CLASS I – THE DRIVERS BEHIND SCIENCE AND TECHNOLOGY SUPPORT

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Seminar

FUNDAMENTALS OF SCIENCE AND TECHNOLOGY PUBLIC POLICYMAKING

Course Introduction -

- **Class Organization:** Aim of class – summary of syllabus
- Your backgrounds, interests; Mine
- What do you want to get from class?
- One Key — you talk, you don't learn unless you talk, and talk to each other not just me –
- have to read - need you in the discussion

- **Innovation is about people** – people not institutions innovate - Craig Venter story (http://www.cwhonors.org/archives/histories/venter.pdf)

Class One Overview

- **<u>Points in Class One</u>**: Solow and Romer – basic growth theory; Jorgenson – role of innovation in 90's;
- Merrill Lynch – how investors look at innovation for investment
- Note emerging debate on comparative advantage of competitor nations
- Review 2 elements of DIRECT innovation policy – R&D and Education
- Review elements of INDIRECT innovation policy
- Look at Innovation as an ecosystem
- Look at the "valley of death" between R&D

Class 1 – Part 1: Economic Models of Innovation

General Background - Definitions

- Science – understanding the natural world – out of "natural philosophy" of the 16th-19th centuries – observes natural world – discovery oriented
- Technology – System to organize scientific and technical knowledge to achieve a practical purpose – "systems" include technical advance plus models to implement that advance – moves from observation to implementation
- Research – increasing scientific OR technical knowledge or both
- Invention – applying research knowledge to create a practical idea/device
- Innovation – built on scientific discovery and breakthrough invention(s) – is the system of Research, Invention, & Development using both science and technology to commercialize (spread advances into societal use) –
- or: "intersection of invention and insight leading to the creation of social and economic value" (NII)
- Innovation System – the ecosystem for developing innovation – operates at 2 levels: the institutional actors, and the face-to-face groups \
- Innovation Wave – 40/50 year cycle of innovation based on radical, breakthrough, disruptive invention, then applications piled on this, productivity rises, then long period of incremental invention
- "Valley of Death" – where invention and innovation usually dies - gap between research and development – institutions often not in place to bridge this gap, and move idea into development prototyping and production, then invention into innovation

[source for some of these – Prof. Charles Weiss, Georgetown University]

Relationship Between Science and Technology:

* Before mid-19th century – technology based on "tinkering" not science – telegraph, RR - early technology gives rise to early technology

*Now: basic science gives rise to technology – lasers

- •but Dr. Lee Buchannan, ex-DARPA Deputy Director– "I get nothing from basic science – could drop that science funding and never miss it"

* Now: technology gives rise to science – IBM scanning tunneling microscope, nanotechnology

Professor Robert M. Solow, MIT – Growth Theory

(NY, Oxford Univ. Press 2000)
- Prof. of Eco., MIT, Nobel Prize 1987, Nat'l Medal Tech.

- Solow Attacks Classical Economic Theory – of Roy Harrod, Evsey Domar:
  - Q: When is an economy capable of steady growth?
  - Classical Answer: When national savings rate (income saved)= capital/output ratio + rate of labor force growth
    - Have to keep capital plant and equip. in balance with labor supply
    - Static view: 3 factors – labor supply/capital supply/savings rate – have to fix these ratios in balance
    - Capitalism: just periods of alternating worsening unemployment and labor shortages

2. Solow's Rethinking:

- Solow: "the story told by these [Classical] models felt wrong"
- Harrod had a hint – vague generalizations about "entrepreneurial behavior"
- Classical Model: recipe for doubling rate of growth was simply to double the national savings rate, perhaps through the public budget (Keynes) – throw money at it
- Economic development: Classical: "key to transition from slow growth to fast growth was sustained growth in the savings rate"
- But Solow: " I thought about replacing the capital and labor output "with a richer and more realistic representation of technology" – a new theory of production not just output levels

3. Solow's Basic Finding:

- The Rate of growth is independent of the savings (investment) rate
- Old "growth theory was mechanical" – simply

"a description of flows and stocks of goods"

- Solow's finding of "technological flexibility...opened up growth theory to a wider variety of real world facts"

- Basic Growth theory – Solow in 1957:
  - "Gross output per hour of work in the US doubled between '09 and '49' [productivity gain]
  - "7/8's of that increase could be attributed to 'technical change in the largest sense'"
  - "all the remaining 1/8 could be attributed to a conventional increase in capital intensity

4. Unpacking Solow – Dennison:

- Reviewed US growth '29-'82 to break out Solow's broad term "technical progress":
  - 25% increased labor output
  - 16% increased education qualification of average worker
  - 12% growth of capital [same as Solow]
  - 11% "improved allocation of resources" [ex.- shift of labor from agriculture to high productivity industry]
  - 11% economies of scale
  - 34% growth of knowledge or technical progress [Dennison's narrow definition]

Total: 109% [extra 9% is misc.factors that reduce growth]

Dennison basically confirms Solow's broad "technical progress" total

Solow reduces Dennison's factors to 3 broad factors

- "straight labor", "straight capital" and "technical change"
- argues that technology and related innovation is 2/3's of growth
- "technology remains the dominant engine of growth" – human capital (talent) is part of that and in second place

5. TRANSLATION OF SOLOW:

- Solow attacks classical economics and transforms growth theory – sees capitalism and growth as dynamic
- We see his point – railroads, canals, electricity, telegraph, telephone, aerospace, computing, internet, all transform growth
- Pattern: initial technology advance – yields new applications, which pile on to broaden the advance – which yields productivity gains throughout economy – which yields real growth in wages, income
- Solow's basic point about classical economics: "No amount of statistical evidence will make a statement invulnerable to common sense"
- The good news: you can increase your rate of economic growth through technological advance – you can improve real incomes/societal wellbeing

6. Under Solow, what is the role of Capital? -- A Supporting Player

- "technological progress ...could find its way into actual production only with the use of new and different capital equipment"
- Therefore the effectiveness of innovation in increasing output would be paced by the rate of gross investment"
- So: much faster transfer of new technology into production with investment

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- Comment: what kind of investment are most important to innovation? (Angel, Venture Capital IPO's, general equity, lending)
- Doesn't technical advance yield investment, not just the other way around?

- Comment: Boom & Bust: Periods of boom and stagnation can and do appear due to Keynesian and classical unemployment – Q: can accelerating the rate of technological advance/innovation reduce the "bust' period?
  - Implication: innovation capacity is a key
  - A healthy innovation system is a key to growth

7. Solow - Exogenous Growth

- Solow sees the power of technological advance as an economic force, but he doesn't see how to measure it
- He's stuck with the traditional toolset of both classical and neoclassical economics - capital supply and labor supply measures and market movements
- He's not ready to measure innovation system elements
- He therefore treats tech innovation as "exogenous" - as outside the understood economic system and outside of metrics

8. Solow's Warning:

* Ex. – there was little economic growth in medieval Europe because so little technical advance – economy was a capture economy -- piracy, war were ways to capture wealth

* Solow Quoting Frost:

"Most of the change we think we see in life is due to truths being in an out of favor"

* p.xxvi: 'social institutions and social norms evolve... so economic behavior will surely evolve with them"

* So: "the permanent substructure of applicable economics cannot be so very large"

Paul M. Romer – Prof. of Economics, Stanford --"Endogenous Technological Change"

(Journal of Political Economy, vol 98, pp. 72-102 (1990)

BASIC POINTS

1. "Growth model" – growth is driven by technological change
   - which is driven by researchers who are profit maximizing agents at the immediate pre-commercial stage
   - Technology is not a conventional good and not a public good" – it is a "non-rival" potentially excludable good, so it won't support price-taking competition, it's more like monopolistic competition
2. The stock of human capital (talent) determines the rate of growth
3. Given that role, too little human capital is devoted to research (the major input into technology, so behind growth)
4. Growth theory is therefore ENDOGENOUS - part of the economic system not outside it
5. Integration into world markets increases access to human capital and technology and therefore increases growth
6. A large population is not enough to generate growth, the key is the size of human capital (talent)

2. Romer’s Growth Model

- Output per hour worked (productivity) now is 10x as valuable per hour worked 100 years ago
- Cause: technological change
- But: what other specific and measurable factors generate growth of output per worker?
  - **“increase in the effective labor force” &**
  - **increase in effective stock of capital/worker**

3. Romer's 3 Premises

1) Technological change ("improvement in the instructions for mixing together raw materials" –ie, tech. is physical product-based, not process) "lies at the heart of economic growth"

- technology provides the incentive for capital accumulation and both of these improve output per worker (of products)

2) Technological change occurs in large part because of people who respond to market incentives

- academic scientists on gov't grants don't but when new knowledge is translated **into** practical goods, market incentives are key

3) Technological knowledge (ie, "instructions for working with raw materials") is inherently different from other economic models:

- developing new and better "instructions" is a fixed cost

- this is the defining economic characteristic of technology

4. Romer–Technological Knowledge:

- (see pp-189-191) “Rival good”-property: use by one person or firm precludes use by another
- “Non-rival good”-property: use by one person or firm in no way limits use by another – so technology is naturally non-rival, it can be readily shared or adopted by others
- “excludable” – if the owner of a good can prevent others from using it – ex., legal (patents) or commercial trade secret
- Technology – is partially excludable
- So: non-rival feature of technology-based growth is “unbounded growth” and “incomplete appropriability”– meaning **it can** only be partly excluded
- So: technology is unlike many other economic goods
- Note: given the power of technology (from human capital in research) for growth, our investment in human capital/research is too low
- Technological innovation needs market incentives as key to growth by technological agents doing research

5. Romer – Role of Human Capital:

- Increase in the total stock of human capital (engaged in research), & increase in the amount of research, are directly proportional to the increase in economic growth
- Total level of human capital and fraction of that capital devoted to research is now highest in human history
- Lack of human capital (engaged in research) = economic stagnation
- So: little growth in prehistoric times (except increase in labor)
- Civilization, therefore economic growth, could not begin until human capital was spared from production and allocated to research
- Gov't policy: subsidies for capital compares poorly to subsidy for human capital (engaged in research)
- Gov't's best policy should encourage allocation of human capital to research; next best: subsidize production of human capital (education)

