ECONOMICS OF SCIENCE: UNDERLYING THEMES AND NEW DIRECTIONS FOR RESEARCH

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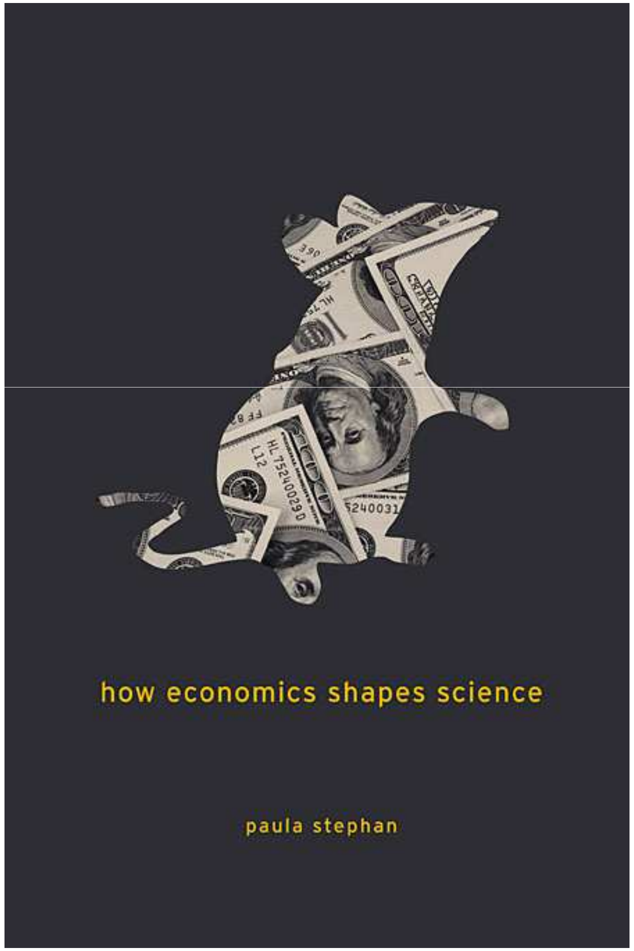
Introduction

- During past few years I've had opportunity to think about the economics of science
- One way to summarize these thoughts is to focus on what I see as underlying themes and new directions for research
- That's what I will do today; focus will be on science produced in the public sector—at universities and at institutes.
- Begin with a discussion of underlying themes/robust findings;
- Continue with a discussion of production of scientific research: researched and under-researched topics
- Conclude with a discussion of lines for new research which focus on the issue of efficiency

Much of discussion based on book



Robust Findings

- Economics is about incentives and costs
- It is also about the study of production—how inputs are used to create output
- Most robust findings are that incentives and cost matter at both the level of the individual scientist and at the institutional level
- Costs also matter
- When it comes to the production of scientific knowledge, we know considerably less about actual production function

Incentives Matter

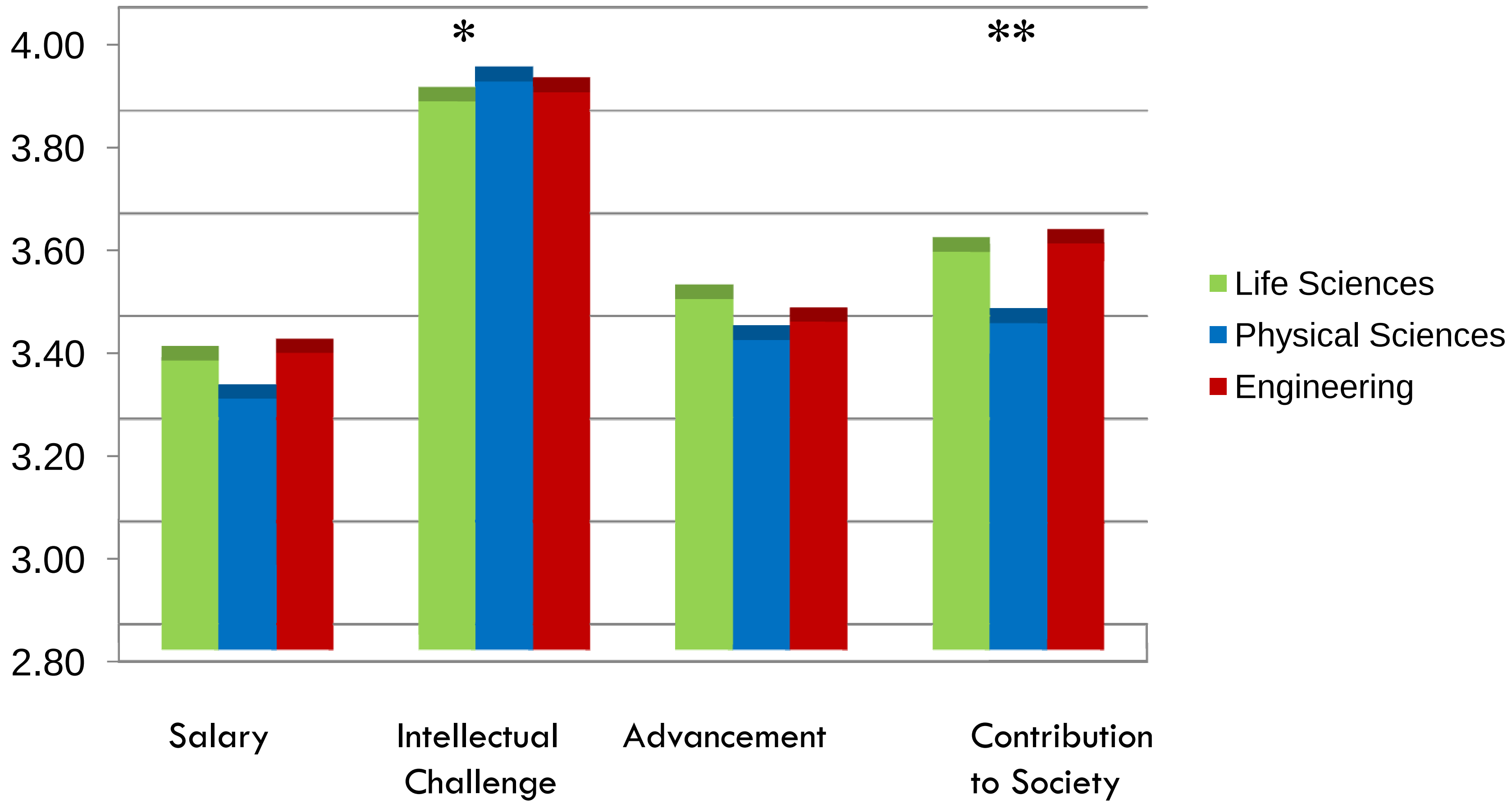
- Puzzle
  - One reason for doing science is the pure "pleasure of finding things out" to quote Richard Feynman. Scientists are clearly motivated by an interest in puzzle solving. For many, it is this interest that attracted them initially to science.
- Ribbon
  - Scientists value the recognition awarded by their peers for being first to make a discovery—to establish priority of discovery
- Gold
  - Scientists are not uninterested in money

