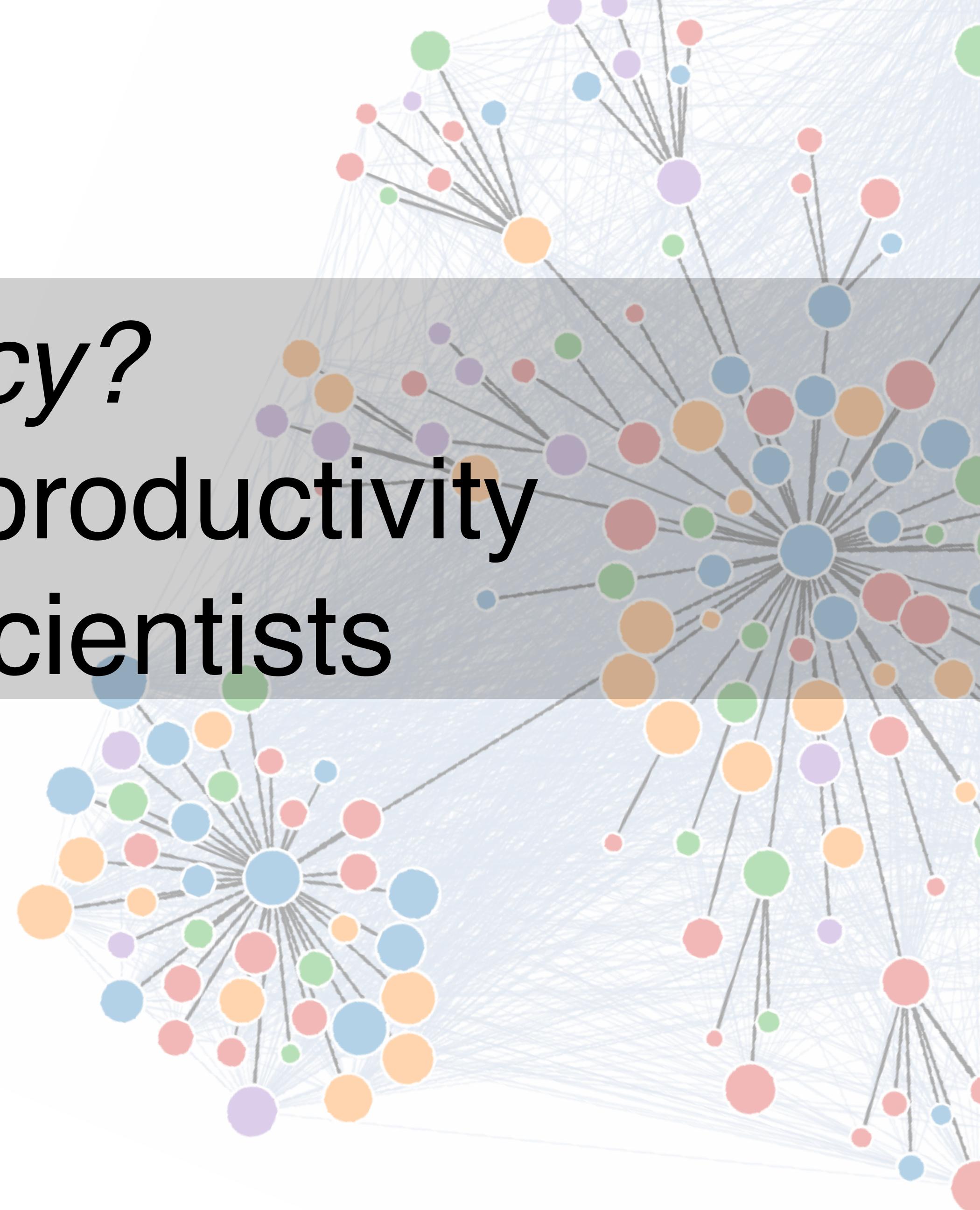


How much of a meritocracy?

Untangling the drivers of productivity and prominence among scientists

Aaron Clauset
@aaronclauset
Professor
Computer Science Dept. & BioFrontiers Institute
University of Colorado, Boulder
External Faculty, Santa Fe Institute



science is not a meritocracy

science is not a meritocracy

good ideas do not always win out over mediocre ones



science is not a meritocracy

good ideas do not always win out over mediocre ones



15 years of Alzheimer's research on A β oligomers

BLOTS ON A FIELD?