6. Romer on Growth, Trade, and Research Relationships (pp. 212-215):

- Growth is co-related with the degree of integration into world markets
- Having a large number of consumers or large population is not key – not a substitute for trade with other nations
- Trade forces economic integration with a large pool of human capital
- <u>Economy with large stock of human capital (engaged in research) fosters economic growth</u>
- <u>Accounts for unprecedented growth of 20th century economies</u>
- Less developed economies can benefit from access to human capital via trade and the integration it brings (story of growth in Asian economies)
- Closed economies stagnate

7. Endogenous Growth Theory

- For Romer, unlike Solow, growth theory incorporates innovation as an ENDOGENOUS not exogenous factor
- Romer views technology innovation as inside and part of an economic system, not outside it
- Romer's concepts of technological knowledge and human capital engaged in research create tools to begin to measure innovation's eco. role
- Romer takes the major next step past Solow
- Classical Economics could not explain why "the rich get richer" - the wealth of nations - it was an equilibrium system
- Growth theory is a dynamic system - explains growth based on innovation capacity - and some nations have big innovation capacity lead

Dale W. Jorgenson, Prof. of Economics, Harvard (in "US Economic Growth in the Information Age" (Issues in Sci & Tech, Fall 2001))

- **Basic Point: 90's – story of technology breakthrough driving economic growth**
  - Resurgence of US economy in '95-'00 outran all expectations
  - Rapid decline in IT prices provides key to the surge in 90's US economic growth
  - This development is rooted in the semiconductor technology sector

2. Jorgenson: "Better,Faster Cheaper" mantra of new economy

- History: Bell Labs '47 (Bardeen, Brattain, Shockley) develops **transistor** – from semiconductor materials: electrical switch for encoding information in digital form
- **Integrated Circuit**:
  - 1958 -Jack Kilby, of Texas Instruments, and Robert Noyce, Fairchild Semiconductor – develop **IC's/semiconductors**
  - IC: millions of transistors to store data in binary form – so at first IC is for data storage – **Memory Chips** (DRAMS)
  - Gordon Moore (Fairchild Semiconductor) – **Moore's Law** – each new IC: every 2 years doubles the no. of transistors per chip & cost of transistors per chip cut in half
  - This is a huge deflationary factor in economy
  - 1968 – Noyce, Moore and Andy Grove found Intel
  - Begin making **Microprocessors or Logic Chips or Microchips**
    - First logic chip – 2300 transistors
    - Pentium 4 has 42 million transistors

3.Jorgenson-Computing price/growth

- Communications Equipment
  - Cost also down driven by cheaper semiconductors
  - Transmission technologies – ie, fiber optics, microwave broadcasting, communications satellites, DWDM (dense wavelength division multiplexing – multiple signals over fiber optic cable simultaneously) -- progress at rates faster than Semiconductors – key to "free" internet
- Result: Growth Resurgence
  - Accelerating growth in output and productivity in 90's
  - Driven by decline in Semiconductor prices
  - Leads to price declines in computers, communication equipment
    - Computers: 90-95: -15%/year price decline; 95-00: -32%/year
    - Software: 90-95: -1.6%; 95-00: -2.4%
  - Yields: capital growth in high productivity goods
  - Big growth in 90's in this area, much higher than any other capital goods -- And:

    - widespread: pervasive in economy - in homes, business, gov't

4. Jorgenson-Accounting for Growth

- Massive increases in computing power in US:
  - Raises productivity in IT-producing industries &
  - Contributes to productivity in whole economy
- Productivity Measures:
  - IT sector productivity increased steadily from '48-'99; sharp acceleration in '95-'00 in response to Semiconductor price drops
- Purchase of productivity enhancing equipment:

  boosts growth in US ONE FULL POINT
  - IT alone accounts for half of this
- IT, 4.26% of GDP, yields surge of US productivity in '95-'00
- **Summary: IT growth drives capital investment in IT capital goods, which drives productivity gains, which drives US growth**
- Background:
  - '45-'73: US productivity growth 3%
  - '73-'93: US productivity below growth 3%
  - '95-'00: US productivity growth 3.5%, and economic growth 4.2%

5: Jorgenson: What's Next??

- Acceleration of growth depends on accelerating productivity
- What happens now that Moore's Law has slowed?
  - Semiconductor industry shifted to 3-year product cycle after '03
- "Performance of IT industries has become crucial to future growth prospects. We must give close attention to uncertainties that surround the future development of IT."
- And: What will IT role be of Korea, Malaysia, Singapore, Taiwan, China, India?
  - Economic law of comparative advantage is now knowledge-based instead of resource-based
  - Knowledge moves faster and is less excludable than physical resources

Class 1 – Part 2: Patterns of investment in Science and Technology

- Private investment requires short time-frames
- Federal direct investment in R&D
- Federal investment in human capital (education)
- Nelson on national innovation systems
- Connecting research to development – the "Valley of Death"

Merrill Lynch – The Next Small Thing

– Steven Milunovich, John M.A. Roy, An Introduction to Nanotechnology – 9/4/01 Merrill Lynch Report (http://www.slideshare.net/tseitlin/intro-to-nanotechnology-merrill-lynch)

- **BASIC POINT: how do investors look at potential technology breakthroughs? Do they believe they drive growth?**
- GROWTH PATTERN:
- Merrill Report cites its economist Norman Poire
- Poire: growth innovations drive the economy and stock market
- Takes 28 years for wide acceptance of a new technology
- Takes 56 years for rapid growth to evolve
- Takes 112 years for technology maturity – after that, growth in the technology area parallels growth of population rates

2. Merrill Report – "Vision /Enabler/ Researcher Mass" Pattern:

- For example, Nanotechnology = fabrication at the molecular scale (ie, at 100 nanometers, where nanometer = 10 hydrogen atoms)
- First: **Vision** – Richard Feynman – "Plenty of Room at the Bottom" – 1959 envisioned the potential of nanotechnology
- Second: **Enabler** – for example, the scanning tunneling microscope (IBM) allowed measurement and basic manipulation of nanoscale systems (20 years ago)
- Third: **Research Mass** – 1^{st}: Eric Drexler's 1981 journal article; by 2000, 1800 journal articles (similar to total number of internet articles in early 90's)

3. Merrill Report: Investment Timetable Must be Short Term

- “Although the futuristic market is fascinating, it is not inevitable” - p.2
- “Nanotechnology is close to commercial markets” – p.2
- Article reviews key short term markets – p.5
  - 0-2 years - short term
  - 0-5 years – mid term
  - 5+ years – long term
- These categories give a good perspective on how far out investors will look
- “The keys to nanotechnology are manufacturing and communication. If you can’t build it in volume, then there is not much you can do with it.” – p.5

4. Merrill Report: Near-Term Nano Investment Focus:

- **Opportunity One: Instrumentation** – p.1 – "In any new technology the first winners are the tool makers"
  - Note the interdisciplinary nature of efforts in nano instrumentation effort: "chemistry and mechanical engineering"; teams of "chemists, physicists, biologists, material scientists to accelerate research and commercial spinoffs"
- **Opportunity Two: Semiconductors**
  - "Within the next ten years, molecular electronics is expected to become available as a replacement for silicon-based computing – HP's Stan Williams – p.4
  - Merrill: no investor interest because the time-frame is too long-term
  - Ultra small nano-based hard drives available at IBM (Peter Vettiger) in 2-3 yrs, or memory chips in 3-5 yrs
  - Intel's Gary Marcyk combined "complementary" aspects of silicon and nanotechnology microprocessors in mid–term, making a better investment option than nanotech microprocessors at HP

SO: WHO WILL DO THE LONG TERM RESEARCH AND DEVELOPMENT? – IS THIS A GOV'T ROLE PROVIDING "PUBLIC GOOD"?