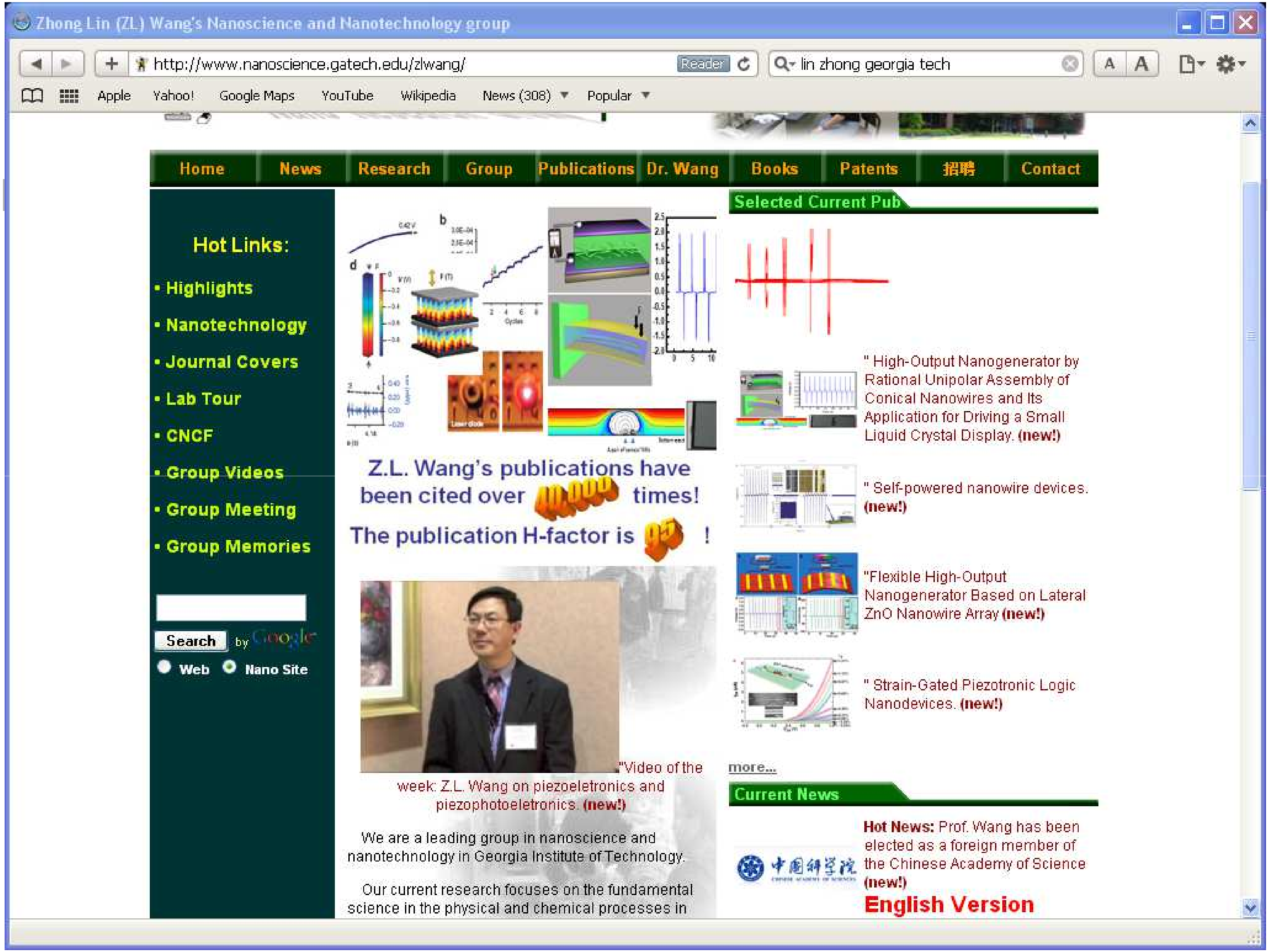
Suggestive supporting evidence

- Scientists place highest weight on “challenge” when asked by NSF to score a number of job characteristics
- Scientists chronically argue over issues related to priority; only on rare occasions do they turn down honors associated with establishment of priority; scientists readily adapt to new measures—such as the *h*-index-- of reputation
- In countries, such as the U.S., where academic salaries vary by institution, scientists move in response to more lucrative job offers

Motives

Motives: “When thinking about a job, how important is each of the following factors to you…” (4-point scale)

