Institutional foundations of scientific progress:  
Implications for collaboration & participation

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Why is there an emphasis on collaboration in science policy today?

- Informal collaborative structure that is central to the scientific community – providing rapid progress & widespread participation - has emerged over many years  

However:

- Informal collaborations are under strain as the community grows larger & more diverse
- Policy-makers seek to “orchestrate” collaborations beyond their traditional informal boundaries
- Re-designing institutional arrangements for science could be a more effective solution to these key challenges
Four Characteristics of Scientific Knowledge

- Its production is a step-by-step process
  - Outputs from one step are inputs into the next (Sarton 1938)
- It is multi-faceted
  - Key outputs include information, materials, know-how, methods (Collins 1974)
- It is non-rival in use
  - One idea can be an input into many follow-on experiments (Arrow 1952, Rosenberg 1986)
- Its follow-on value can be uncertain
  - Wide ranging perspectives on what the most interesting possible direction (Shane 2001)
Implications for scientific research

For follow-on research to be rapid, productive, inclusive & cumulative we must ensure that scientific knowledge outputs are widely available:

=>

- Access to **multiple** dimensions of a given knowledge output
- Access to **many** follow-on innovators not merely a small group
- Access terms **unrestrictive** – should not prescribe the path for follow-on innovation i.e. must allow follow-on innovators to select their chosen line
Meeting these conditions requires a complex of scientific institutions

Mere production of knowledge does not guarantee its use by the next generation (Rosenberg 1984; David & Dasgupta 1994; Mokyr 2002):

Complex of institutions is needed to support disclosure and exchange of knowledge outputs for follow on researchers.

- Disclosure – what is disclosed and thru what means?
- Access – under what terms is knowledge provided for replication, validation & accumulation?
- Rewards – what are the rewards for access
Traditional scientific progress was supported by informal institutional complex

- Small elite communities
- Grounded in close personal relationships e.g. Erdos
- Knowledge exchanged and accumulated peer-to-peer under shared norms & culture
- Informal mechanisms to deal with competition, lack of reciprocity etc.

Old World
Informal peer-to-peer institutional complex & few formal institutions
Letter were another critical form of exchange that operated within the informal structures.

Multiple letters exchanged between Watson & Crick, Max Delbruck, Linus Pauling in the race to the structure of DNA.

Letter from Watson & Crick to Delbruck, March 12 1953
Scientific materials in private collections were accessible to those participating in informal institutions.

FLIES gathered, bred & shared under the watchful eye of Thomas Hunt Morgan (“Lord of the Flies” (Kohler 1988) & his former post-doc Sturtevant.

A.H. Sturtevant in the Drosophila stock room. Courtesy of the Caltech Archives ©
Clubs & societies played a central role in the traditional informal institutions

“The origins of the Royal Society lie in an "invisible college" of natural philosophers who began meeting in the mid-1640s to discuss the ideas of Bacon”.

While democratic on some levels, Shapin (1984) vividly described participation was closely guarded & tied to being a “gentleman”
Informal institutional complex functioned effectively to allow for speed, participation & diversity of follow-on research in a **small** scientific community

**SUPPLY-SIDE STRAINS**
- Knowledge outputs growing in complexity
- Knowledge outputs increasingly costly to maintain; hard to standardize & validate
- New rules e.g. Bayh-Dole requires suppliers to triage the terms of access

**DEMAND-SIDE STRAINS**
- Increase in size of the scientific community
- Growing participation in science from nations not traditionally part of invisible college
- Growing diversity of participants e.g. industry demand for scientific knowledge
Formalizing requirements for collaboration is a widespread response to this crisis

- It forces researchers with key knowledge outputs to work with a more diverse groups of researchers
- It requires them to work on different types of follow-on projects
- By collaborating it may increase speed (although the evidence is weak)
- BUT – it reduces the freedom of researchers which decreases a powerful motivating incentive (Aghion et al. 2008)

Why not focus on the root cause of the problem – the limits of informal institutions?
Complementary Response:
Re-design institutional complex to establish a complex of more formal institutions

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Over 16,000 researchers in more than 60 countries rely upon JAX® Mice. They are the most published and well characterized models in the world.
Key Question

Do these formal institutions actually increase efficiency of exchange, broaden participation & increase diverse of follow-on research

In other words…

if we design these institutions correctly, can we accomplish many of the goals that we strive for with our current emphasis on formal collaboration?
Empirical Analysis of these formal institutional changes is challenging

- Need to define the counterfactual: What type of innovation would we expect to take place under different institutional conditions?
- Need systematic measures of follow-on: Can we measure the follow-on innovation we care about?
- Need “experiments”: What sorts of settings allow us to examine institutional arrangements that vary independent of variations in the underlying type of knowledge? i.e. identification is key

=> we need to distinguish between selection & marginal effects
Analyzing Effectiveness of Formal Scientific Institutions

Plot forward citations over time as a measure of scientific knowledge accumulation building on a “piece of knowledge.”