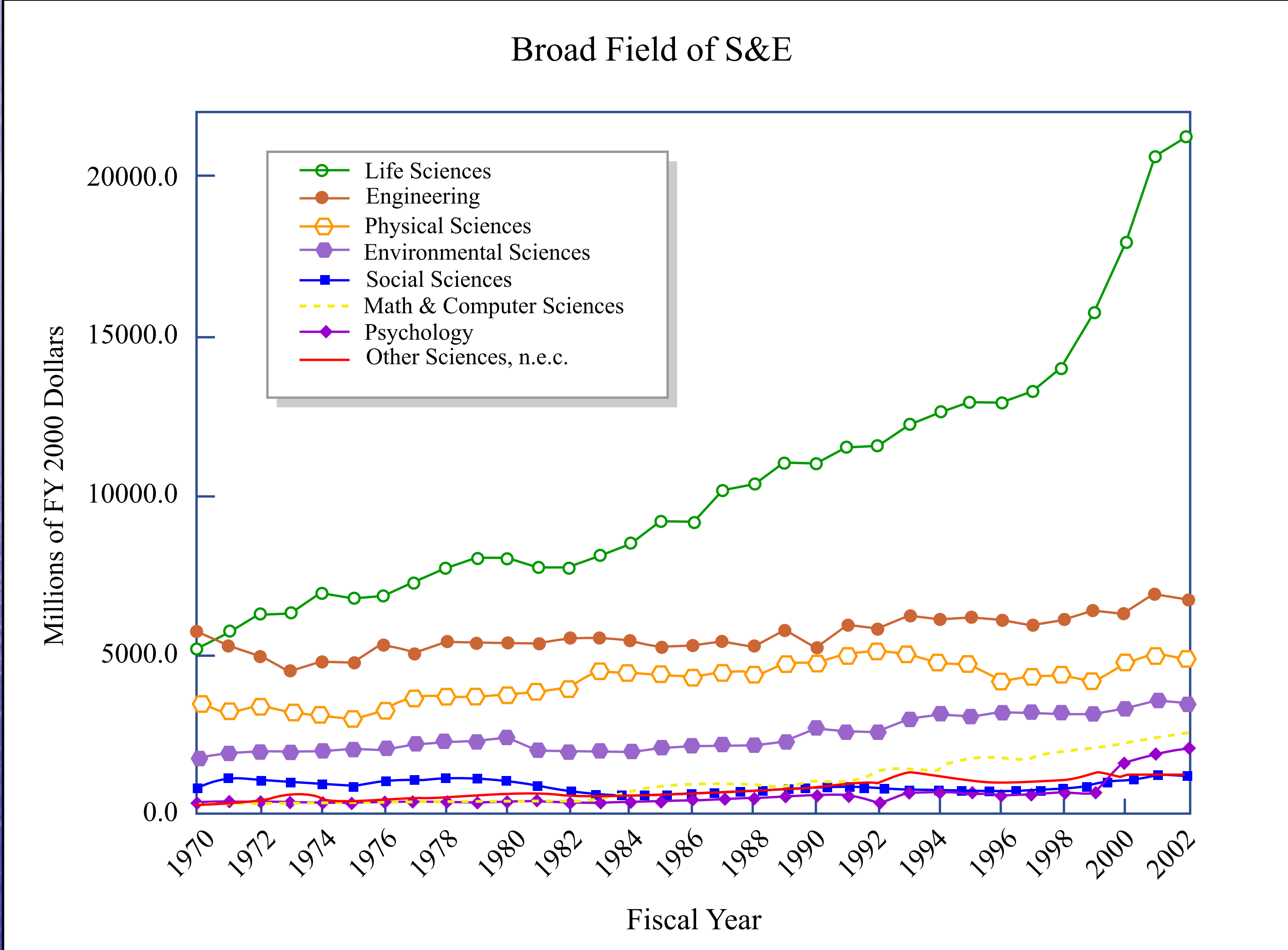
DIRECT (EXPLICIT) INNOVATION FACTOR #1: R&D INVESTMENT

- **<u>BASIC POINT</u>:**
- **IF SOLOW IS RIGHT,**
  - IE, TECHNOLOGICAL AND RELATED INNOVATION IS RESPONSIBLE FOR 2/3'S OF US ECONOMIC GROWTH
- **THEN R&D INVESTMENT IS A CRITICAL PILLAR FOR OUR ECONOMY.**
- LET'S REVIEW R&D INVESTMENT PATERNS:

I. FEDERAL RESEARCH FUNDING:

FEDERAL R&D FUNDING PRIORITIES

Composition of R&D Funding Has Shifted To the Life Sciences

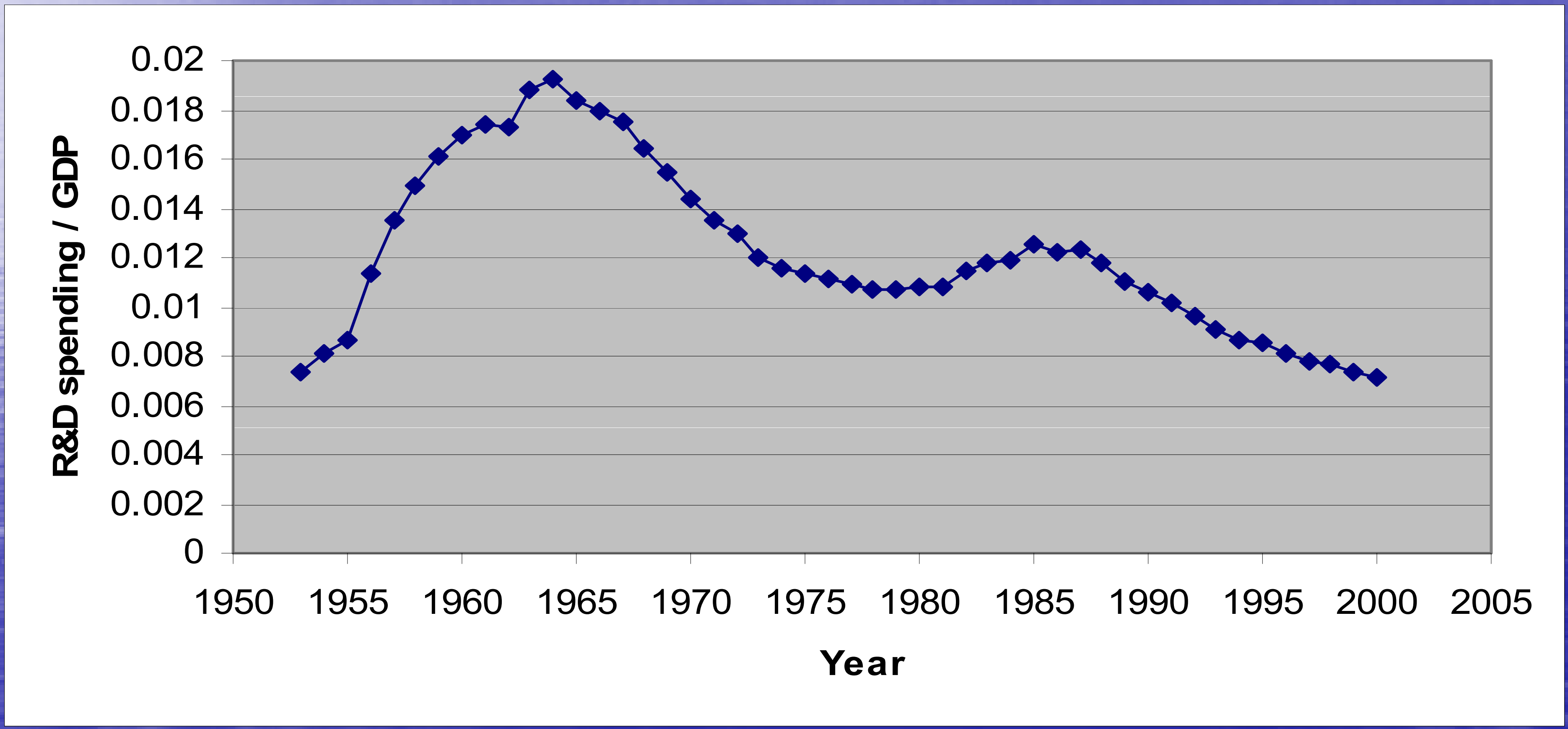


Note - FY 2001 and 2002 data are preliminary

Figure by MIT OpenCourseWare.

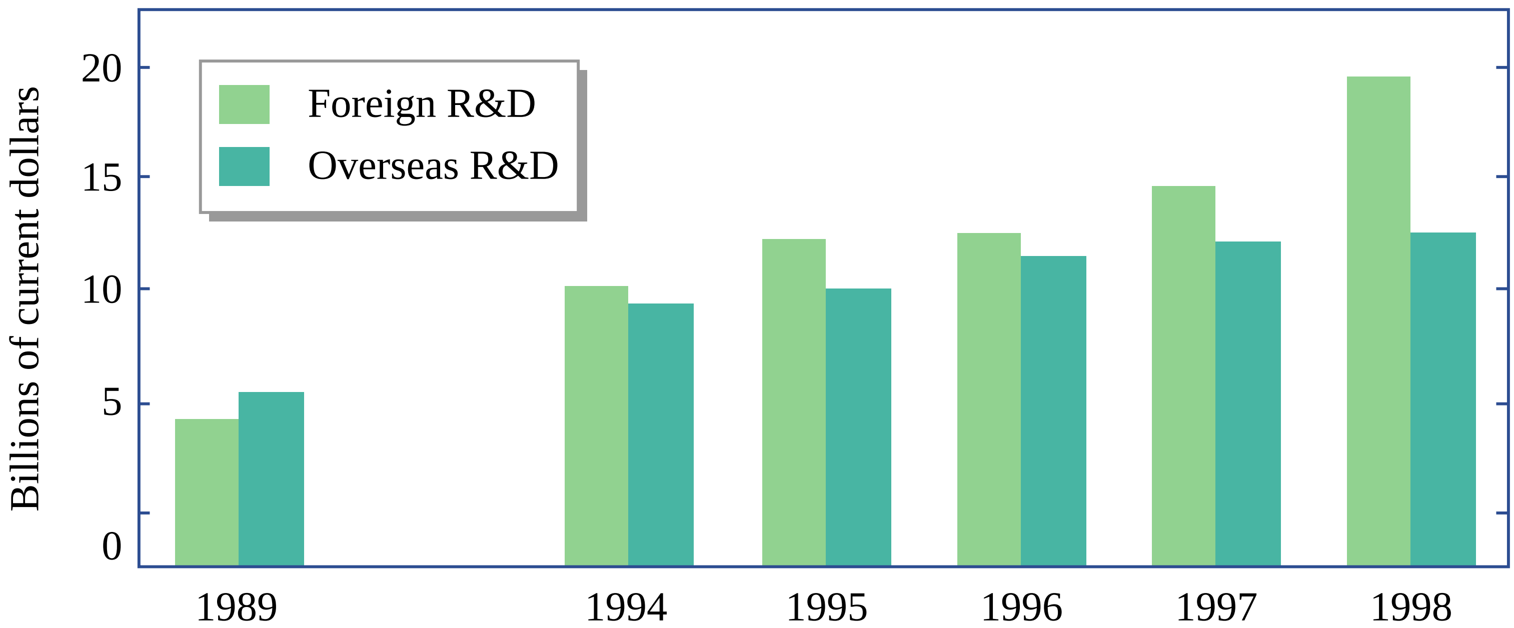
Rand, based on NSF data; cited: E.Milbergs, Innovation Metrics, NII, 1/2004

