HOW ECONOMICS SHAPES SCIENCE

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Specific Focus

- Focus on central themes of book
- How these relate to problems/concerns regarding way U.S. scientific enterprise functions today
- Areas where additional research is called for
- Role for private foundations
Major themes

- Economics is about incentives and costs
  - Incentives matter in practice of science, from point of view of scientists doing research and point of view of the institutions where they work
  - Costs matter as well, again for scientists and for institutions
- Responsiveness of scientists and institutions to incentives and costs—as currently structured—have unintended consequences which detract from scientific enterprise
- Economics is also about the study of efficiency—can reallocate resources used to support science and get more without getting less?
- Economics can help inform our understanding of the production of knowledge

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Incentives Matter to Scientists

- **Puzzle**
  - One reason for doing science is pure “pleasure of finding things out” to quote Richard Feynman. Scientists are motivated by an interest in puzzle solving. For many, it is interest in puzzles that attracted them initially to science.

- **Ribbon**
  - Scientists value recognition awarded by their peers for being first to make a discovery—to establish priority of discovery. This is a functional reward—encourages the production of the “public” good knowledge—the only way a scientist can make their discovery “theirs” is by giving it away.

- **Gold**
  - Scientists are not uninterested in money
Example: Response to Incentives to Publish in Top Journals: Submissions by Country to Science

Source: Franzoni, Scellato, Stephan (2011) Paula Stephan Georgia State University & NBER
Not all about puzzle, ribbon and gold

- Other incentives matter, but we know less about them.
- 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%
  - Related findings in Japan, Germany
- Do not find similar results for other fields—a reminder that incentives vary across fields

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Other Incentives

- What motivates individuals to participate in writing open source software?
- What motivates individuals to contribute to Wikipedia, etc.?
- No evidence that patent activity of university faculty relates to the “share” that university offers inventor
- In short, need to know more about what motivates scientists

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Incentives Matter for Institutions, as well

- Quest for prestige plays key role in way institutions allocate resources
  - Goal of many institutions is to increase their standing: AAU membership, Shanghai rankings
  - Membership/rankings depend in turn upon publications and awards of faculty
    - Saudi Arabia
- Money
  - Rankings also depend upon amount of resources faculty bring in for research
    - University of Georgia
  - Ability to attract highly productive faculty costs money—both in terms of start-up packages and salary but also in terms of research space
  - One reason universities prefer to support grad students as GRAs rather than on training grants is because they can collect about $12,000 more in indirect on GRA position rather than training grant—despite fact that training grants may have better outcomes

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

Net Assignable Square Feet by Field and Year

- Agricultural sciences
- Biological, Biomedical and Health Sciences
- Computer sciences
- Engineering
- Physical Sciences & Math
- Other sciences

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Costs Affect Practice of Science

- Cost of doing science—even “small” science-- is non-trivial and growing

- Examples:
  - Telescope easily cost over $1 billion
  - LHC cost in excess of $8 billion
  - Cost of researchers’ time: Costs more than $400,000 to staff a small lab with 8 researchers at a U.S. university before indirect costs are added

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Even Mice Costs Money

- To buy/design
  - 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 a disposition for a disease such as obesity, alcoholism, Alzheimer's, diabetes, cost considerably more—on the magnitude of $3500

- To keep: $.10 to .18 per day

- To study—equipment such as a “mouse” ultrasound; cage enhancements
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

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Mouse equipment

- 6 million cages
- New area for innovation:
  - Mouse ultrasound: $150,000 to $400,000
  - Cage enrichments
 Costs Affect Practice of Science cont.

- Europe had to “settle” for the E-ELT telescope (extremely large) after plans to build OWL (overwhelmingly large) telescope proved too expensive and overly complex.
- The LHC shuts down in winter when price of electricity, due to demand, increases.
- Faculty substitute postdocs for graduate students in US: reason—postdocs are cheaper, primarily because faculty member does not have to pay for tuition for postdocs and postdocs work more hours.
- Universities “hire” faculty on soft money positions—contributes to building reputation and, after startup costs, costs universities a minimal amount.

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Costs Affect Location of Research

- 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

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Responsiveness of Scientists and Universities to Incentives and Costs Leads to Unintended Consequences

- Overtraining: graduate research assistants and postdocs are cheap and flexible way to staff labs
  - Evidence that production of newly minted exceeds demand for research positions
  - Especially a problem in a stalled economy—we are at risk of losing much of a cohort of scientists
- Community is highly resistant to changing this model of staffing labs
  - Last NRSA (National Research Service Awards) study concluded that “the body of graduate students and postdoctoral fellows [supported by NIH training grants] provides the dynamism, the creativity and the sheer numbers that drive the biomedical research endeavor.”
  - Despite problems that trainees encounter in finding jobs, the system is “incredibly successful in pushing the boundaries of scientific discovery.”
  - What to do? “One highly needed and valuable outcome is for biomedical and behavior sciences trainees to teach in middle school and high school science.”
  - Turn them into teachers? After 7 years in graduate school and 5 years as a postdoc?