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"Video of the week: Z.L. Wang on piezoeletronics and piezophotoeletronics. (new!)
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Selected Current Pub
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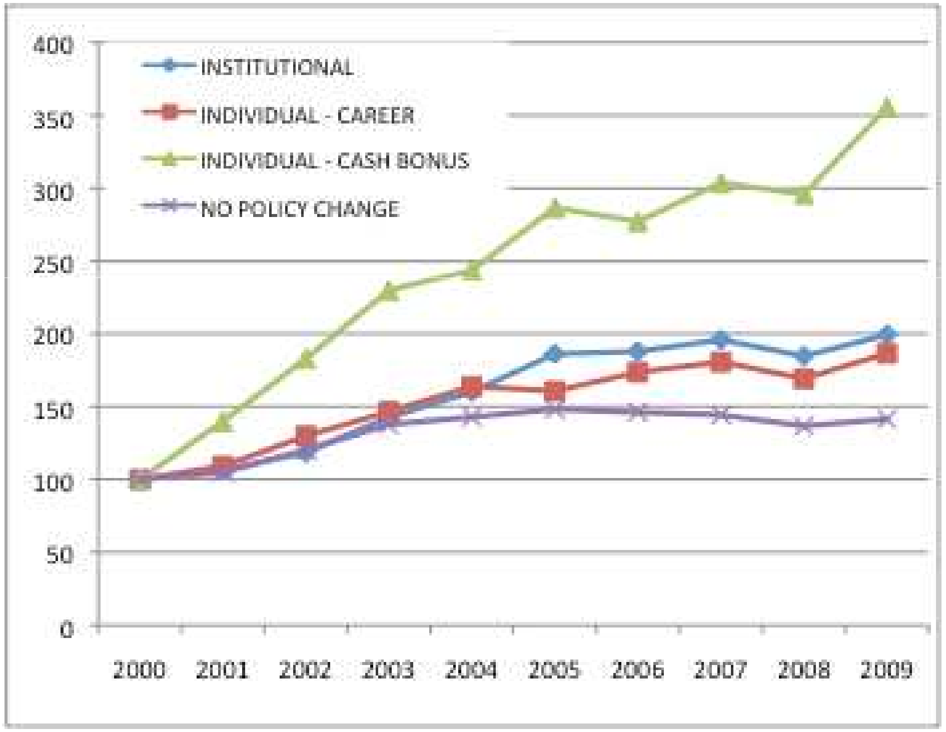
" Strain-Gated Piezotronic Logic Nanodevices. (new!)
more...
Current News
Hot News: Prof. Wang has been elected as a foreign member of the Chinese Academy of Science (new!)
中国科学院
English Version

Response to Incentives to Publish in Top Journals: Submissions by country to *Science*



Source: Franzoni, Scellato, Stephan (2011)

