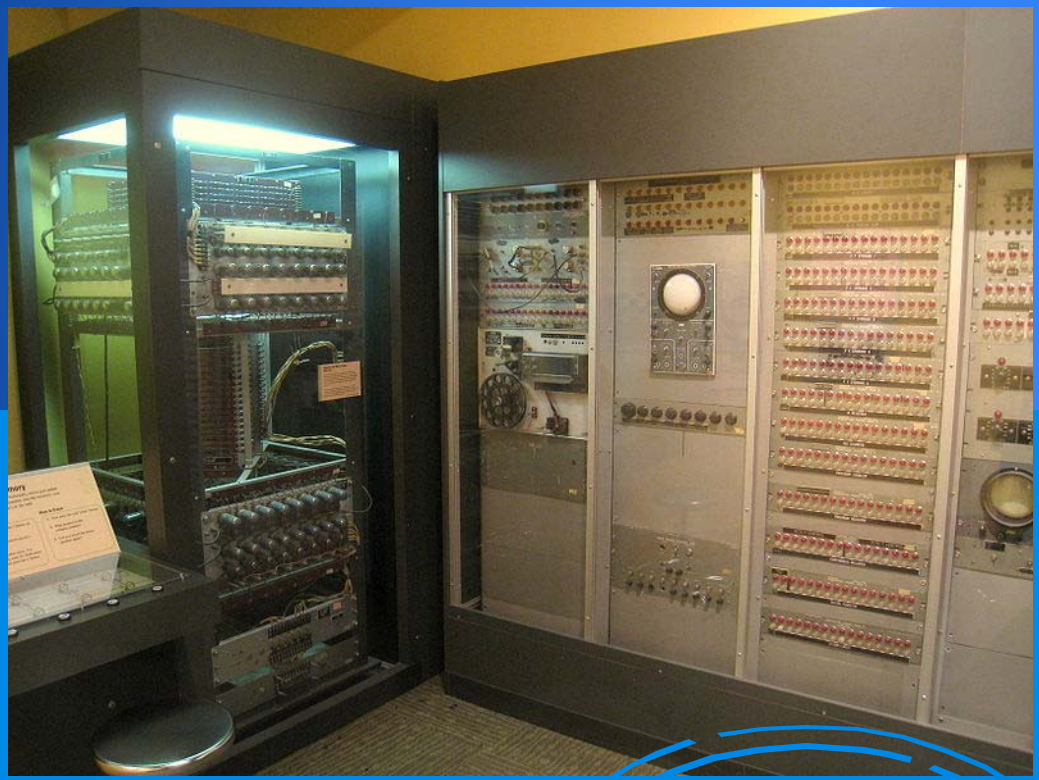
- Next Key Figure - John Hall of Portland, Me.
  - Develops early breech-loading rifle
  - Becomes armorer at Harper's Ferry and develops the machine tools to build interchangeable musket parts
  - War Dept. goes to second private contractor using Hall's system - parts made in Middletown, Conn. for rifle can be interchanged with Harper's Ferry parts
  - System copied all up and down Conn. River Valley - for clocks, guns, simple machines
  - By 1850 English industrialists visiting US - trying to understand "American System"
  - Leadership in industrial revolution shifts from Britain to US
  - By the end of the 19th century US factories attain high volume production - Colt's is model for Henry Ford
  - Only Army had resources and risk timetable to stand whole new system of production

