Why Scientists Chase Big Problems/Hot Topics: Individual Strategy and Social Optimality

Yangbo Song[1] Jacob G. Foster[2] Carl T. Bergstrom[3]

[1] Department of Sociology, UCLA

[2] Department of Sociology, UCLA

[3] Department of Biology, University of Washington, Seattle

October 31, 2015

Motivation

Ideology: epistmically pure

VS

"Behind one door is tenure - behind the other is flipping burgers at McDonald's."

Copyright © 2003 David Farley, d-farley@ibiblio.org

Reality: epistemically sullied

Motivation

Given that scientists are epistemically sullied, how do the incentives created by contemporary scientific institutions affect their research effort allocation?

- One hot problem
  - Well-defined in scope, agreed to be important
  - Pull scientists away from other research
  - e.g. decoding DNA sequence
- Multiple scientists
  - Get credit if solve the hot problem
  - Must put aside day-to-day work in the process
- Winner-take-all game

Literature Review

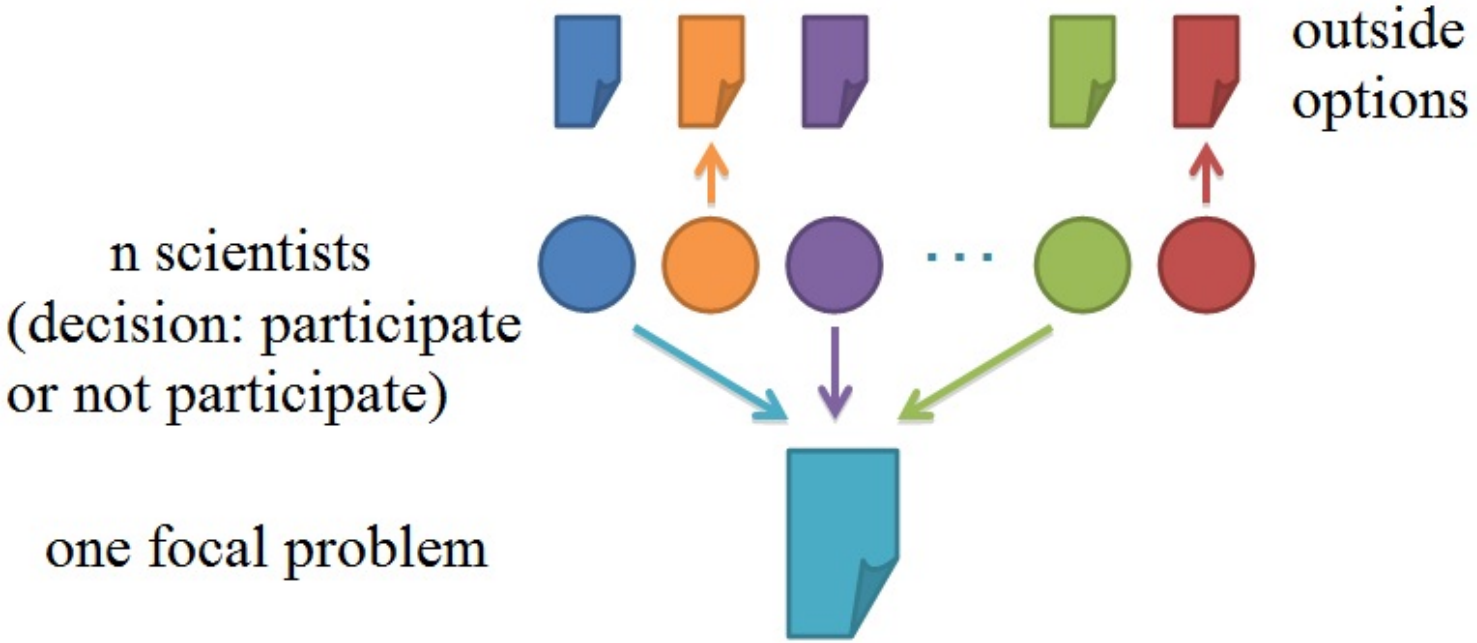
Confluence of prior streams

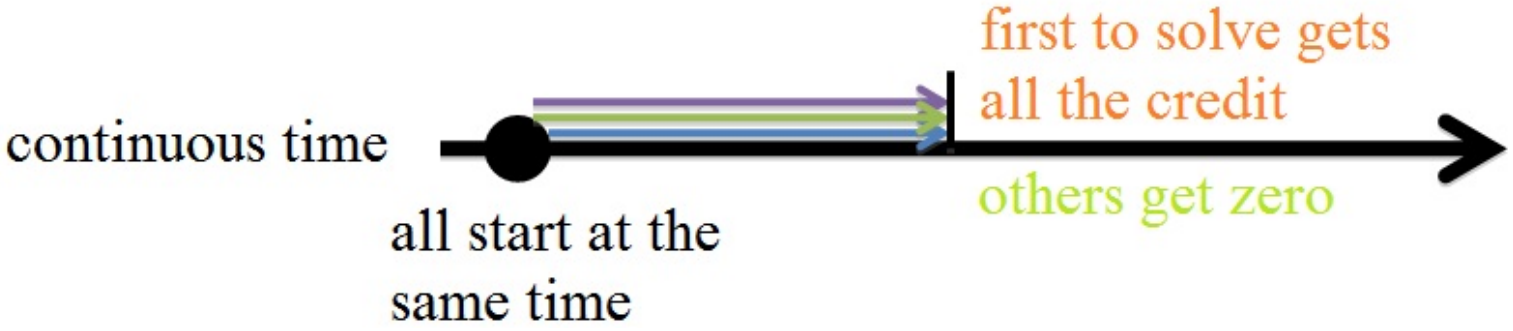
- Kitcher and Strevens; Oren and Kleinberg: cognitive labor allocation
- Lowry, Lee and Wilde, etc.: patent races
- Bourdieu, Latour, etc.: scientists as self-interested agents

Our contribution

- Introduce opportunity cost for scientists
- Predict unique equilibrium behavior
- Evaluate social consequence of "open science"

Credit Race Game





Credit Race Game

n scientists simultaneously decide whether to participate in a focal problem.

- Participation requires paying a **fixed cost** $F > 0$.
- Winner (solver of the problem) gets payoff $V > 0$. Everyone else gets 0.