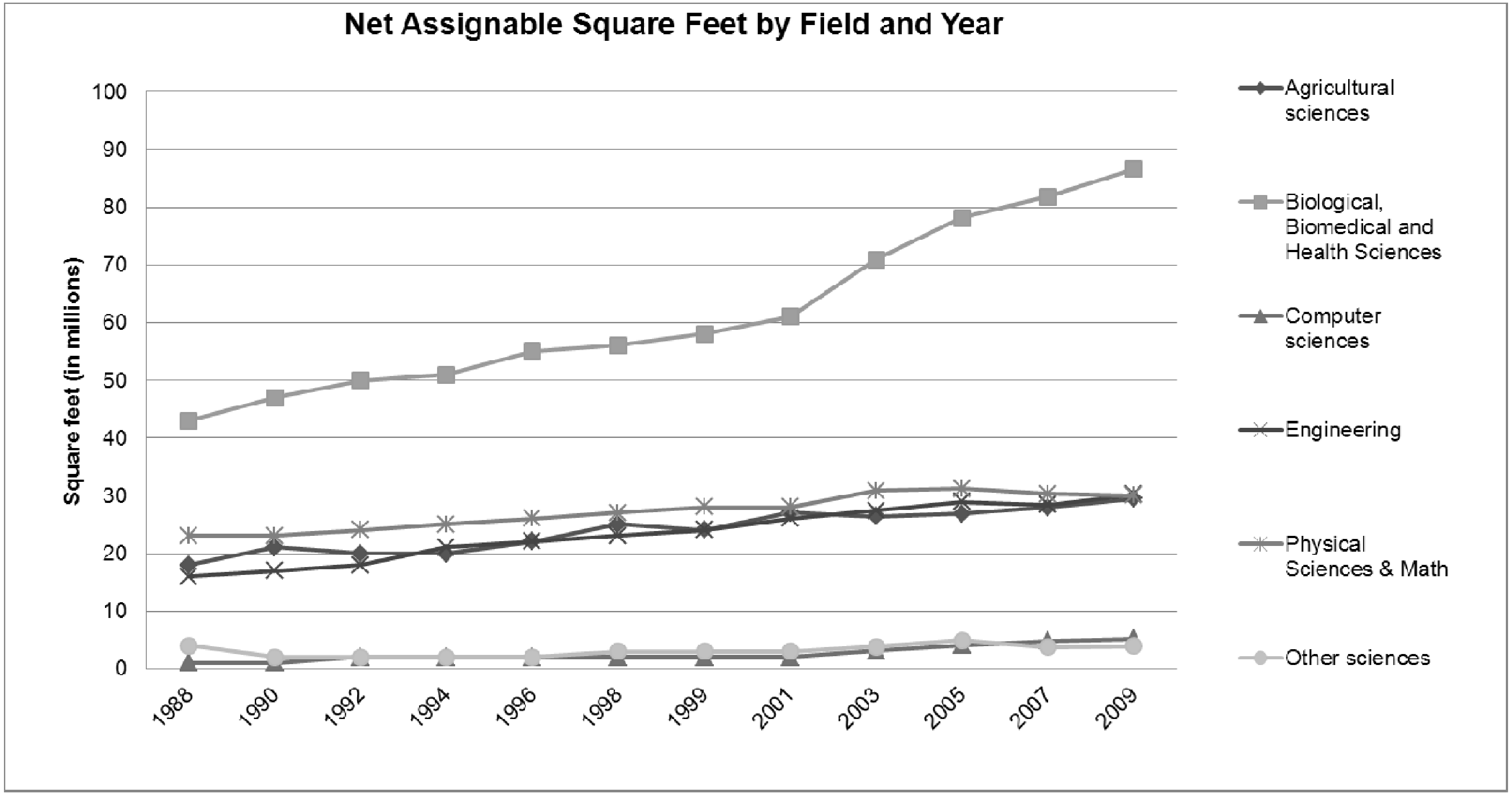
Not all about puzzle, ribbon and gold

- Other incentives matter, as well
- By way of example, best predictor of which faculty in the life sciences in the U.S. patent is value faculty member places on "contributing to society;"
  - a one standard deviation increase in importance a life scientist places on contributing to society increases expected patent count by almost 50%
- Do not find similar results for other fields—a reminder that incentives vary across fields

Institutions Also Respond to Incentives

- Case of Australia
  - University funds were initially allocated partly on basis of quantity of ISI publications
  - Response: Publications grew considerably; largest increases were in the bottom quality quartile with exception of medical and health sciences where bottom two quartiles grew at a similar rate
- Just-in-time hires in UK in response to Research Assessment Exercise:
  - Between 2002-2006 number of faculty earning more than £100,000 grew by 169%
- Saudi Arabia following similar approach.
  - In an effort to move up in the Shanghai rankings Saudi universities are offering “most cited authors” $72,000 to list Saudi university as an affiliation and spend a limited amount of time on campus.

Building Boom in Biological, Biomedical and Health Sciences in U.S.



Costs Affect Practice of Science

- Important to recognize because cost of doing science—even "small" science-- is non-trivial and growing
- Examples:
  - Telescope can easily cost over 1 billion €
  - LHC cost in excess of $8 billion
  - Cost of researchers' time: I estimate it costs more than $400,000 to staff a small lab with 8 researchers in the U.S.

Even Mice Costs Money

- Off the shelf mouse cost $17 to $60
- Mutant strains cost $40 to $500-plus
- Cost $1900 to recover a strain from cryopreservation—that's where 67% of lab mice come from
- Designer mice with disposition for such diseases as obesity, alcoholism, Alzheimer's, diabetes, cost considerably more—on the magnitude of $3500

Many Mice Are Used in Research

- Mice are king

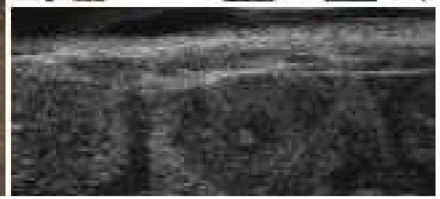
- 90% of all animal models are mice
- At least 20 million mice in use in labs
- Johns Hopkins University alone has 200,000

Keeping mice

- Costs per day: $.10 to $.18
- Can add up: one researcher was paying Stanford $800,000 a year for mouse upkeep
- At aggregate, spending about $1 billion a year keeping mice

Mouse equipment

- 6 million cages
- New area for innovation:
  - Mouse ultrasound: $150,000 to $400,000.
  - Cage enrichments



Mice continued

- Cost of mouse upkeep factor encouraging Tian Xu of Yale University to work at Fudan University 3 months each year
  - Fudan provides facilities for 45,000 mouse cages (usually 5 to a cage)
  - Could cost over $12,000,000 annually in U.S. to keep.
  - Also issue of where one could keep that many mice in US—more mice than all the mice at Johns Hopkins

Examples of How Costs Affect Practice of Science

- Europe had to "settle" for the E-ELT telescope (extremely large) after plans to build the OWL (overwhelmingly large) telescope proved too expensive and overly complex
- The LHC is shut down in the winter when the price of electricity, due to demand, increases
- Faculty began to substitute postdocs for graduate students in US: reason—they are cheaper, primarily because faculty member does not have to pay for tuition for postdocs and postdocs work more hours (incentives!)

Examples of Costs continued

- Cage rates, which vary considerably across institutions, can play a role in where scientists choose to work
- Costs affect whether researchers work with male or female mice (males turn out to be cheaper)

To Recap

- Considerable evidence that practice of science is affected by incentives and cost
- We have made considerable head way in understanding how these factors affect the practice of science—especially how incentives affect the practice of science--both at the individual as well as at the institutional level; policy makers are beginning to pay attention to these findings
- But scientific results do not just come out of a hat—they involve the combination of inputs—and we know considerably less about this production process

Production of Scientific Research: the Researched and the Under-researched

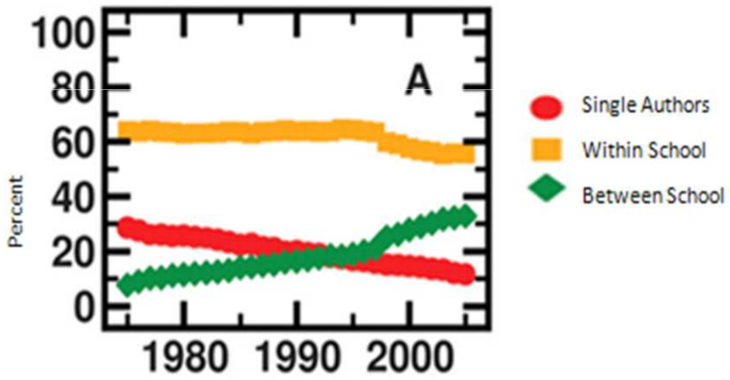
- Production of scientific research involves multiple inputs, including knowledge, time, materials and equipment
  - Q=f(k, t, m, e)
  - Some inputs, such as knowledge and time, are embodied in people
- Most research in economics of science related to productivity focuses exclusively on the relationship between people and output
  - Age publishing relationship
  - Patterns of collaboration and networking
  - Role of mobility and individual productivity

But Numerous Areas of Ignorance Regarding the "People" Input

- Know very little about how structure of teams relates to productivity
  - Age structure of authors and how this contributes to productivity
    - Particularly important to investigate given way labs are staffed in countries like the U.S. by graduate students and postdocs
  - Number of collaborators: when do diminishing returns set in?
  - International collaboration vs. national collaboration? What accounts for the advantage that international teams appear to have?