Federal R&D Spending As a Percent of GDP



Source: NSF R&D and BEA GDP data

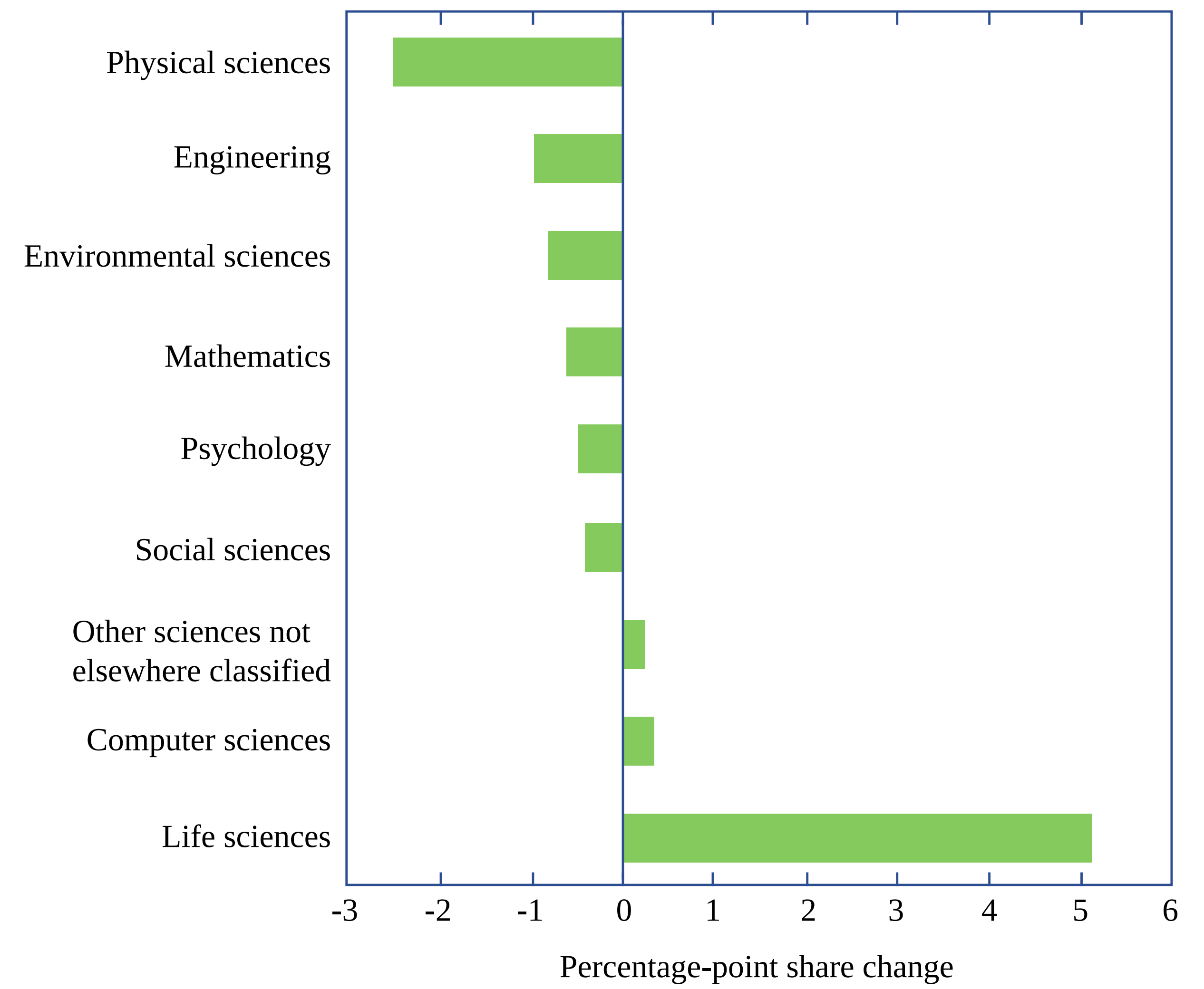
Globalization of US Industrial R&D



Notes: Foreign R&D refers to R&D performed in the United States by U.S. affiliates of foreign parent companies. Overseas R&D refers to R&D performed abroad by foreign affiliates of U.S. parent companies.

Source: P.Fluery, Yale Eng.Sch.

‘90-’99 Changes in Federal Academic Research Obligations by Field



P.Fleury, Yale Eng. Sch.

SUMMARY-FEDERAL R&D FUNDING

FEDERAL R&D ROLE DECLINING:

Federal share of R&D as % of GDP in decline

- Life science (NIH) –doubled ’98-’03, near $30b
- Physical science research declined as % of GDP

R&D FUNDING CAPACITY THREATENED:

Increasing pressure on Federal budget

- Explosive short term debt -$400+B deficits through decade, which will be exacerbated with baby boomer retire
- Soc. Sec./Medicare Trustees estimate $72 trillion new present value of federal unfunded entitlement liabilities – total US wealth $45 T
- Taxation capacity may be politically broken
- Congressional budget, appropriations processes breaking down

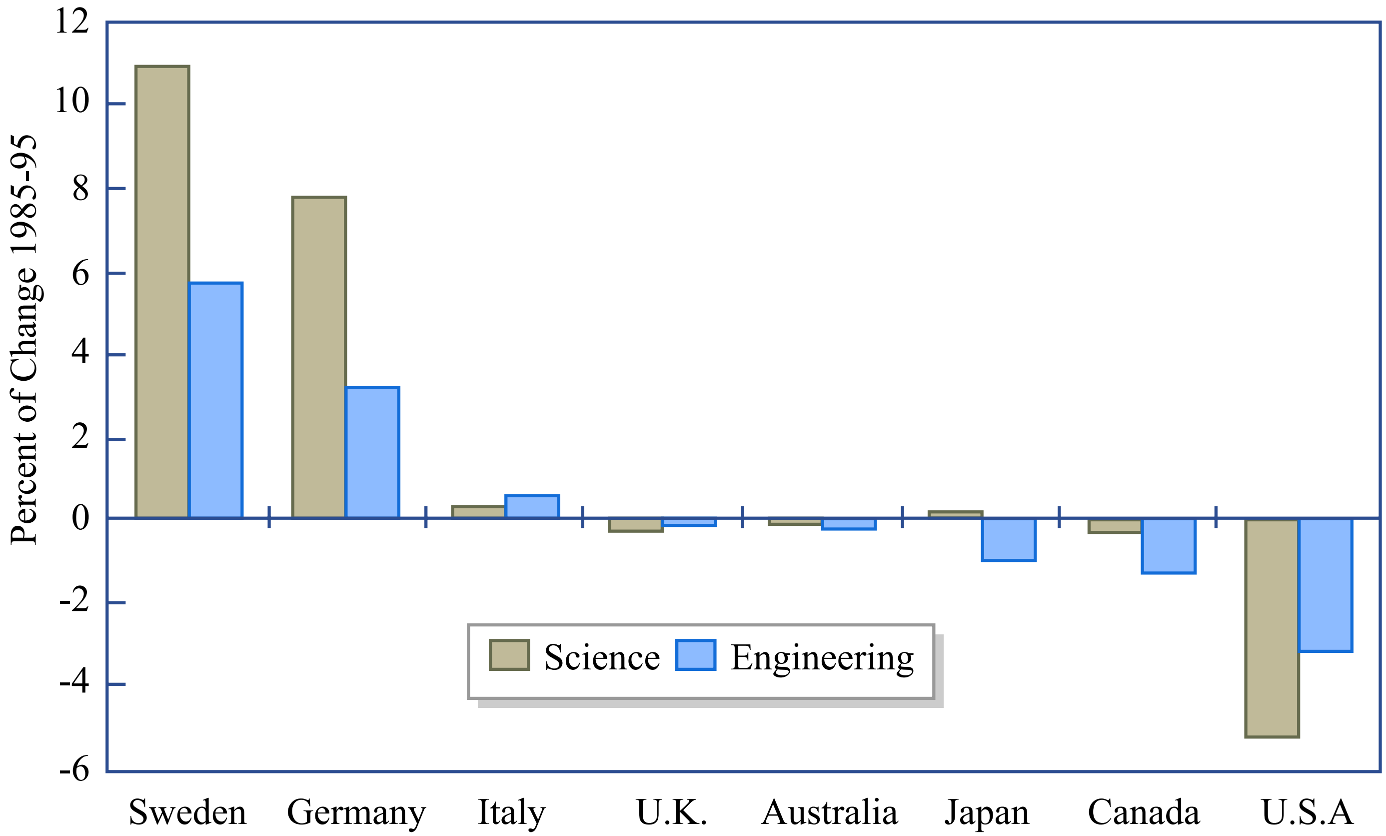
DIRECT (EXPLICIT) INNOVATION FACTOR #2: TALENT -

- **BASIC POINT: IF ROMER IS RIGHT,**
  - HUMAN CAPITAL (TALENT) ENGAGED IN RESEARCH, IS CRITICAL INPUT FOR THE TECHNOLOGICAL ADVANCE WHICH DRIVES ECONOMIC GROWTH
- **THEN TALENT DEVELOPMENT IS A SECOND KEY ECONOMIC PILLAR**
- LET'S LOOK AT US TALENT PATTERNS:

TALENT:

- – Romer: Prospector theory - # of “prospectors” impacts number of finds
- – You don’t fit your talent base to your economy; your talent base sizes your economy – they relationship is dynamic
- – Total # overall US degrees increased between ’90 and ’00
- – But: science/engineering degrees declined same period

The Proportion of Science and Engineering Degrees Grew Abroad While Declining in the United States



Change in Science and Engineering Degrees as a Percent of First University Degrees, 1985-95

Figure by MIT OpenCourseWare.