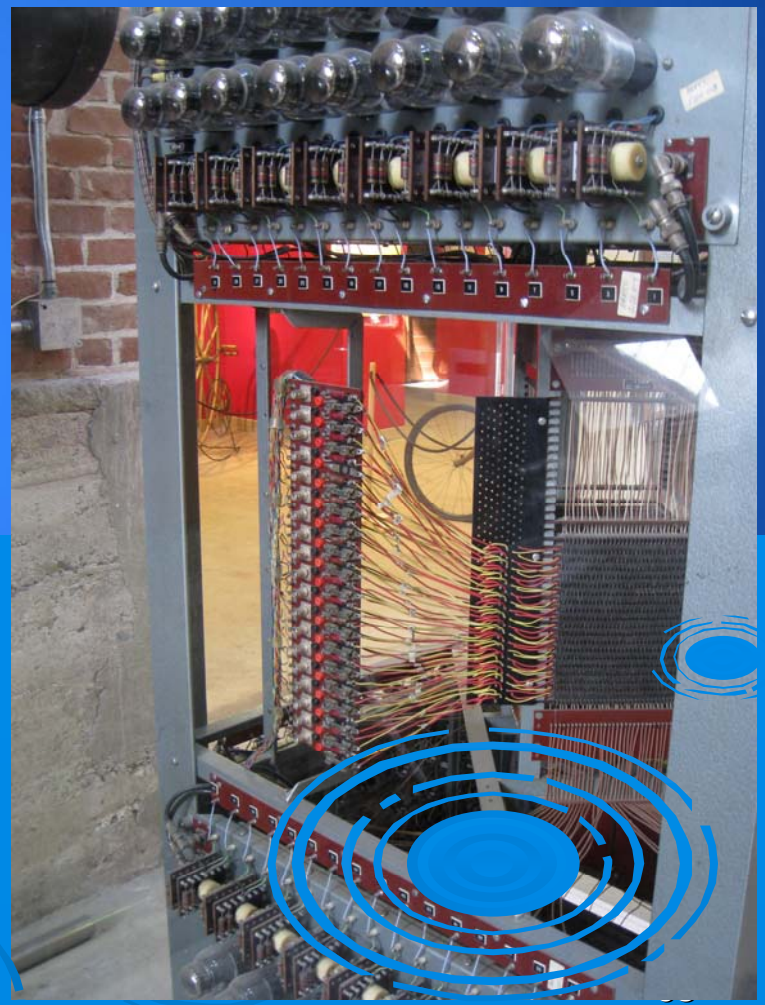
RUTTAN, CON'T

DOD STANDS UP COMPUTING - CHAPT. 5

- DOD funds the first all digital computer - ENIAC in 1946 at Penn
  - for calculating the artillery firing tables
  - Used in calculating hydrogen bomb ignition
  - John Van Neumann architecture - CPU pulls instructions from central memory
  - UNIVAC 2nd gen does the '50 census
- Whirlwind and Sage at MIT
  - George Valley of MIT convinces the USAF that US is defenseless against air attack and needs radar defense - SAGE
  - Jay Forrester of MIT was developing Whirlwind computer for Navy's ONR as flight simulator - but Navy winds it down
  - Valley sees that Whirlwind can provide real time processing for SAGE system
  - Whirlwind - First real time computer - not just fast calculator
  - Operators sit in front of CRT's with keyboards inputting data and making commands - use light pen (mouse)
  - SAGE messages over phone lines (internet) - networked

Whirlwind - 1st real time computing, magnetic core memory, CRT/keyboard computer, networked over phone lines





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Ruttan, Con't

- **Semiconductors**
  - transistors at Bell Labs - w/initial DOD contracts (Bardeen, Brattain, Shockley) - fundamental advance and technology advance simultaneously
  - Next two big steps - Integrated Circuit (TI-Kilby)and Fairchild Semiconductor - Kilby and Noyce
  - The Microprocessor (Intel - Noyce)
  - Both: DOD purchase support - Minuteman and Apollo
  - Lithography - backed by DOD
  - Sematech - recovery of US sector in 80's DARPA backed
- **Supercomputers**
  - Nuclear and missile design and ballistic tracking requires supercomputing
  - Cray machines - DOD, DOE labs was the market
  - To this day, market for supercomputers is DOD, DOE labs ("stockpile stewardship") IBM and Cray successor

RUTTAN, CON'T

- **Software**
  - As late as the 80's DOD is the largest purchaser of software in the US
  - DOD role in software is through DARPA creating the first computer science dept's (at MIT, Carnegie Mellon and Stanford, then others) - software programming is the initial heart of the curriculum - different pattern from role in computing and semiconductors
  - Software has yet to follow the productivity curve of computing and semiconductors
- **Personal Computing and the Internet**
  - We will study but DOD builds these (Chapt. 6)
- **Other 20th Century DOD tech revolutions:**
  - **Aviation, nuclear power, space**