Another Area of Ignorance Regarding People: Why Increase in Collaboration?

The Rise in Multi-University Collaboration, Science and Engineering



Source: B.F. Jones et al., Science 322, 1259 -1262 (2008)

- Well established reasons for increase
  - Internet lowers cost of collaborating
  - Data and material sharing promote collaboration
  - Big equipment promotes collaboration
  - Increasing specialization of researchers promotes collaboration
- But unanswered questions regarding reasons for specialization:
  - Is it burden of knowledge hypothesis put forth by Ben Jones?
  - Or does specialization occur because it meets needs of PI and PI encourages students to specialize?

Is Collaboration Compatible with Current Rewards to Science?

- Promotion and tenure are important rewards in science
  - How does one evaluate contribution of coauthors at promotion and tenure time?
  - How does one evaluate contribution of faculty who participate in collaborative grants?
- Disconnect between prizes and collaboration
  - Prizes awarded generally to at most three scientists
  - If collaborative research produces better science—and there is evidence it does—need to encourage creation of prizes to be awarded to groups of scientists
    - Status, as Nobel Peace Prize so aptly demonstrates, need not be conferred on one person at a time!

Materials: Know Something about the Relationship of Materials to Productivity

- Some research on role of materials in fostering or hindering research
  - Research that focuses on how changes in property rights, which can affect access to materials, affects production of science
    - Murray and Murray and Stern's work
    - Recent work that examines how NIH MOUs regarding Crelox and Oncomouse® mouse changed research outcomes (joint with Aghion and others).
  - Work of Furman and Stern that examines how deposit of material at BRCs affects research outcomes
  - Surveys by Walsh and others regarding access to materials and productivity

Equipment: We Know Very Little About Its Role in Production

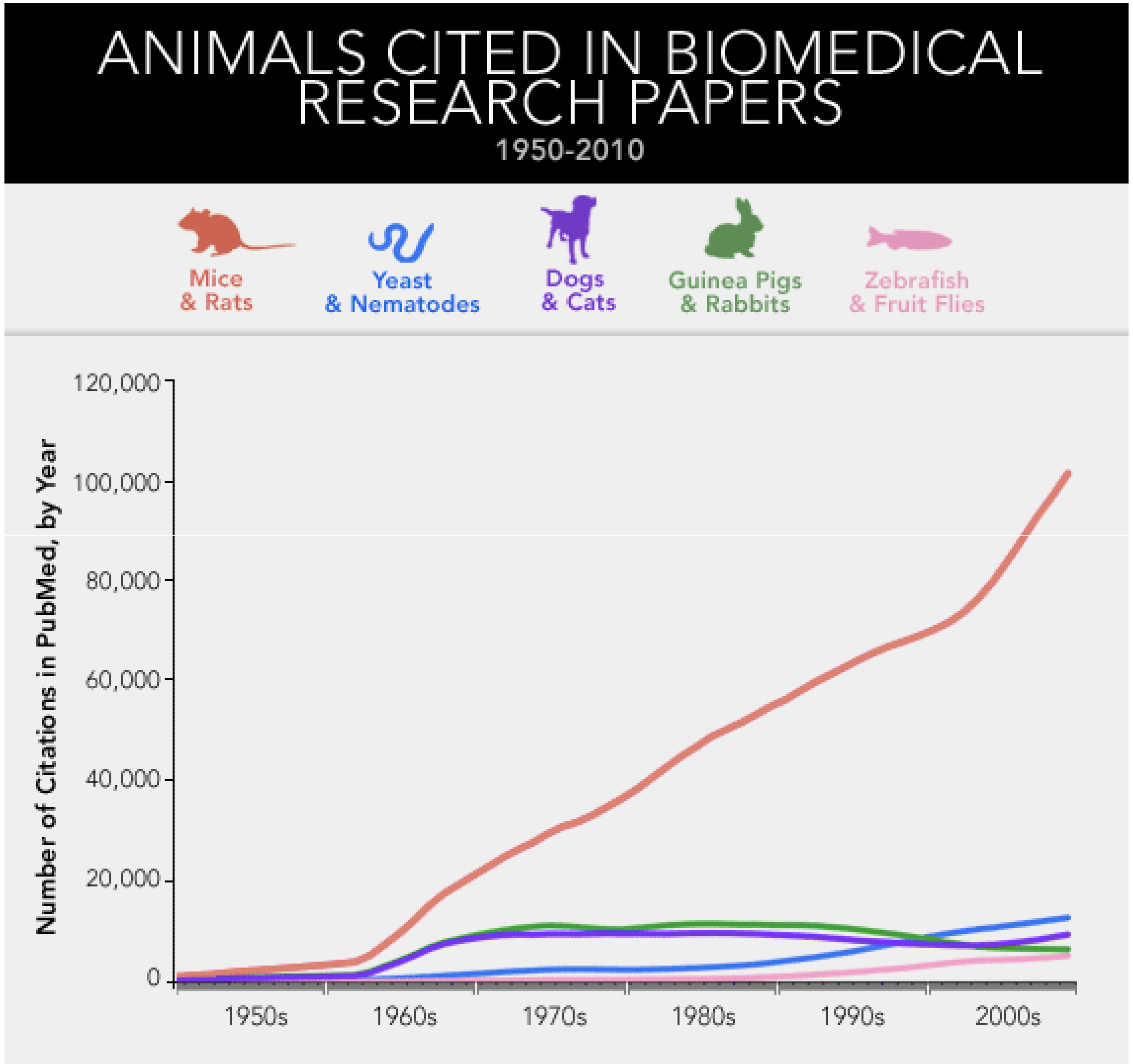
- What happens to capital-labor ratio in the lab as new technologies are introduced?
  - What happens to skill needs of lab? Need as many graduate students to staff labs?
- How efficient are markets for scientific equipment? What is extent of price discrimination? (Illumina controls 66% of sequencing market)
- How quickly does new equipment diffuse? Where does it diffuse?
- To what extent does equipment dictate where research is performed, in terms of number of research centers and distinction between private and public sector?
- What role does equipment play in recruitment of scientists?
- Do changes in scale of equipment contribute to concentration of where research is conducted? Or do new technologies contribute to democratization?
- Does remote access affect who does science?
- What happens to the data? Do scientists have the necessary skills to analyze/model the data?
- Are scientists overly focused on collecting data and do not sufficiently discriminate between what may be useful and what may not be useful?