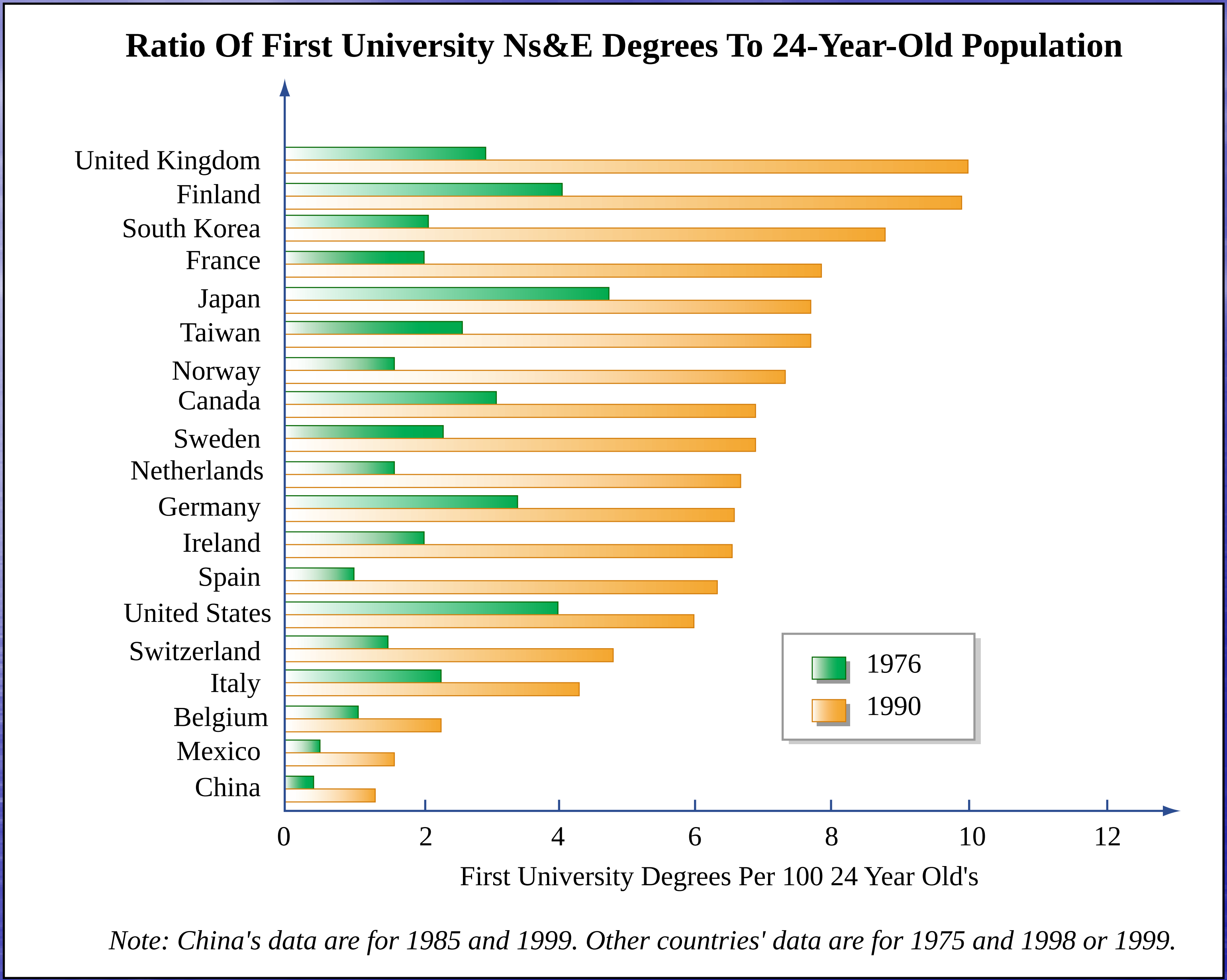
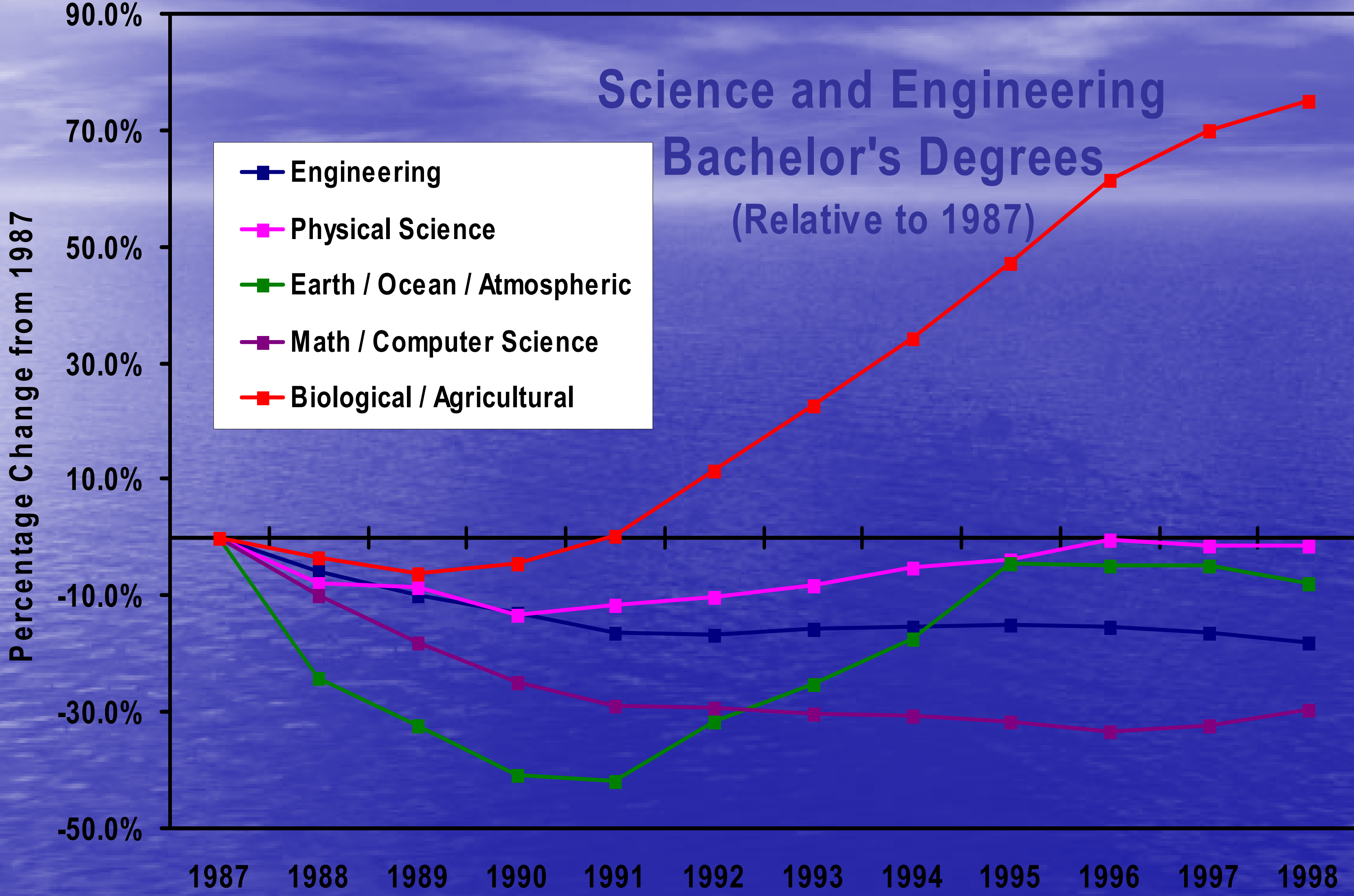


Figure by MIT OpenCourseWare.

NSF, Indicators, 2002 –
Cited in E.Milbergs, Innovation Metrics, NII, 1/2004



Source: NSF Report "Science and Engineering Degrees: 1966-1998"

Doctoral Degrees --

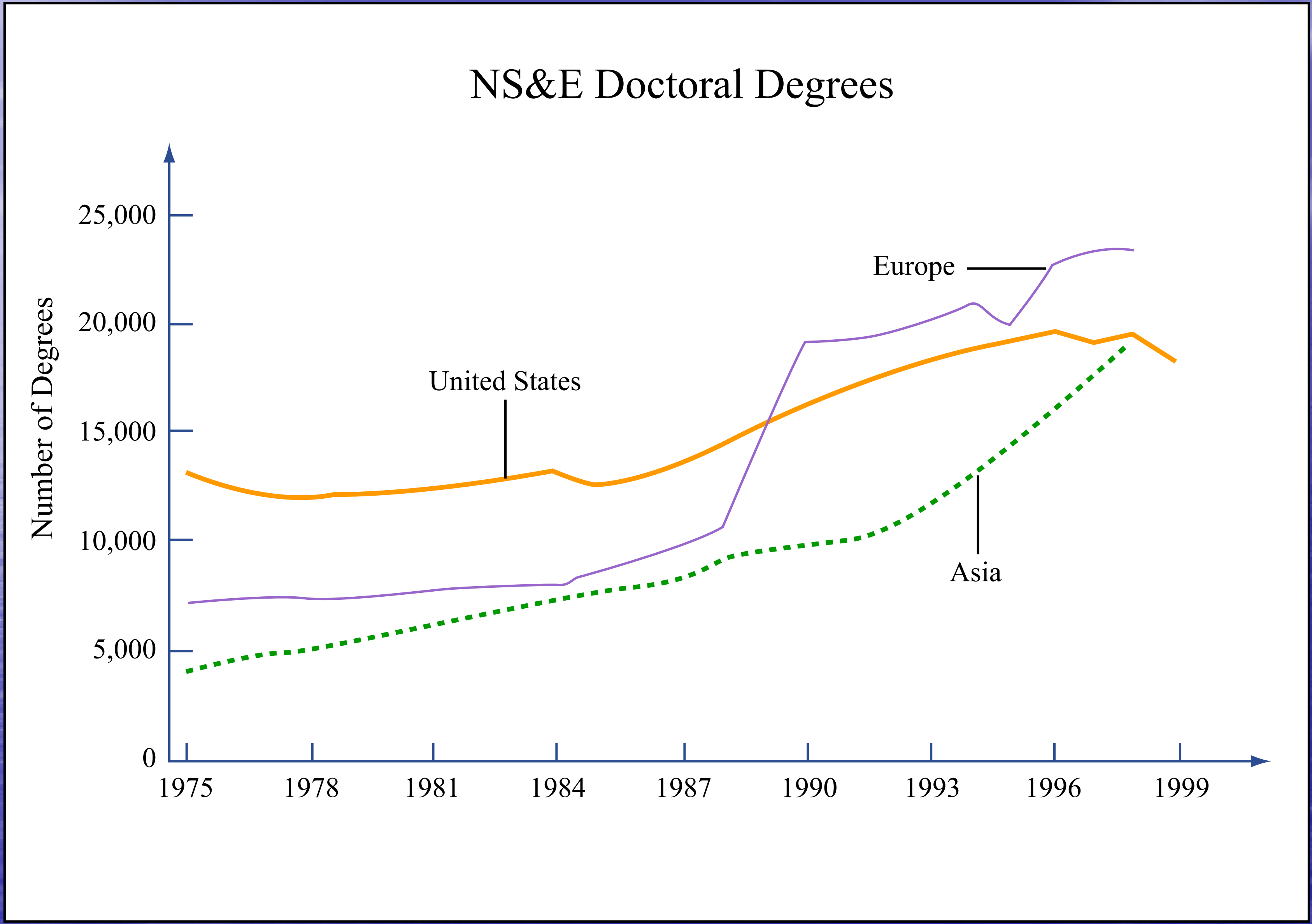


Figure by MIT OpenCourseWare.