A neuroscience image sleuth finds signs of fabrication in scores of Alzheimer's articles, threatening a reigning theory of the disease *By Charles Piller*

Science 377, (2022)

science is not a meritocracy

good ideas do not always win out over mediocre ones



BLO
A neuroscience in
articles, thr

Science 377, (20

The Dunning-Kruger Effect Isn't What You Think It Is

The least skilled people know how much they don't know, but everyone thinks they are better than average

By Eric C. Gaze, The Conversation US on May 23, 2023

Scientific American (2023) statistical artifact and sampling bias

science is not a meritocracy

good ideas do not always win out over mediocre ones



The image displays two side-by-side scientific journal articles from the early 20th century. The left article is from 'Science' (vol. 377, 2019) and the right is from 'Nature' (vol. 70, 1904). Both articles discuss controversial topics where good ideas did not immediately prevail.

Science Article (Left):

- Title:** The Discovery of Polywater
- Abstract:** Vibrational spectra indicate unique stable polymeric structure.
- Authors:** Ellis R. Lippincott, Robert R. Stromberg, Warren H. Grant, Gerald L. Cessac
- Journal:** Science 164 (1969)
- Notes:** statistical artifacts and dirty samples

Nature Article (Right):

- Title:** The *n*-Rays
- Author:** R. W. WOOD
- Published:** 29 September 1904
- Journal:** Nature 70, 530–531 (1904) | [Cite this article](#)

science is not a meritocracy

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poor experimental design & causal misinterpretations

A thumbnail image of a Science magazine cover. The title 'BLOCKBUSTERS' is partially visible at the top. Below it, the text 'The D...' is visible. A dark sidebar on the left contains the text 'A neuroscience in articles, thr...' and 'Science 377, (20...'. The main text area has 'The least skilled pe...' and 'Vibrational spectra in...'.

Science 377, (20

The least skilled pe

Vibrational spectra in

Scientific America

Power Posing: Brief Nonverbal Displays Affect Neuroendocrine Levels and Risk Tolerance

Psychological Science 21 (2010)

Dana R. Carney¹, Amy J.C. Cuddy², and Andy J. Yap¹

¹Columbia University and ²Harvard University

is article

Ellis R. Lippincott, Robert R. Stromberg,

Warren H. C

Science 164 (1969)

Female hurricanes are deadlier than male hurricanes

Kiju Jung^{a,1}, Sharon Shavitt^{a,b,1}, Madhu Viswanathan^{a,c}, and Joseph M. Hilbe^d

PNAS 111 (2014)

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A screenshot of a news article from Scientific American. The title reads "BLO The D" and the subtitle "An Sce". The main headline is "Power Posing: Brief Nonverbal Displays Affect Neuroendocrine Levels and Risk Tolerance".

Power Posing: Brief Nonverbal Displays Affect Neuroendocrine Levels and Risk Tolerance

these are "epistemic inefficiencies"

¹Columbia University and ²Harvard University

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the best scientists are not reliably recognized



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the best scientists are not reliably recognized



HISTORY OF INNOVATION

Who do we invent for? Patents by women focus more on women's health, but few women get to invent

Rembrand Koning^{1*}, Sampsa Samila², John-Paul Ferguson³

Science 372 (2021)

WHO BECOMES AN INVENTOR IN AMERICA?
THE IMPORTANCE OF EXPOSURE TO INNOVATION*

ALEX BELL
RAJ CHETTY
XAVIER JARAVEL
NEVIANA PETKOVA
JOHN VAN REENEN

The Quarterly J. Economics (2019)

* "Lost Einsteins" paper

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The Diversity–Innovation Paradox in Science

Bas Hofstra^{a,1}, Vivek V. Kulkarni^b, Sebastian Munoz-Najar Galvez^a, Bryan He^b, Dan Jurafsky^{b,c},
and Daniel A. McFarland^{a,1}

cognitive & identity diversity correlate with innovative concepts

PNAS 117 (2020)

* "Lost Einsteins" paper

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HISTORY OF INNOVATION

Who do we invent for? Patents by women focus more

WHO BECOMES AN INVENTOR IN AMERICA?