- Scientist i has **scientific capital** of amount $h_i > 0$.
- Participation yields constant instantaneous probability of solution $\frac{h_i}{d}$, where $d > 0$ is the **difficulty** of the problem.
- The **time to solution** τ the satisfies $Prob(\tau \leq t) = 1 - e^{-\frac{\sum h_i}{d} t}$, and probability that scientist j wins is $\frac{h_j}{\sum h_i}$.
- **Outside option** pays off in credit at rate $h_i x$, $x > 0$.

Credit Race Game

Where I' is the set of scientists who pursue the problem, expected payoff U_i to scientist i of pursuing the problem is

$$U_i(I', h_i, h_{I'-i}) = V\frac{h_i}{h_{I'}} - h_i\, x\frac{d}{h_{I'}} - F$$

Reward

Chance of winning

Opportunity cost

Expected duration

Cost of entry

Nash Equilibrium

A Nash equilibrium of the credit race game is a subset I^* of scientists such that those in I^* and no others do better to pursue the focal problem rather than their outside options.

Every participant does better to stay in

$$U_i(I^*, h_i, h_{I^*-i}) \geq 0 \text{ for every } i \in I^*$$

$$U_j(I^* + j, h_j, h_{I^*}) \leq 0 \text{ for every } j \notin I^*$$

Every non-participant does better to stay out

Example

Mysterious symbols are found in Paleolithic cave art. Paleolinguists Alice (full professor), Bob (assistant professor), and Carol (postdoc) could drop everything and try to decode them.

- Captical: $h_A = 10, h_B = 5, h_c = 4$
- Value $V = 20$, difficulty $d = 5$, fixed cost $F = 4$, opportunity cost $x = 1$

There are two NEs:

	$U(Alice)$	$U(Bob)$	$U(Carol)$
$\{Alice, Bob\}$	6	1	(-0.84)
$\{Alice, Carol\}$	6.71	(-0.05)	0.29

Can they be compared in any way?

Risk Dominance

Answer: yes – by **risk dominance**.