NSF Indicators, 2002 – Cited, E. Milbergs, Innovation Metrics, NII, 1/2004

1) Richard Nelson,
Prof. of Economics, Columbia Univ.

National Innovation Systems – A Comparative Analysis (Oxford U. Press 1993)

- "Technological capabilities of a nation's firms are a key source of their competitive prowess"

  →Nelson develops the term:

  "national innovation systems"

Does the term make sense despite transnational businesses? – arguably yes

"innovation" - Nelson uses broad def., "process by which firms master and get into practice product designs and new manufacturing processes"

2) Nelson: "Schumpeterian Innovator"

- Destructive Capitalism occurs via innovation - it's not necessarily the first innovator that captures most of the economic rents associated with the innovation
- Therefore: a nation's concern is in broader "innovative capability"
- Not limited only to firms or only to science research but to a SYSTEM – " a set of institutional actors" that influence innovative performance
- Q: What's "the way technical advance proceeds" – what are the "key processes"?–A: science and trial and error learning
- Q: **Institutional actors**? A: univ.'s, firms, government agencies and policies
- Q: is there a "common analytical framework" across nations?

3) Nelson: Science as Both Leader and Follower:

- "New science gives rise to new technology" (and vice versa)
- Electricity – Science as Leader:
  - Faraday 1831 – electromagnetic induction
  - Incandescent light, gramaphone–Edison, telephone-Bell
  - Hertz 1887 – radio waves – radio, TV
  - Radio/TV, electricity – NOT because scientists seeking applications
- Chemistry Science as Follower:
  - First-alchemy, tanning, dyeing, brewing – practical applications
  - 1860's – Kekule – molecular structure of benzene – leads to organic chemistry
  - Polymer chemistry – grew from industry needs
  - "Chemical Engineering" – merger of chemistry and mechanical engineering – interdisciplinary advance

4) Nelson: More Science as Follower:

- Steam engine – J. Willard Gibbs creates science of thermodynamics to describe steam engines
- Edison – develops electricity-based lighting (flow of electricity across gap)– has to develop electron theory – yields much of 20^{th} century physics, electronics
- Aircraft technology (starts with Wright Bros – bike mechanics) – yields aerospace engineering
- Transistor (Bardeen, Shockley, Brittain - Bell Labs) in 1940 leads to growth of solid-state physics
- Computing – yields computer science
- Lasers and optical fiber yield science of optics
- SO: science yields technology but technology yields science – rich and complex interaction
- Need both science and technology leadership for both science and technology leadership - interact

5) Nelson: Limits of Science:

- Innovation in high tech – is not only invention but:
- → Design – choosing the right "mix of performance characteristics" – ex.- modern aircraft wing
- Most R&D spending is "incremental improvements" – ex., jet engines added to aircraft replacing propellers
- process of incremental advance is not classic science breakthrough
- Incremental vs. radical innovation - need both

SC1

6) Nelson: Who are the Innovation "Institutional Actors"?

- 1. Industry Lab- by WWI industrial research lab staffed by Univ.-trained scientists and engineers – dedicated to "invention" and incremental enhancements
  - More important than university or government labs –
  - because: after initial tech. in place users have knowledge of strength and weaknesses that transcends general public scientific knowledge
- Reverse engineering is R&D in many countries
- Note: R&D only part of larger innovation picture – management style, organizational organization, including for R&D, also important

7) Nelson: Innovation Institutional Actors, Con't.

- 2. University Labs –
  - Univ.-Firm Connection – modern industrial research lab and modern research univ. grew up as companions/partners
  - Many academic science fields are applied-oriented: material science, computer science, engineering
  - If a Univ. supports technical advance – how channeled to nation's firms? Some argue it isn't
- 3. Government Labs
  - US gov't. labs key to advance in agriculture, health, nuclear energy – they act via public service missions
  - [Gov't. labs substitute in many countries for Univ. research – Korea, Finland]

8) Innovation "Institutional Actors" Con't

- 4. Public Sector Support for Industry R&D
  - Controversial in the US, assumed everywhere else in world.
  - In US-industrial R&D is rationalized under gov't. agency mission - ie, defense R&D with industry- for defense

There are Inter-industry Differences in Innovation Actors:

* affected by role of suppliers/users, etc.

* no standard model

* in <u>complex technologies</u>: supply chain and customer/users play role in innovation; also

* component and systems producers

* So: "<u>innovation networks</u>: - result of a community of actors

9) Nelson: Comparison – U.S./Japan Innovation Systems:

- ’45-’75 US Innovation System :
  - US firms larger in scale/serving continental sized markets
  - US firms spend more on R&D
  - US gov’t spends more on R&D, via defense mission
  - US Univ. research stronger – better connected to industry than in Europe – tied to strong public financing for Univ. R&D after WW2
  - Most US goods sold into US market – little export orientation
    - Note: US research Univ’s (Hopkins, Columbia are first) are modeled on German Univ.’s; R&D of US chemical industry (first large scale industry R&D) modeled on Germany
- ’70’s-’80’s Japan Innovation System Model:
  - Resource poor so strong export orientation since 1880’s
  - R&D more tied to industry
  - Gov’t via MITI has explicit technology development policy

10) Nelson: Country Innovation System Differences:

- 3 Basic Categories of Countries:
  - 1) Large high income countries
    - Large fraction of economy in R&D-oriented industries
  - 2) Small high income countries
  - 3) Lower income countries
- Countries without resources have export orientation – Germany, Japan, Korea
- National security imputed to/connected to innovation system – in US,UK, France
  - Defense R&D is majority of gov't industrial R&D
  - Japan – industrial cartel structure set with high industry R&D pre-WW2 period
- Differences in gov't role:
  - US, UK – limited gov't role in industrial R&D outside defense
  - Low income countries and resource short, export-driven countries – large gov't industrial R&D role

11) Nelson: What Leads to Innovation Success?

- KEY FACTOR: STRONG FIRMS (not necessarily large), highly competent in:
  - product design,
  - management,

    fitting consumer needs,
  - linked to upstream suppliers and downstream markets,
  - access to investment,
  - -must compete in world markets to be strong, &
  - -the bulk of their innovation has to be by firms themselves [even if networked to others]

12) Nelson: Other Key Innovation Success Factors:

- EDUCATION & TRAINING science-based industry depends on university education – the government has a key role supporting higher education
  - Hightech sector requires broad base of educated talent in and outside R&D
    - Korea, Taiwan – education led growth
- FISCAL, MONETARY, TRADE POLICY – government fiscal and monetary policy are one of the most important ways governments influence successful innovation
- PUBLIC SUPPORT OF UNIV. OR GOV'T LAB RESEARCH --
  - For univ. or gov't labs – direct interactions between researchers and commercial enterprise is critical for moving innovation into practice – you need a "technological community"

    Defense research has supported many new fields, especially in the US (electronics, computing, semiconductors, aerospace)
    - There is "declining spillover" because US military has shifted from new generic technology to specific hardware – And note: US public R&D funds much lower outside defense

13) Nelson - Q: What About Explicit Gov't High Tech Innovation Role?

- Backdrop: High tech advance key to high wages, high skills, top competitive management ability
- Innovation System Goal: create systematic technical advance in series of areas
- Much value occurs downstream in industries incorporating these advances
- Active gov't policies can be effective in generating competitive advantage in tech advances and are comparatively low cost
- And – these active gov't policies can play a role in helping an industry take advantage of upstream technology advances
- Overall – advances in key tech sectors are "building blocks" for advances in downstream industries, as well as upstream

MENU OF **DIRECT** U.S. INNOVATION SYSTEM FACTORS:

- DIRECT– GOV'T –
  - Univ. R&D
  - Gov't Labs
  - Education, Training
  - Support for Industry R&D (primarily via Defense, agency missions)
    - Primarily research, but support through all stages if agency mission
- DIRECT – PRIVATE SECTOR
  - Industry R&D
    - Primarily **Develo**pment
    - Goes through engineering, prototyping and production
  - Training

MENU OF **<u>INDIRECT</u>** U.S. INNOVATION SYSTEM FACTORS:

- INDIRECT INNOVATION FACTORS – SET BY GOV'T:
  - Fiscal/tax/monetary policy
  - Trade policy
  - Technology standards
  - Technology transfer policies
  - Gov't procurement (for mission agencies)
  - Intellectural Property protection system
  - Legal/Liability system
  - Regulatory system (environment, health, safety, market solvency and market transparency, financial institutions, etc.)
  - Accounting standards (via SEC through FASB)
  - Export controls
  - ETC.

MENU OF **INDIRECT** U.S. INNOVATION FACTORS, CON'T.:

- INDIRECT INNOVATION FACTORS – SET BY PRIVATE SECTOR:
  - Investment Capital – angel, venture, IPO;s, equity, lending
  - Markets
  - Management & Management Organization, re: innovative and competitive quality of firms
  - Talent Compensation/Reward system
  - ETC.