ON*

social biases

drive epistemic inefficiencies

Bas Hofstra^{a,1}, Vivek V. Kulkarni^b, Sebastian Munoz-Najar Galvez^a, Bryan He^b, Dan Jurafsky^{b,c}, and Daniel A. McFarland^{a,1}

NEN

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PNAS 117 (2020)

science is not a meritocracy

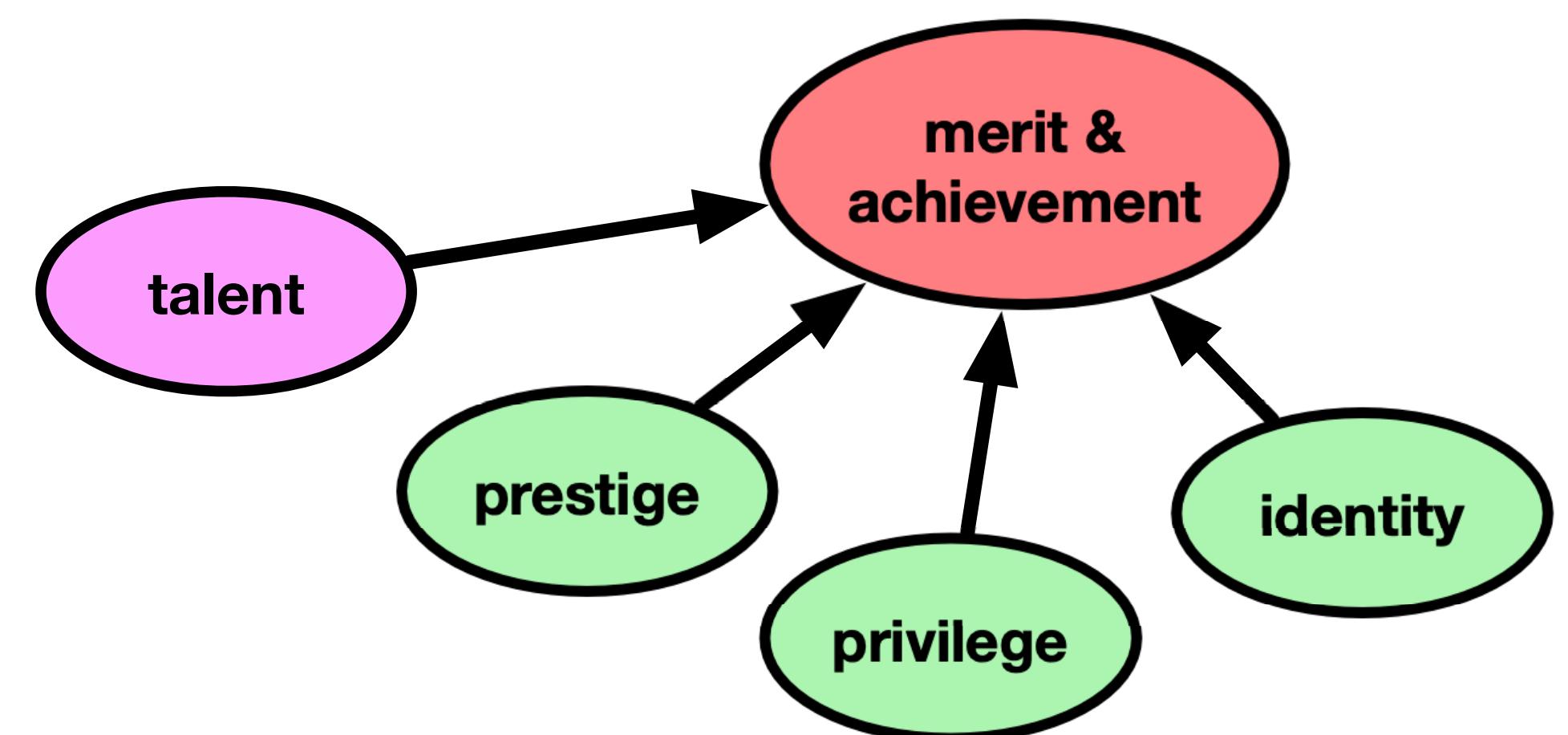
good ideas do not always win out over mediocre ones

the best scientists are not reliably recognized

because "merit" is entangled with social factors like **prestige**, **privilege**, and **identity**

untangling the effects of social biases can make science better and *more* meritocratic