Example of Change In Capital Labor Ratio: Sequencing

- Ratio of capital to labor depends on relative prices and technology—increase in relative price of labor should lead to substitution of capital for labor
- Amount of labor used also depends on scale of operation
- When it comes to sequencing, substitution effect seems to be dominating scale effect with introduction of new equipment:
  - Venter Institute eliminated 29 sequencing center jobs about 5 years ago
  - Broad Institute eliminated 24 three years ago

Areas of Ignorance Regarding Role of Equipment continued

- How efficient are markets for scientific equipment? What is extent of price discrimination?
  - Market concentration: Illumina controls 66% of sequencing market
  - Some equipment is sole sourced
- Role of consumables: Xerox model?
- How quickly does new equipment diffuse? Where does it diffuse?



Survey National Library of Medicine; Daniel Engber, Mouse Trap, *Slate,* Nov. 16, 2012

Areas of Ignorance Regarding Role of Equipment continued

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Example: Location and Sequencing

- Sequencing traditionally done at “core” facilities— in 2010 half of 1400 sequencing machines in world were at 20 large academic or government centers (Matthew Harper)
- New equipment has potential to decentralize and democratize process: Companies are betting on it
  - In March 2010 silicon chip sequencer was introduced—analogy for some is when photography went from film to digital. A common model sold for $50,000
  - In February of 2012 Oxford Nanopore introduced a device the size of a USB memory stick called a MinION, which will be sold for less than $900 and supposedly can deliver 150 megabases of DNA sequences per hour. Larger version will also be marketed
    - High error rate of 4%