Exogenous SHIFT in institutional arrangements

Measure citations before & after to estimate impact of SHIFT

Pre-period institutional setting

Post-period institutional setting

Control group

Treatment group

Publication

Publication

Publication

Publication

Publication

Publication

Publication

Publication
Use forward citations to capture a variety of features of follow-on knowledge production:

- Level (pre- and post-)
- Diversity of participation (new versus already contributing authors or universities)
- Diversity of ideas (new versus already used key words or journals)
Specific example of formal institutional arrangements

A tale of three (blind, obese, diabetic, epileptic…) mice engineering technologies….

…setting to explore impact of changes (negotiated by NIH) that allowed for both greater formal access (via JAX) and lower IP restrictions

Onco transgenic mouse technology

Cre-lox mouse technology

Knock-out mouse technology
EMPIRICAL APPROACH

- “Mouse-articles” - Sample of mice linked with specific scientific articles – Cre-lox, Onco, Knock-Out & Spontaneous (1983-98)
  - Mouse Genome Informatics (MGI) database catalogs over 13,000 mice & links each mouse to an original publication in a scientific journal – mouse-articles
  - Cre-Lox (52), Oncomouse (160), Knock-Out (2171), Spontaneous (255)

- Citations to mouse-articles in other scientific publications observed over time
  - PubMed for information about mouse-articles & ISI Web of Science SCI for citations

- “Shifts” to the openness of Cre (1998) & Onco (1999) mice – after their publication - but not to Knock-out or Spontaneous

=> observe the citation of mouse-articles in both the pre- and post-shift period and compare the use of “treatment” and “control” group

=> evaluate the impact of openness on the rate & nature of follow-on research
Analysis:
Effectiveness of Formal Institutions for Changing Access to Research Mice

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<tr>
<th>Neg. Binomial</th>
<th>Last Authors</th>
<th>Key Words</th>
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<td></td>
<td>Annual Citations with New Last Author</td>
<td>Annual Citations with Old Last Author</td>
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<tr>
<td>Post Shock</td>
<td>1.380***</td>
<td>1.14</td>
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</table>

*Conditional Fixed Effects for Article, Margin-Age and Margin-Calendar Year, Window Effects*

- The impact of institutional change concentrated in citations by “new” last authors and in papers using new key words
- Robust to “New Institution” v.“Old Institution”, Reprint Authors, Journals etc.

Murray, Aghion et al., 2009
Analysis: Results for Biological Resource Center Deposit

<table>
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<tr>
<th>Neg. Binomial Model</th>
<th>Dep. Var. Annual Forward Citations</th>
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<tr>
<td>Calendar Year FE</td>
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- Evidence for the positive impact of material deposit and lower cost open access on scientific accumulation

Furman & Stern 2008
## Analysis

Impact of stem cell policy changes (restricting formal institutions supporting access to cells & funding)

- Evidence for shift in entire collaborative structure in human embryonic stem cell research after government policy changes restrict access to cell lines through formal institutional arrangements & formal funding channels.

*Furman, Murray & Stern 2008*

<table>
<thead>
<tr>
<th>Author Type</th>
<th>No collaboration</th>
<th>US-only collaboration</th>
<th>US &amp; EU collaboration</th>
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<tbody>
<tr>
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<td>1.084 (0.203)</td>
<td>3.180 (1.781)**</td>
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<tr>
<td>US-Not Top 50</td>
<td>0.986 (0.228)</td>
<td>1.421 (0.235)**</td>
<td>5.137 (2.512)***</td>
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<td>Article FE</td>
<td>Y</td>
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<td>Age &amp; Year FE</td>
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414% Increase in International collaboration-based citations after policy
Conclusions

Formal collaboration requirements increasingly imposed to solve a set of problems for the scientific research community
- The speed
- The diversity of participants
- The breadth of follow-on paths pursued

These challenges have emerged because the informal institutional complex that traditionally supported the speed, diversity & breadth of scientific research are strained

Alternative response is re-designing institutions – emphasizing formal institutions allowing for rapid access to key research outputs & thus
- Speeding-up follow-on innovation
- Increasing diversity of participants by decreasing reliance on informal ties
- Increasing the breadth of follow-on paths pursued by limiting restrictions
Open Questions

Global Access to Scientific Knowledge

Can the shift from informal to formal institutional complex really bring global equity in participation?
Is collaboration still required at the emerging “margins” to jump start participation?
What are the strategies to get to the knowledge frontier with and without formal institutions?
Thank you!

Questions or comments?

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