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Overbuilding

- Incentives played big role
  - NIH funding was growing
  - Rules allow interest on debt to be included in calculating indirect rate
  - Universities sought to fill new buildings with researchers on soft money—no risk to universities in terms of salary commitment—all in an effort to increase their reputation

- Consequences
  - Universities may have trouble servicing the bonds given that NIH budget is not growing
  - Unless they default, “others” will pay
    - Students
    - Faculty
    - Other disciplines

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Risk aversion on part of scientists and funding organizations

- Considerable concern that scientists and funding agencies are increasingly risk averse

- Why?
  - In order to keep one’s lab functioning one must have external support; university only supports lab for 3 years
  - Need for faculty to obtain grants to support their salary—especially important for faculty on soft money—perhaps 35% of NIH investigators—no funding, no job!
  - Low probability of success (17 to 20 percent at NIH)—reviewers prefer proposals with convincing preliminary data: “no crystal, no grant.”
    - Roger Kornberg: To quote the Nobel laureate Roger Kornberg, “If the work that you propose to do isn’t virtually certain of success, then it won’t be funded.”
  - Propensity of funding agencies to choose proposal by proposal, rather than to think of their portfolio of research; little room for risk in this approach

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Concern for Economic Growth

- Pretty clear that if most scientists are risk averse, little chance that transformative research will occur, leading to significant returns from investments in research and development.
- Incremental research yields results, but in order to realize substantial gains need more people doing transformative work.

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Overburdening of referees?

- By way of example, cash incentives for publishing in a top-tier journal such as Science leads to tremendous increase in submissions—46% to be precise
- But absolutely no corresponding increase in number of publications
- Challenge grant program of ARRA at NIH: received over 20,000 proposals—only 840 funded!
  - Tremendous amount of time spent reviewing them, and writing them (at minimum 1000-person years)
Second Theme: Efficient Use of Resources Used to Support Research?

- Rationale for providing funding to support research:
  - Public nature of knowledge makes it difficult for scientist to appropriate financial returns although production of knowledge benefits society;
  - Large costs of research
- Historically, foundations and donors were primary supporters of research in the public sector
- Government has played a strong role in last 60 plus years

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Current situation

- Universities receive approximately $55 billion for R&D annually
- 60% comes from the Federal Government
- Over half of that is National Institutes of Health funding (NIH)
- National Science Foundation (NSF) is about 10%; Department of Defense, Department of Energy also support university research
- 6 out of 10 federal dollars distributed by peer review to university researchers in United States;
  - Most of what is reviewed are “project” proposals
  - Most are for three to five years

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Other trends

- Percent of industry funds has been fairly flat
- Percent of funds from institutions themselves has increased (start-up packages important here)
- State and local government support as a percent has been declining
- Percent from “other” fairly constant—includes non-profits
Efficiency questions related to funding

- Is mix of what is being funded efficient?
- Is the structure of grants efficient?
  - Size
  - Duration
  - Age structure of recipients
  - Criteria for evaluation

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Efficient Mix of What is Funded?

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Focus on Biomedical Sciences

- Two-thirds
- Why?
  - Extremely organized disease-focused lobby in United States for biomedical research
  - Public is supportive
  - Congress is “old” and has been getting older

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Inefficient?

- Is putting all these funds into the biomedical sciences efficient?
- Does strong focus on biomedical sciences affect fabric of university?
- Is it time to readjust U.S. federal R&D portfolio?
- Biomedical research has had great run
- But unclear that marginal product of another dollar spent in biomedical research is as high as it once was. May be time to reallocate!
  - Diminishing returns are likely present—suggested by slowed rate at which new drugs are being brought to market and less than stellar increase in U.S. publications associated with the doubling of NIH budget.
  - Many of breakthroughs that have contributed to better health outcomes have come from other fields of science—the laser and the MRI, for example—and other fields provide important complementarities to research related to health outcomes
  - Funds for the physical sciences in the United States (in terms of the percentage of federal research funding) are close to a 35-year low.

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Structure of Grants

- Are size of grants/labs efficient?
- During NIH doubling there was a significant increase in number of researchers with multiple grants; once again, incentives played a key role—bigger is better: more citations, more funding and more trainees
- Was this efficient?
- Analysis by NIGMS suggests possibly not

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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.
Criteria for Evaluation?

- Support for projects is dominant model—permeates NIH, NSF
- But support for people does exist—HHMI, for example
- 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

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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
- Clear role for private foundations to experiment with other ways of supporting researchers that promote risk taking and diversity of topics

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But Is It Scalable?