we can study these epistemic inefficiencies scientifically



science is not a meritocracy

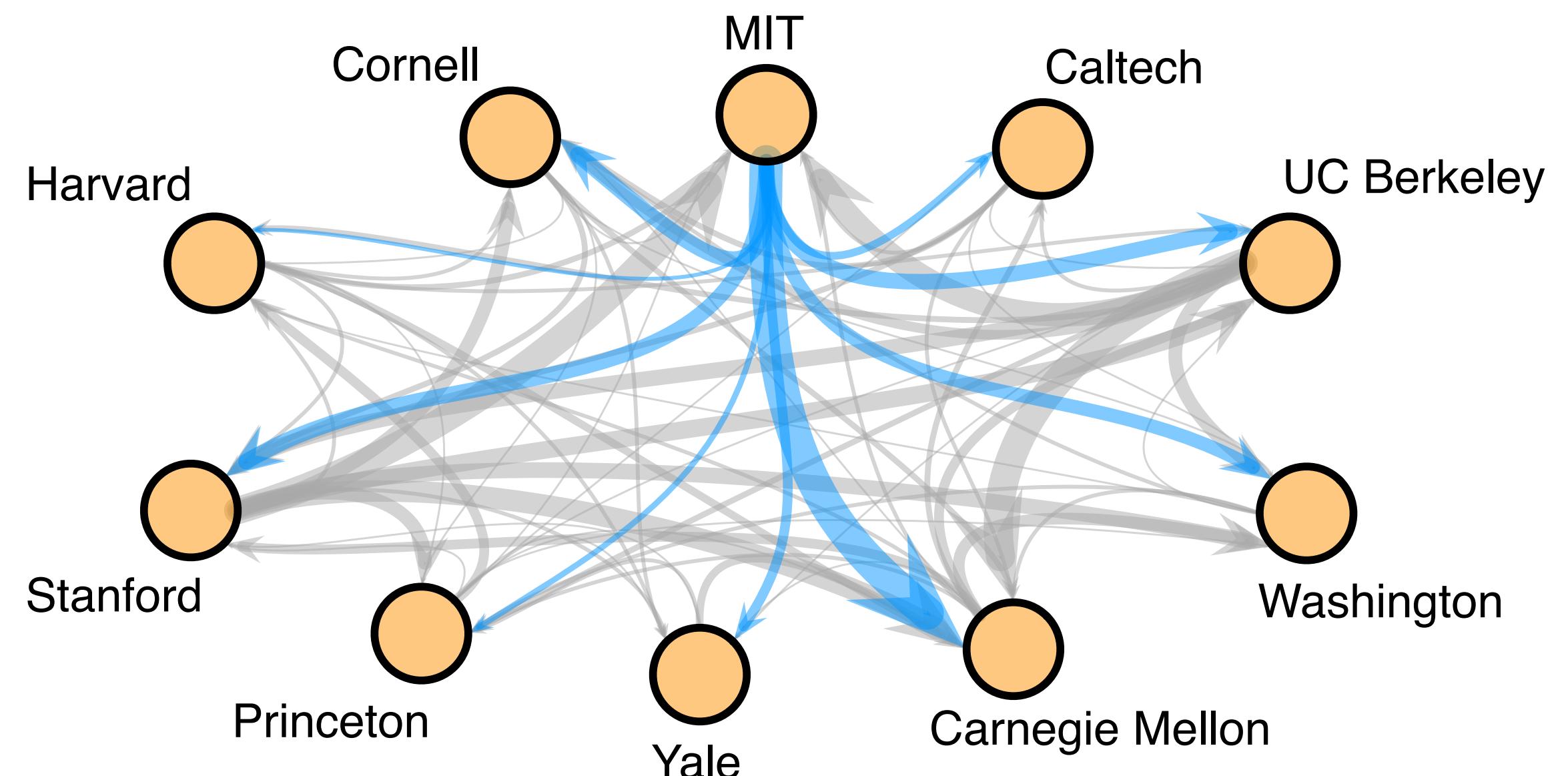
- who *hires* whose graduates as faculty?  [jobs]
- what *drives* scientific productivity and prominence?  [ideas]
- how important is *who* you work with?  [connections]

who hires whose graduates as faculty?

faculty are special → produce new discoveries & train new scientists



faculty hiring is a *network* → what does its shape tell us about academia?