LEWIS M. BRANSCOMB & PHILLIP E. AUERSWALD,

BETWEEN INVENTION AND INNOVATION – AN ANALYSIS OF FUNDING FOR EARLY-STAGE TECHNOLOGY DEVELOPMENT
(Commerce Dept., NIST
Report GRC 02-841, 11/2002)

- ***FINDINGS:***
  - *1) Funding for technology development in the stage between invention and innovation comes from:*
    - *Individual private-equity "angel" investors*
    - *Corporations*
    - *Federal government programs*

  Does NOT come from Venture Capital

Lew Branscomb-Prof. Emeritus, Kennedy School, Harvard.; VP & Chief Scientist – IBM; Director of NIST; physicist – atomic and molecular ions; NSF's V.Bush Award winner

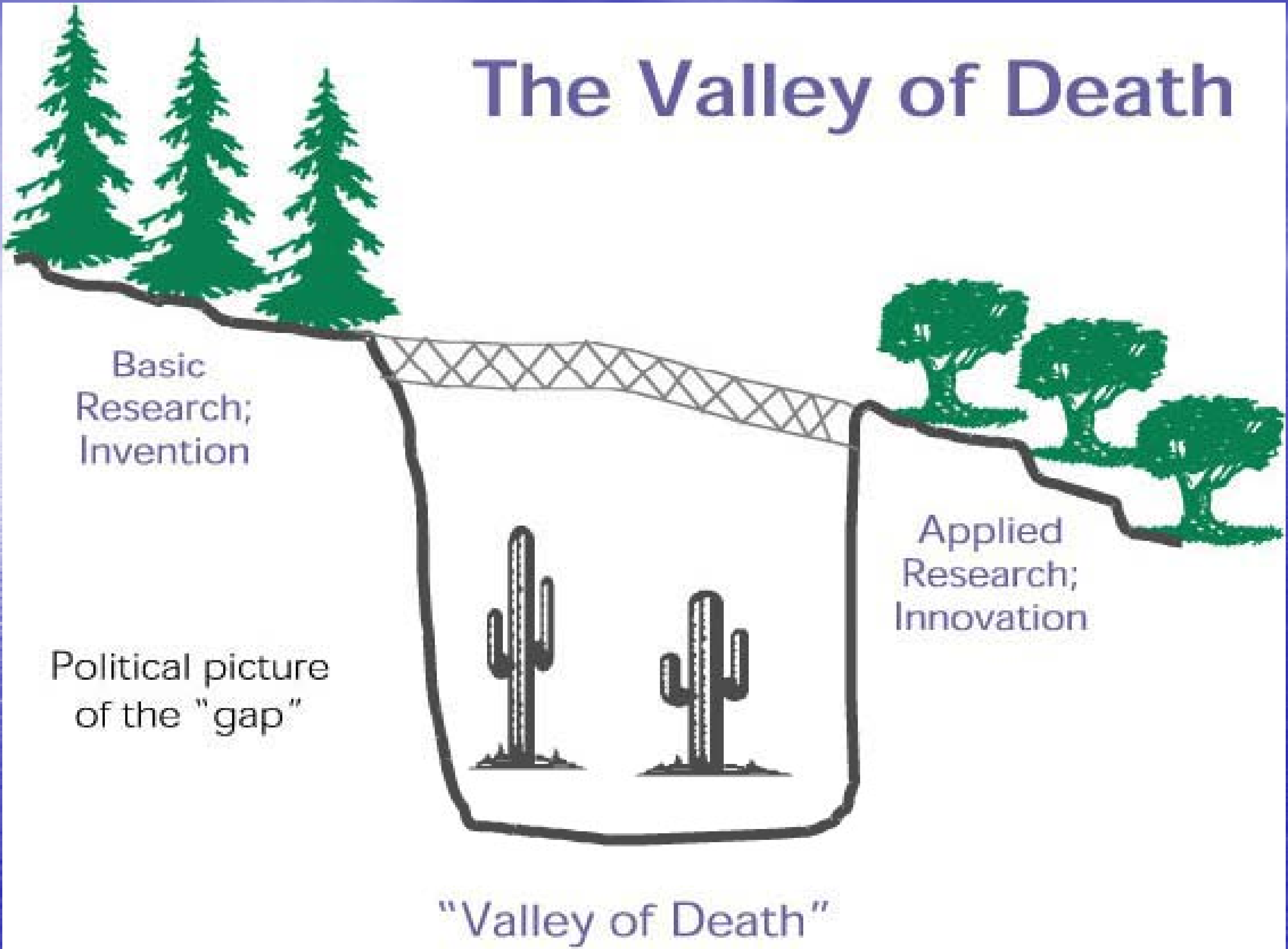
Phil Auerswald–Ass't Prof. at George Mason-> Branscomb's student & collaborator at Harvard

Branscomb & Auerswald

FINDINGS, CON'T –

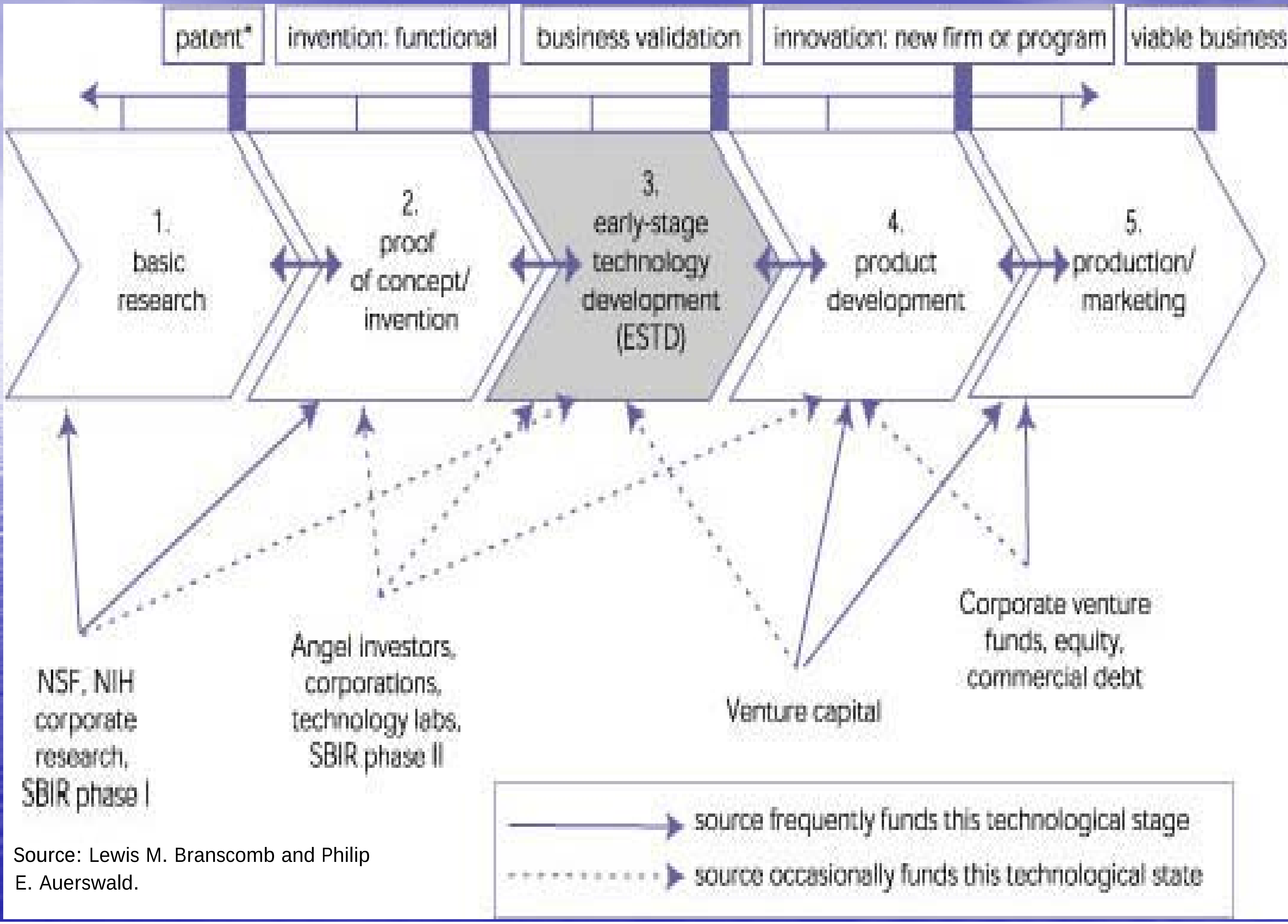
- *Markets for allocating capital to early-stage tech ventures are NOT efficient*
- *In response to these inefficiencies, institutional arrangements have evolved for early stage funding*
- *Conditions for success in science-based tech innovation are concentrated in a few geographical areas*
- *Innovator-investor proximity is important*
- *Federal role in early stage tech transition is very significant*
- *Fed. Tech development funds complement and don't substitute for private funds*

The Valley of Death



Source: Lewis M. Branscomb and Philip E. Auerswald.