- Wellcome Trust is now using the “people” rather than project approach.
- But is it scalable? Size of U.S. science may be an impediment in using a “people” model for distributing research funds—easier to differentiate among 1000 individuals than to differentiate among 50,000.
Are We Supporting Right Age Mix?

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Age structure of recipients relates in part to incentives

- Incentive to delay first submission—importance of preliminary data—and importance of “first chance”
- Delay of retirement and ability of older researchers to get multiple grants and continuations of existing grants
Figure 1. Average Age of Principal Investigators with MD, MD-PhD, or PhD at the time of First R01 Equivalent Award from NIH, Fiscal Years 1980 to 2011

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What about collaboration?

- Is heavy focus on funding collaborative research an efficient way to allocate resources?
- Major criteria in Europe; a significant criteria at NIH
- Evidence that coauthored papers are “better”
  - But little evidence regarding marginal product of an additional investigator in an additional country or an additional investigator at another institution
  - Some research that suggests that coordination can be problematic across multiple research cites

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Role for Private Foundations

- **Mix**
  - Number of new foundations has been growing
  - Many are focused on the biomedical sciences where donors have personal interest
  - Role for foundations in supporting other areas, such as climate change, alternative energy sources, water quality, etc.

- **Support young scientists**

- **Experiment/provide leadership in way grants are structured and awarded**
  - Different evaluation criteria
  - Ways to encourage risk taking
  - “Institute model” vs. “university model”? 

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Third theme: Economics provides framework for thinking about production of knowledge

- Widely recognized that 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

- Despite this, almost all research in economics of science related to productivity focuses on relationship of output to people
  - Some examines individual productivity
  - Some examines patterns of collaboration among researchers overtime and how these change
  - Some examines location of collaborators and relationship to productivity

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The Rise in Multi-University Collaboration, Science and Engineering

But Numerous Areas of Ignorance When It Comes to Collaboration

- Know virtually nothing about how structure of teams relates to productivity
  - Age structure
  - Position—postdoc, graduate student mix
    - Particularly important to investigate given way labs are staffed in the U.S. by graduate students and postdocs and that such a staffing model results in overproduction of PhDs in terms of research jobs
  - Number of collaborators: when does diminishing returns set in?
  - Mix of fields
  - International collaboration vs. national collaboration

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Why Increase in Collaboration?

Reasons for increase

- Internet lowers cost of collaborating
- Data and material sharing promote collaboration
- Big equipment promotes collaboration

Some unanswered questions

- Burden of knowledge hypothesis?
- Incentives to specialize?
  - Efficient or does specialization meet needs of PI?
Is Collaboration Compatible with Current Rewards to Science?

- How to evaluate contribution of team members when it comes to promotion and tenure time?
- How to evaluate contribution for 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!

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Areas of Ignorance Regarding Role of Equipment

- 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?
- 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?
Ignorance Regarding Role of Equipment

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Large Scale

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Small Scale: MinION Sequencer

<table>
<thead>
<tr>
<th>Introduced in February 2012 by Oxford Nanopore</th>
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<tbody>
<tr>
<td>Price: $900</td>
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<tr>
<td>Disposable—runs for 6 hours—150 million base pairs</td>
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<tr>
<td>Larger version: GridION</td>
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http://www.wired.co.uk/news/archive/2012-02/20/minion-dna-sequencer
Equipment can play 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.”

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Role of Materials

- How is access to materials affected by property rights?
- By BRC’s?
- Thanks to research of Fiona Murray and co-authors know that property rights, when poorly administered, can affect access to materials—relaxation of property rights can be a democratizing force
- Know that BRC’s can have a democratizing effect in science

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Role for Private Foundations

- Encourage study of labs
  - Pin factory studies?
- Promote study of structure of equipment markets?
Summing Up

- Incentives and costs play a major role in shaping science
- Both scientists and institutions where scientists work are highly responsive to incentives and costs
- Unintended consequences abound
  - Overtraining
  - Overbuilding
  - Risk aversion
  - Overburdening of review system; administrative overburdening on part of investigators

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Questions That Need Addressing

- How and what to do to bring balance between needs of PIs for staff and needs of trainees; many proposals but virtually no consensus
  - Need for a voice that does not have a vested interest here

- Efficiency issues
  - What is funded
  - How awards are made
  - Size of awards
  - Size/scale of collaborations
  - Etc.

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Some Areas to Think About

- Prizes designed to reward collaborative science?
- New programs for graduate students; better dissemination of information about careers; programs for transition to different careers? Cohort specific programs?
- “Shopping list” for philanthropists that goes beyond biomedical sciences
- New models of funding science?
- New models of where research is performed: research need not always be coupled to training

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Thank you!

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