- NE 1 risk dominates NE 2 if agents suffer more from making the wrong move (e.g. play NE 2 action while everyone else plays NE 1 action)
- If there is a NE that risk dominates every other NE, then it is **risk dominant**.
- In the example, the unique risk dominant NE is $\{Alice, Bob\}$.

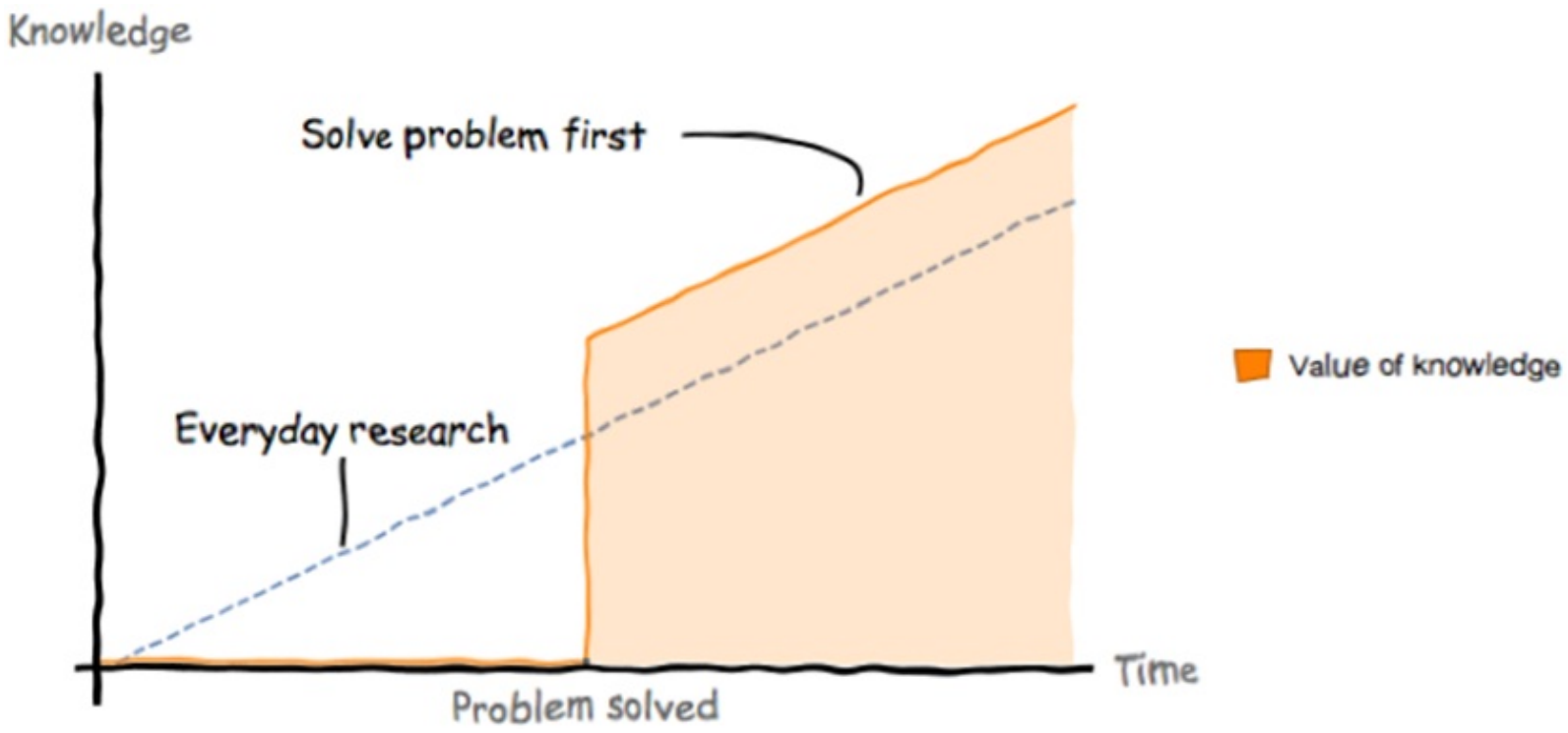
Proposition 1

A unique risk dominant Nash equilibrium exists.

In this equilibrium, **top researchers chase hot topics**: only the scientists with the highest scientific capital pursue the problem and all others opt out.