Summary of PART TWO:

- MAZUZAN ARTICLE – NSF DOES BASIC RESEARCH
  - NSF will not be a unifying agency for US science coordination – other agencies grow up
  - Although it plays with some applied work in the 60's, it remains a basic research agency
  - [Same approach at NIH]
- DONALD STOKES
  - Attacks whole concept of separating basic research
  - Argues that not the way science evolves
  - Science is not linear, not a pipeline
  - Science is interactive between basic and applied
  - Suggests US made a great mistake in focusing two of its great science agencies (NSF, NIH) on basic-only model
- RUTTAN
  - Central role of DOD with connected science model - moving from R to D to prototyping to product to initial market

THOUGHT : ONE THING

- SCIENCE IS ONE THING!
- THE CREATOR'S BRAIN IS NOT DIVIDED INTO SEPARATE PARTS THAT DO NOT CONNECT, FOR PHYSICS, CHEMISTRY, BIOLOGY, COMPUTING
- CAN'T ORGANIZE THE SCIENCE ENTERPRISE THIS CENTURY ON A SEGREGATED SCIENCE MODEL
- WON'T WORK – SCIENCE IS A UNITY

THOUGHT : SWARM THEORY OF INNOVATION

- Mitch Waldrop – “Science takes a Village”
- It’s more than a village
- An ant hill; a beehive
- Invention at one time may have taken just one person – with complex technologies even invention may require team
- Innovation requires a network (see Rycroft, GWU, and Kash, GMU) – a swarm
- Look at the swarms assembled at the Rad Lab or by Licklider/DARPA for interactive computing

PART THREE - Organizational History of U.S. R&D Innovation Actors:

- THE EMERGENCE OF THE DARPA MODEL OF "CONNECTED" U.S. SCIENCE

DARPA AS A UNIQUE MODEL (Bonvillian, "Power Play", The Amer. Interest (Fall 2006))

- Arguably, innovation organization is a third direct innovation factor, and noted that it operates at both the institutional level and the personal level. Unlike the other models we have discussed above, DARPA has operated at both the institutional and personal levels.
- Eisenhower's initial 1957 creation ended up as a unique entity. It got around the post WW2 dismantlement of the connected science model, and end of the "Great Group" culture at the Rad Lab.
- DARPA becomes a bridge organization connecting these two organizational elements, unlike any other R&D entity stood up in government.

JCR Licklider - “Man-Machine Interface” / “Human-Computer Symbiosis”: "The hope is that in not too many years, human brains and computing machines will be coupled together very tightly, and that the resulting partnership will think as no human brain has ever thought.” -1960

JCR Licklider & the DARPA Model

- (see discussion in: Mitchell Waldrop, Dream Machine (2001)
- In 1960 Licklider writes about the "Man-Machine Interface" / "Human-Computer Symbiosis": "The hope is that in not too many years, human brains and computing machines will be coupled together very tightly, and that the resulting partnership will think as no human brain has ever thought."
- By 1960 – Licklider has envisioned both personal computing (as opposed to the then-dominant main-frame computing), the internet, the www, and nearly all the features we are still realizing
- Then Licklider goes to (D)ARPA – given job of solving Kennedy's and MacNamara's command and control problem
- Rare case of the visionary being placed in the position of vision-enabler
- He funds, selects, organizes and stands up the support network of talent – researchers at Univ's and co's – that builds personal computing and the internet
- DARPA under Jack Ruina, Charles Herzfeld, and even George Heilmeier back Licklider in creating the first and greatest success of the DARPA model
- Licklider creates a series of Great Groups – these in turn have the key features of Rad Lab, Los Alamos – Doug Englebart's Demo, Robert Taylor at Xerox Parc

Elements in the DARPA Model

- At the Institutional level – DARPA is able to do connected science – model requires: Right to Left
- Revolutionary technology development - fundamental science connected through the development and prototyping stages

- Other ways DARPA assures connectedness:
- -Cook-Deegan - in the midst of the notorious Pentagon bureaucracy is a group of freewheeling technology pirates – developed ability to make connections across the DOD stovepipes
- -Uses funding to leverage contributions from other DOD service tech development organizations, and promote service adaptation and production
- -Uses other DOD entities as its agents – promotes cooperation across the stovepipes – helps assure prototypes will move into production stage where DOD will create first market