Silicon chip sequencer introduced by Ion Torrent Systems: $50,000

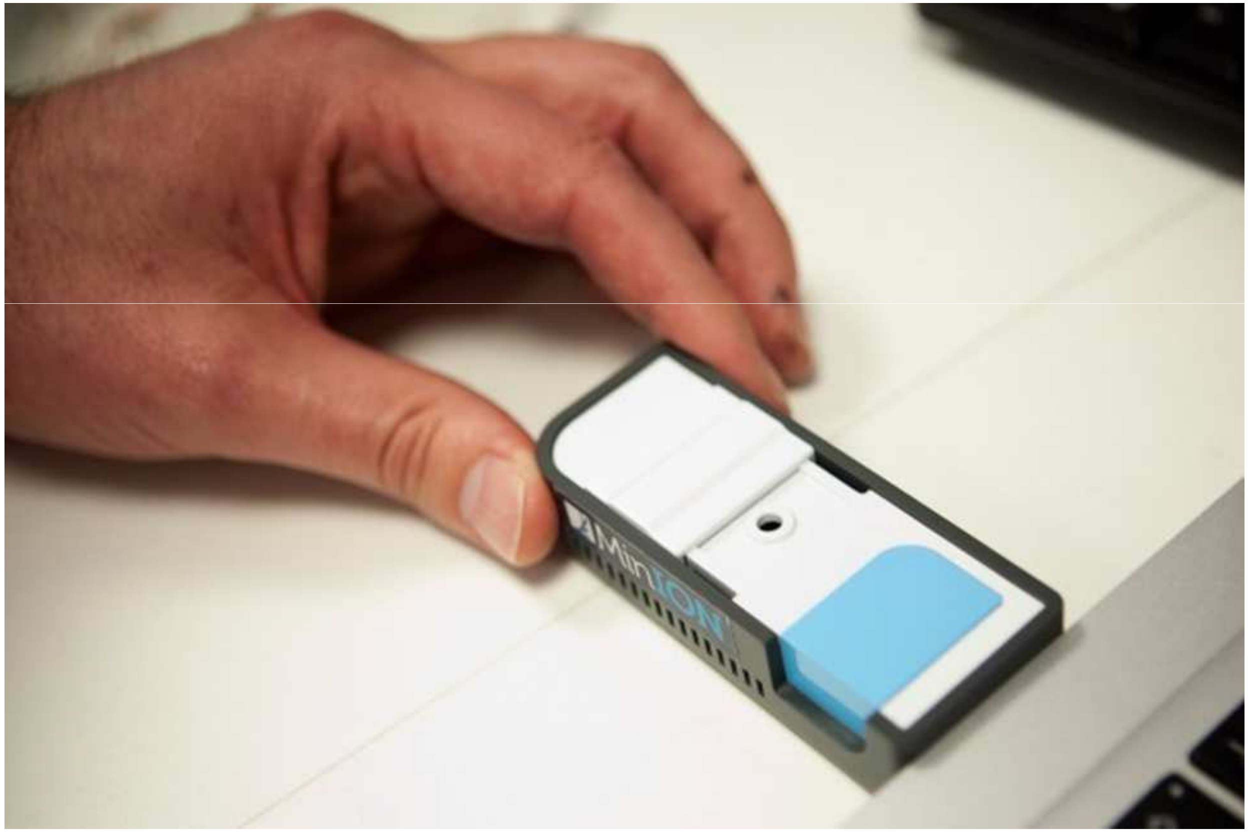
Small Scale: MinION Sequencer

Introduced in February 2012 byOxford Nanopore

Price: $900

Disposable—runs for 6 hours—150 million base pairs

Larger version: GridION



http://www.wired.co.uk/news/archive/2012-02/20/minion-dna-sequencer

Additional areas of Ignorance Regarding Role of Equipment

- What role does equipment play in recruitment of scientists?
  - In public sector as well as in private sector

Equipment and Recruitment

Lila Gierasch

- Gila Gierasch was “Wooed by an NMR machine” to University of Texas Southwestern Medical Center
- NMR’s not cheap: currently run $2 to $16 million
- Access to equipment matters to researchers

Equipment and Recruitment continued

- Not only location within non-profit sector
  - Equipment plays a role in sector scientists choose to work in: "I have worked in some of the best-funded academic laboratories in the world and even these labs don't have access to the fancy next-generation machines in a way that large biopharmaceutical companies do."
- What role does access to equipment play in university-industry collaborations?

Other Areas of Ignorance Regarding Role of Equipment continued

- Does remote access affect who does science?
- What about growing amount of data? Do scientists have necessary skills to analyze/model the data?
  - Are funding agencies falling into a “data” trap?
  - Are we overly focused on collecting data and do not sufficiently discriminate between what may be useful and what may not be useful data?

Other Open Questions/Lines for New Research Focus on Efficiency

- Major importance to policy
  - Are we spending “right” amount on R&D in the public sector?
  - Is current allocation of funding for R&D which— in U.S. gives about 2/3rds to the biomedical sciences-- efficient?
  - Are grants structured in an efficient way in terms of
    - size, duration, criteria for evaluation and number of people?

Difficult but important questions

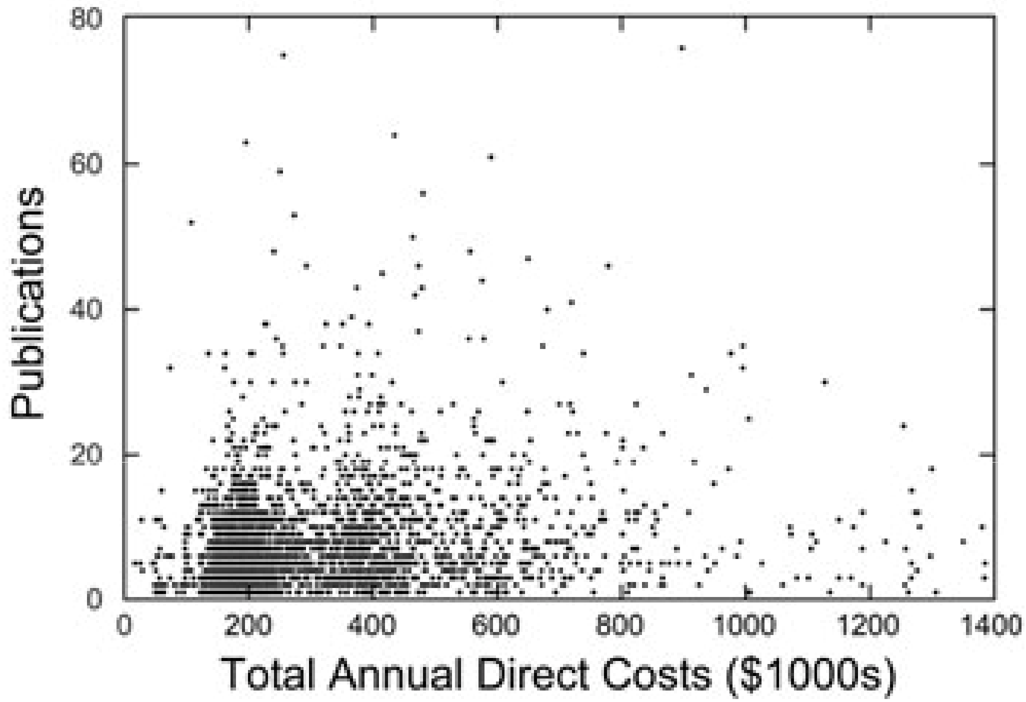
- Especially in an era of flat resources
- Some, due to measurement problems, may never be answerable
- For example, with regard to amount…case can be made that we don't know the "right" amount but the research that has been done shows reasonable returns and suggests that we are underinvesting

What about Mix?

- There have been impressive returns from research in the biomedical sciences
- But is marginal benefit from another dollar spent in biomedical sciences equal to that in other sciences?
- Case could be made that it is lower
  - Drug discovery model has produced few winners in recent years suggesting diminishing marginal productivity
  - Spillovers and complementarities from other disciplines
    - lasers, MRI, etc. are important

Structure of Grants

- Fund people rather that proposals?
- Fund collaborative groups rather than individuals?
- Are rules—such as requirement of EU to have researchers from three or more countries—efficient?
- Large grants or small grants?
  - Did NIH use their funds efficiently during the doubling of its budget?
  - NIGMS study suggests the answer may possibly be "no."
    - Found a correlation of only .14 between number of publications and total annual direct cost of grants



https://loop.nigms.nih.gov/index.php/2010/11/22/
another-look-at-measuring-the-scientific-output-and-impact-of-nigms-grants/
A plot of number of grant-linked publications from 2007 to mid-2010 for 2,938 investigators who held at least one NIGMS R01 or P01 grant in Fiscal Year 2006 as a function of the total annual direct cost for those grants.