Flow of Knowledge

We view both everyday research and solution to the problem as generating **flows of knowledge**.



Social tradeoff: forgone everyday research before solution vs. higher flow after solution

Discounted Welfare Function

Suppose that solving the problem generates a flow of $\hat{V} > 0$. Let $\hat{x}$ be the social opportunity cost per unit scientific capital, $\hat{F}$ be the social startup cost per scientist, and r be the exponential discount rate. The social welfare when scientists $\{1, 2, \cdots, i\}$ with total capital H_i work on the hot problem is

$$W(i) = \underbrace{\frac{\hat{V}}{r}\frac{H_i}{H_i + r\,d}}_{\text{Discounted Reward}} - \underbrace{\hat{x}\,d\frac{H_i}{H_i + r\,d}}_{\text{Discounted opportunity cost}} - \underbrace{i\,\hat{F}}_{\text{Cost of entry for } i \text{ scientists}}$$

Equilibrium vs Efficiency

Proposition 2

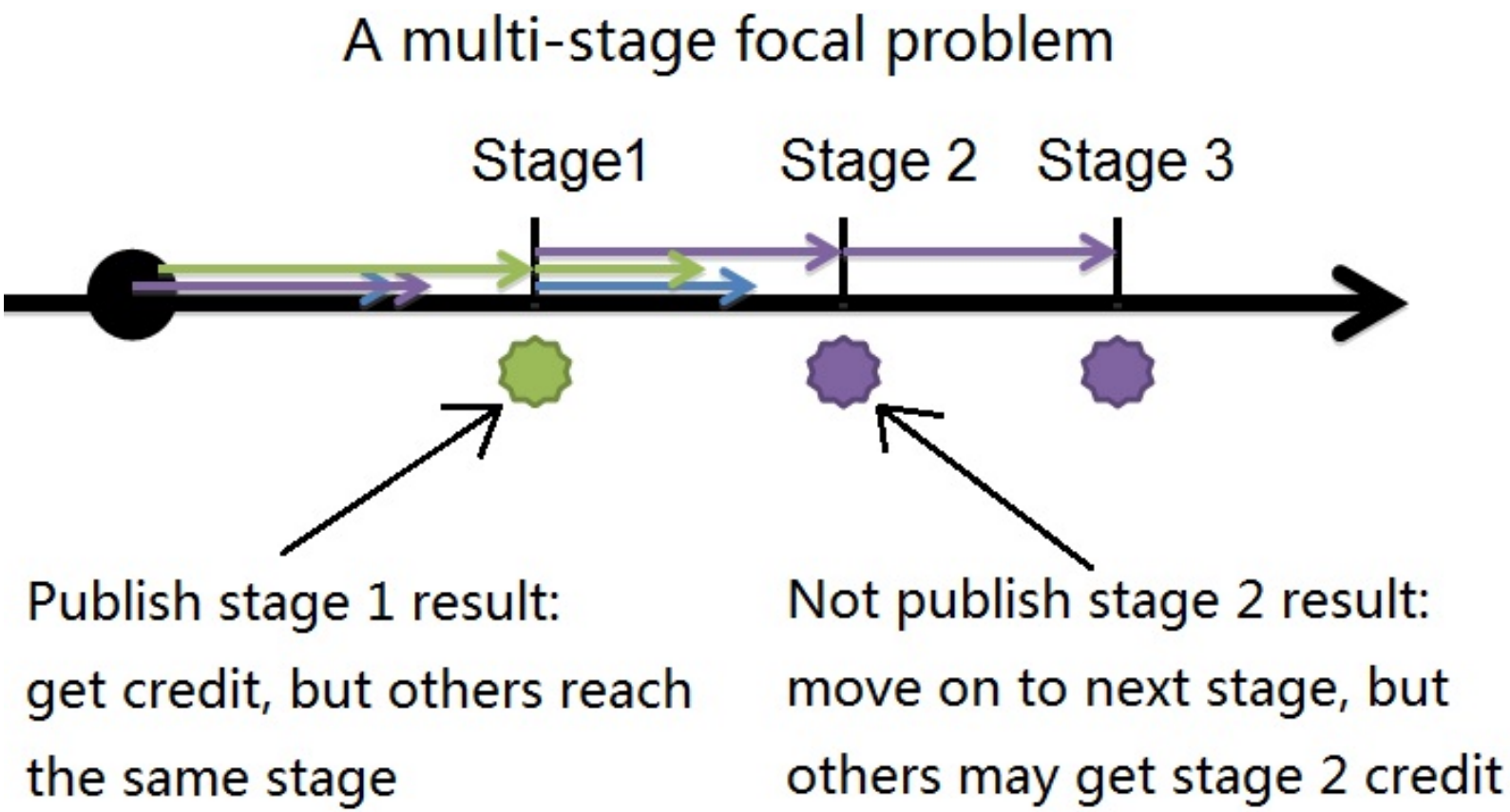
There is a unique social optimum, in which the i_e scientists with the highest scientific capital work on the hot problem and the rest opt out.