- Other DARPA Characteristics – affect it's ability to operate at the Institutional and Great Group levels

Elements of DARPA Model, Con't

- **Small and flexible –**100/150 professionals – "100 geniuses connected by a travel agent";
- **Flat organization -** no hierarchy, 2 levels;
- **Substantial autonomy and freedom** from bureaucratic impediments – operates outside civil service hiring and gov't contracting rules;
- **Technical staff drawn from world-class** scientists and engineers with representation from industry, universities, government laboratories and Federally Funded Research and Development Centers (FFRDC's);
- **Technical staff hired or assigned for 3-5 years** and rotated to assure fresh thinking and perspectives;

- **Project based –CHALLENGE MODEL -**
- all efforts typically 3-5 years long with strong focus on end-goals. Major technological challenges may be addressed over much longer times but only as a series of focused steps.
- The end of each project is the end. It may be that another project is started in the same technical area, perhaps with the same program manager and, to the outside world, this may be seen as a simple extension. For DARPA, though, it is a conscious weighing of the current opportunity and a completely fresh decision. The fact of prior investment is irrelevant;

Elements of DARPA Model, Con't

- **Necessary supporting personnel (technical, contracting, administrative) are "hired" on a temporary basis** to provide complete flexibility to get into and out of an area without the problems of sustaining the staff. This is by agreement with Defense or other governmental organizations (military R&D groups, National Aeronautics and Space Administration, National Science Foundation, etc.) and from System Engineering and Technical Assistance (SETA) contractors – builds collaboration and leverages help across DOD stovepipes;

- **Program Managers (the heart of DARPA) are selected to be technically outstanding and entrepreneurial.** "The best DARPA Program Managers have always been freewheeling zealots in pursuit of their goals";

- **Management** is focused on basic stewardship of taxpayer funds but imposes little else in terms of rules. Management's job is to **enable the Program Managers – empowerment model;**

- **A complete acceptance of failure** if the payoff of success was high enough – high risk model for breakthrough opportunity

Elements of DARPA Model, Con't

- Oriented to **Revolutionary Technology breakthroughs** – Radical not Incremental Innovation – emphasis on High Risk Investment
- Fundamental through prototype – hands off production to services OR commercial sector
- Usually works on solutions to Joint Service problems – works across DOD's stovepipes – and leverages them
- Typical project:
- $10-40m over 4 years
- Single DARPA Project Manager controls
- Other Defense R&D agency or outside contractor manages administrative side–buy in
- Typically combines private co's and Univ's, all aimed at common goal
- This is DARPA's Hybrid model - univ's/small co's

How healthy is the DARPA Model?

- Arguably economic innovation sectors are best described as ecosystems and Marco Iansati and Roy Levien have argued (in The Keystone Advantage, Harvard Bus. Sch. Press 2005)) that within these systems are keystone firms that take on the task of sustaining the while ecosystem by connecting participants and promoting the progress of the whole system.

- Iansati has also argued that these innovation systems start to decline or shift elsewhere where the keystone firms cease being thought leaders and instead shift to what he calls "landlord" status. There, the landlord shifts to simply extracting value from the existing system rather than continuously attempting to renew and build the system. Does this analogy apply to DARPA?

- DARPA appears increasingly focused on a problem DARPA ran into the end of the Cold War and its higher levels of procurement – the breakdown of technology transition into services. DARPA has had to shift to less radical innovation and more incremental innovation, shifting investment into late stage development. So: had to cut back on breakthrough model, its historic mission.
- Classified/"black" programs up, hybrid model/"mindshare" down

Summary - Part Three - DARPA

- DARPA operates at BOTH the institutional and personal levels of innovation
- Creates "connected science" resolving the V. Bush "valley of death" problem Stokes decries
- bridges basic and applied, R and D, using the hybrid model and the left-right model
- Innovation Organization is the THIRD DIRECT INNOVATION FACTOR

Resource: Science Policy Bootcamp

William Bonvillian