People vs. Projects?

- Support for projects is dominant model in U.S.—permeates NIH, NSF
- But support for people does exist—HHMI, for example, Wellcome Trust recently adopted
- There is some evidence, collected by Azoulay and colleagues, that supporting people rather than projects produces higher impact papers at a much higher rate than the project approach does
  - Not just that HHMI chooses people over projects, provides for a longer period of funding

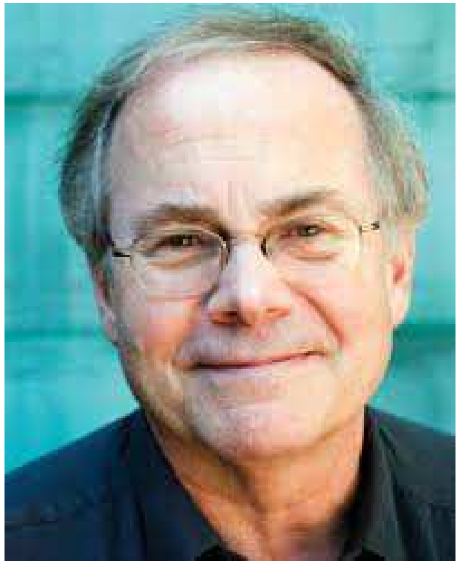
Intuitively Pleasing Result

- People approach requires less administrative time (another serious efficiency concern when it comes to way in which science is currently being conducted)
- Encourages risk taking; HHMI is more forgiving of failure than is a project approach
- Wellcome Trust sufficiently impressed to have replaced project model with people model

Public Funding and Risk Aversion

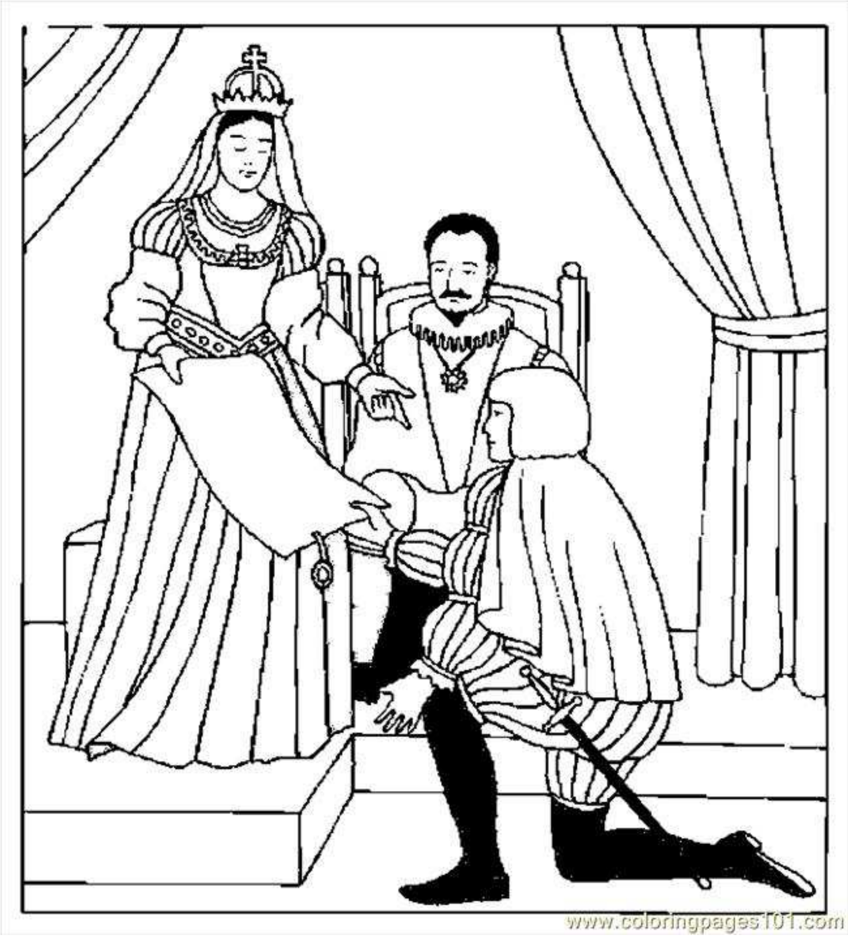
- Major criticism in U.S.
- Relates to incentives
  - Faculty must have funding to get tenure
  - Faculty are on soft money—no grant no pay
  - Reviewers favor proposals with preliminary results
  - Agencies fear criticism of misuse of funds if they fund things that do not pan out
  - Proposals are picked “one by one,” not with an eye towards building a portfolio

“Goodbye, Columbus”



- Gregory A. Petsko
- Brandeis University
- “Explores” reasons why Columbus’s proposal “Finding a New Route to the Indies by Sailing West” is (hypothetically) rejected
- *Genome Biology* 2012 13:155

Columbus's Rejection



- Too ambitious—suggest he go to Portugal, instead.
- Lack of preliminary data
- Failure would be disastrous for funder-- "think of how it would look if we funded something that didn't pan out."
- Poor fit for reviewers: Experts (da Gamma and Magellan) too busy to review proposal
- Limited funds
  - Funds are used for data collection ("Grape Vine Sequencing") rather than hypothesis testing—data collection projects are "guaranteed to work"

Summarize

- Many robust findings—especially that incentives and costs play an important role in science
- Many new directions for research
  - Production of science
    - Structure of collaboration
    - Role of equipment and materials in production of new knowledge
    - Market for equipment
  - Efficiency issues when it comes to funding of science
    - Amount
    - Structure
    - Ways to encourage risk taking

Comments/Questions?

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