In the risk dominant NE, both **over-participation** (more scientists opt in than social optimum) and **under-participation** (less scientists opt in than social optimum) are possible. Two key factors:

- Attractiveness of problem: $\frac{\frac{\hat{V}}{r} - \hat{x}d}{\hat{F}}$ (social)/$\frac{V - xd}{F}$ (game)
- Relative importance of scientist: $\frac{h_i}{(h_i + H_{i-1} + dr)(1 + \frac{H_{i-1}}{dr})}$ (social) $/\frac{h_i}{H_i}$ (game)

Publication of Partial Results

One huge difference between academic credit races and patent races is that academic researchers often find it worthwhile to publish partial results.



Public Sharing Equilibrium

A **public sharing equilibrium (PSE)** is an equilibrium in which all participants publish immediately upon solving any stage.
Suppose that the sub-problem at stage m has value V_m, difficulty d_m and requires fixed cost F_m.

Proposition 3

A unique risk dominant PSE exists if for each consecutive pair of stages m and m',

$$\text{For any } i,\ \frac{V_m h_{I_m^*-i}}{d_m} - \frac{h_i}{d_{m'}}\left(\frac{V_{m'} h_{I_{m'}^*-i}}{h_i + h_{I_{m'}^*-i}} + \frac{x d_{m'} h_i}{h_i + h_{I_{m'}^*-i}}\right) \geq 0,$$

where $I_m^* = \{1, 2, \cdots, \max\{i : V\frac{h_i}{\sum_{j=1}^{i} h_j} - h_i\, x\frac{d_m}{\sum_{j=1}^{i} h_j} - F_m \geq 0\}\}$.

Public Sharing Equilibrium

A researcher will publish partial results when

- When a (solved) stage is relatively valuable or easy
- When there are many competitors and/or competitors with high scientific capital
- When she has low scientific capital
- When the opportunity cost is low

Social Consequence of Open Science

Example: two scientists may attempt a two-stage problem.

- Value: $V_1 = 60, V_2 = 30$ (for scientists), $\hat{V} = 100$ (flow for society); difficulty: $d_1 = d_2 = 15$
- Cost: $x = \hat{x} = 1$, $F_1 = \hat{F}_1 = 1$, $F_2 = \hat{F}_2 = 6$
- Scientific capital: $h_1 = 10, h_2 = 6$

Unique PSE of this game:

- Both scientists attempt stage 1. Whichever solves it first publishes immediately.
- Regardless of who solved stage 1, only scientist 1 attempts stage 2.
- **Expected social welfare is** 51.03**.**

If partial progress sharing is not allowed:

- Both scientists attempt the entire problem.
- **Expected social welfare is** 55.28**!**

Social Consequence of Open Science

Contrary to conventional wisdom,

Proposition 4

Allowing partial progress sharing does not necessarily accelerate the rate at which a hot problem is solved.

- Holding the set of participants constant, partial progress sharing would accelerate solution.
- However, participation is a strategic decision.
- The institution of partial progress sharing allows scientists to drop out after working only on early stages.

Future Research Directions

Problems of unknown difficulty

- Why scientists give up on a problem
- Strategic informational issues around non-publication

Policy implications

- How do alternative forms of credit allocation influence scientists behavior?
- What can a govt. agency do to shift scientists efforts toward social optimum?
- Fund direct research to increase relevant capital?