Branscomb & Auerswald, Con't- The Linear Model

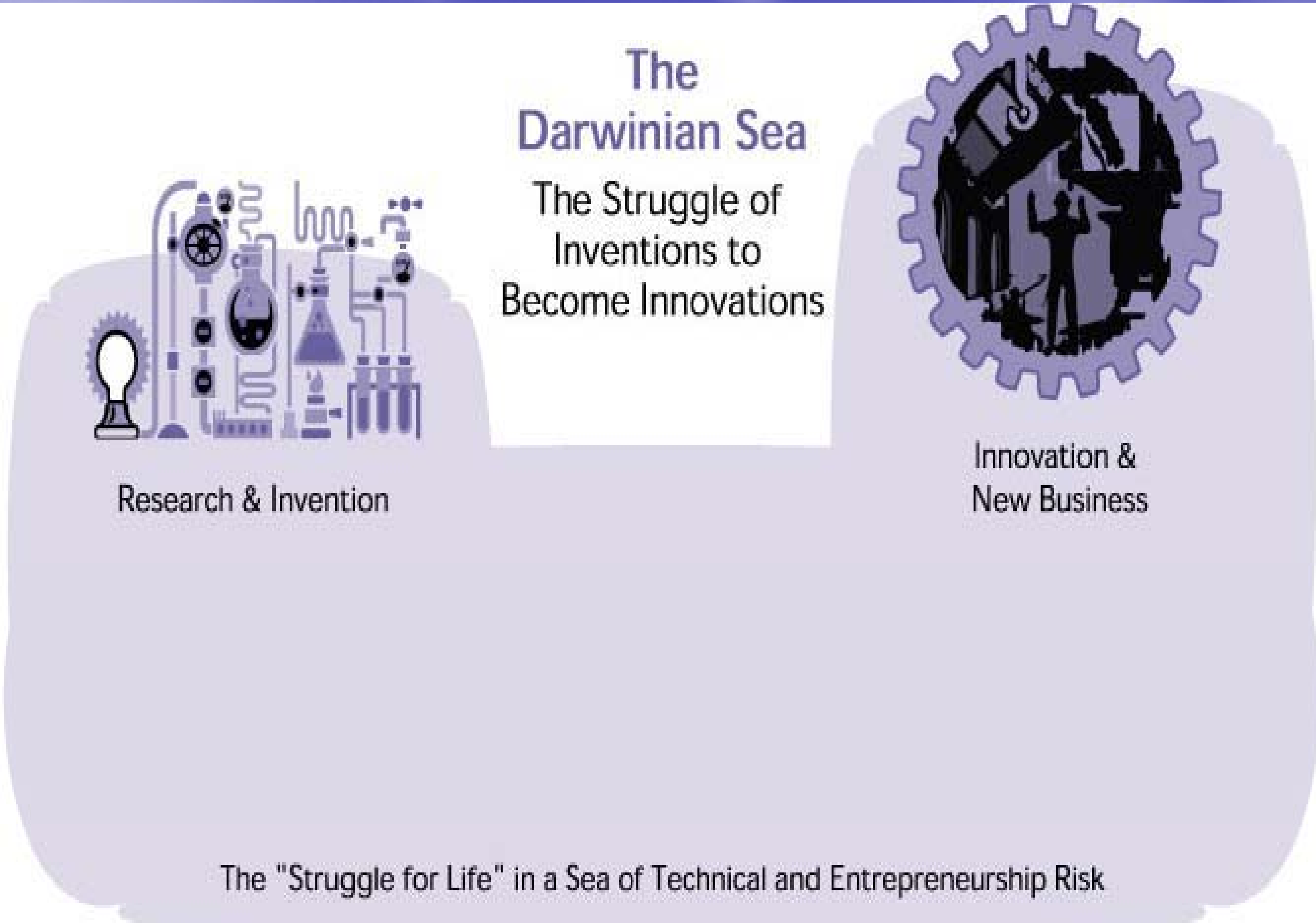


Source: Lewis M. Branscomb and Philip E. Auerswald.

Branscomb & Auerswald – The Linear/Pipeline Model, Con't

- The linear model is unrealistic – "the actual pathway included multiple parallel streams, iterative loops through the stages, and linkages to developments outside the core of any single company"
- realistically, "patents occur throughout" the phases
- The top line of the chart does not capture "the full range of exit options, the alternatives and branches of where projects go, and what happens to them"
- "Darwinian Sea" of interaction between R and D and development stages better term ---

Branscomb & Auerswald, Con't



Source: Lewis M. Branscomb and Phillip E. Auerswald.

Branscomb & Auerswald, Con't

Funding Sources – Early Stage Technology Development ($5-$36B):

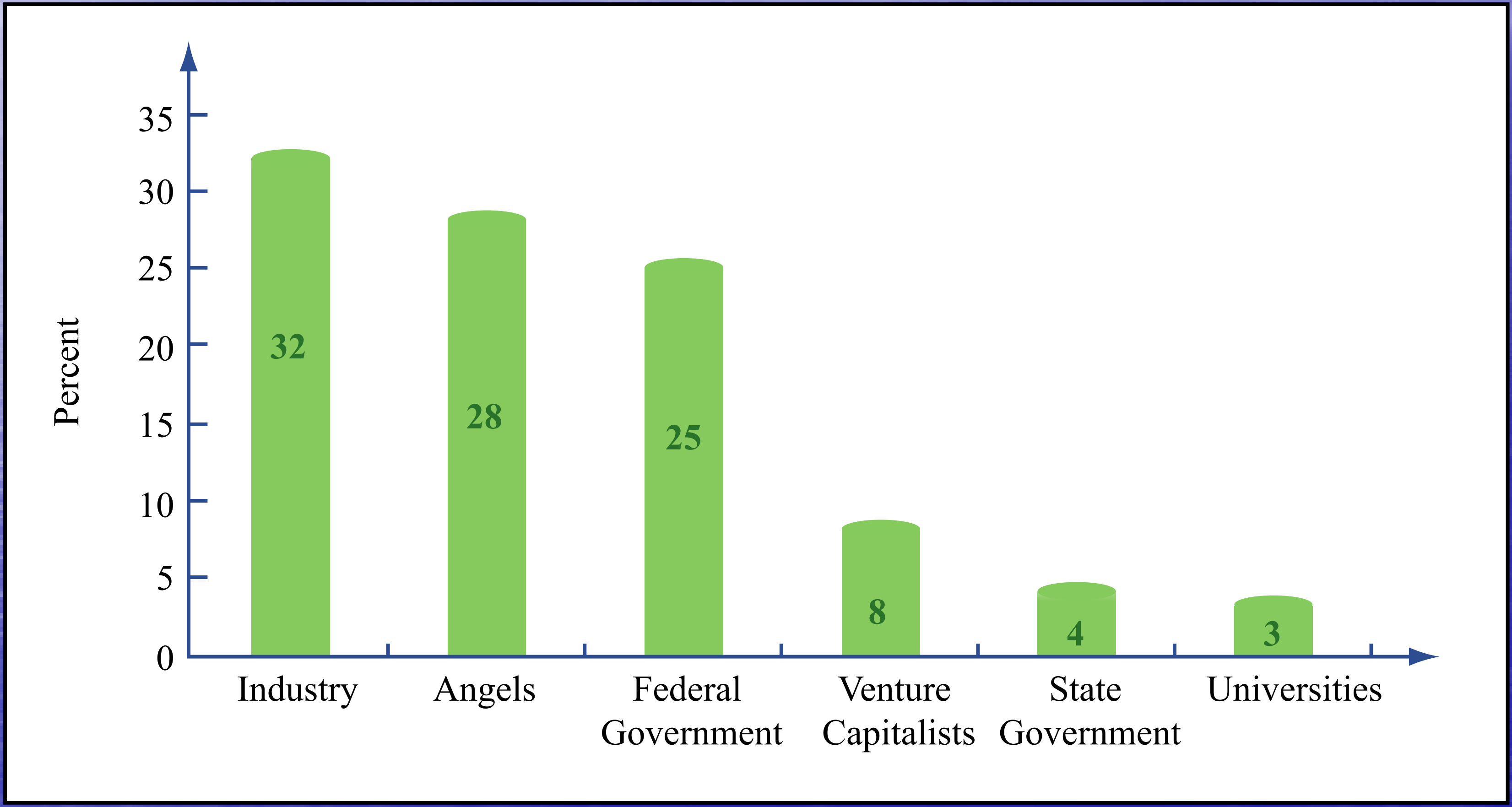


Figure by MIT OpenCourseWare.

Branscomb & Auerswald, Con't

- *Early stage tech development:* *product specs for an identified market are developed and production processes are reduced to practice, defined, and product cost established. So in this stage: Invention turned into prototype(s), engineering design, design for mfg., and product market set.*

- *Venture capital* *funding is spent on product development and business development not early stage tech development*

- *Between $5B (2%) and $36B (14%) of overall US R&D spending* *was devoted to early stage tech development – the 2 numbers were modeled based on different definitional "early stage" interpretations*

Branscomb & Auerswald, Con't

- **Corporate Innovation:** *Generally has to be within firm's core business*
- *focused on incremental innovation, rarely radical innovation*
- *Corporate management tends to drive investment toward products where the commercial case is stronger – i.e., incremental R&D in core business*
- *Outsourcing R&D: Corp's increasingly using external alliances/partnerships/consortia – more reach for less money and risk, enabling early stage investment justification*
- *Some corp's establish their own venture funds to locate and support innovation outside firm*

Branscomb & Auerswald, Con't

- OTHER PLAYERS:
- Univ's - 19 have own venture capital funds to push Univ. research to commercial range; use Bayh-Dole Act (Univ. holds patent for federal R&D it conducts)
- States: a few starting commercialization funds
- Angels–initially family members, friends; now"Band of Angels" and solo professionals
- Federal – strongest programs: SBIR, ATP

WRAP-UP:

- **Solow** – key to growth: "technology and related innovation" (shorthand: R&D)
- **Romer** – behind technology: "human capital engaged in research" – prospectors (shorthand: Talent)
- **Jorgenson** – key to 90's growth: SC's, multiply productivity throughout economy
- **Merrill** – investors understand value of technology breakthroughs, but only support short term development
- **Direct Innovation Factors** -
  - R&D and
  - Talent

WRAP-UP, CON'T:

- **NELSON:**
  - Idea of innovation as a complex system
  - Operates at a national scale
  - We can do comparative analysis of national innovation systems
  - System operates at the INSTITUTIONAL LEVEL -look a connections, interaction between innovation actors in public and private sectors
- **INDIRECT INNOVATION FACTORS, TOO**
  - Mix of indirect and direct innovation factors in interacting in an innovation ecosystem
- **BRANSCOMB AND AUERSWALD**
  - **Valley of Death between R&D**
  - **Not linear, a Darwinian Sea**

Resource: Science Policy Bootcamp
William Bonvillian