who hires whose graduates as faculty?

faculty are special → produce new discoveries & train new scientists



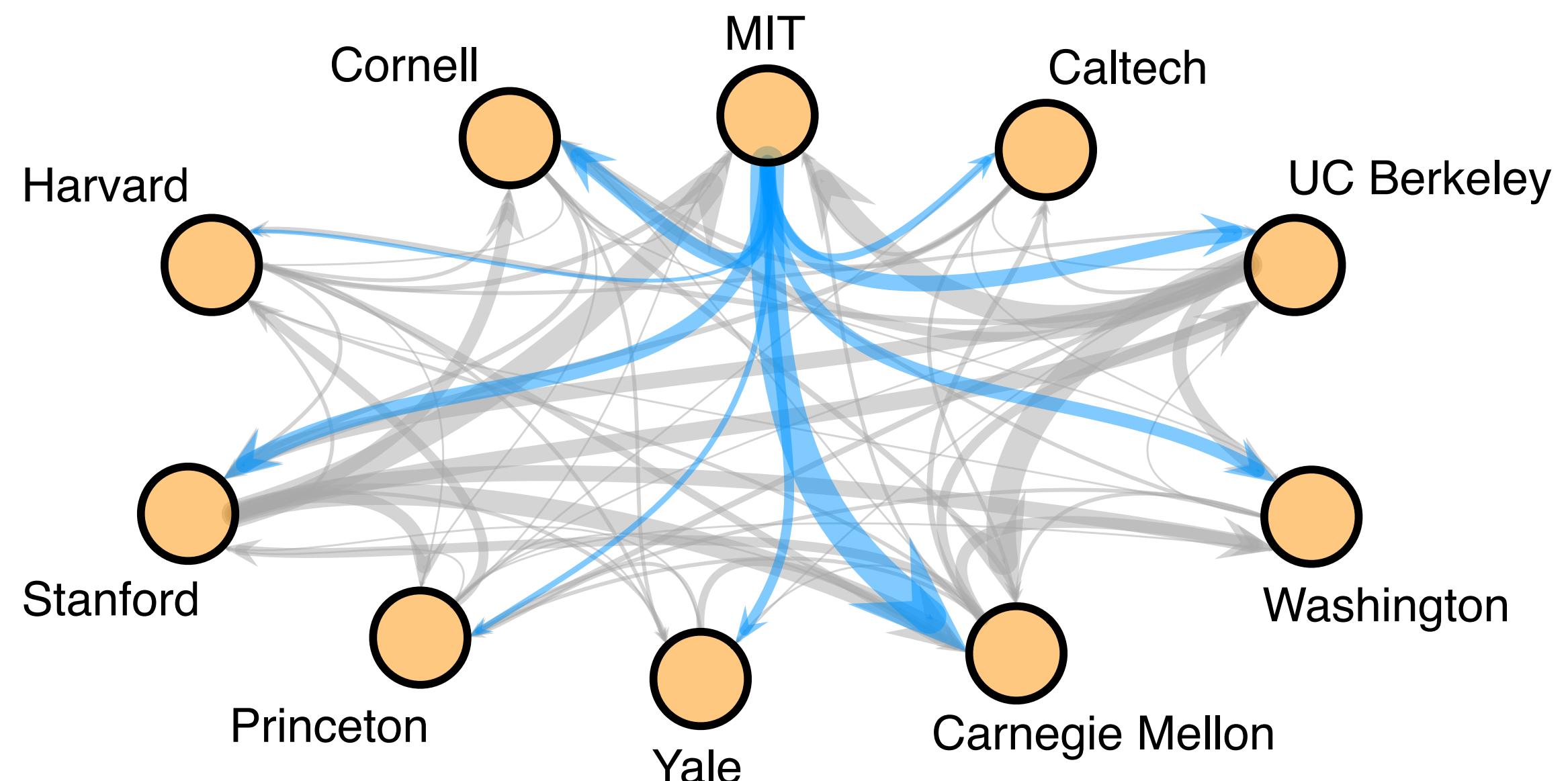
faculty hiring is a *network* → what does its shape tell us about academia?

AARC

census-level data on education and placement of 291,123 regular faculty at 10,612 PhD-granting departments across 86 fields, 2011 – 2020

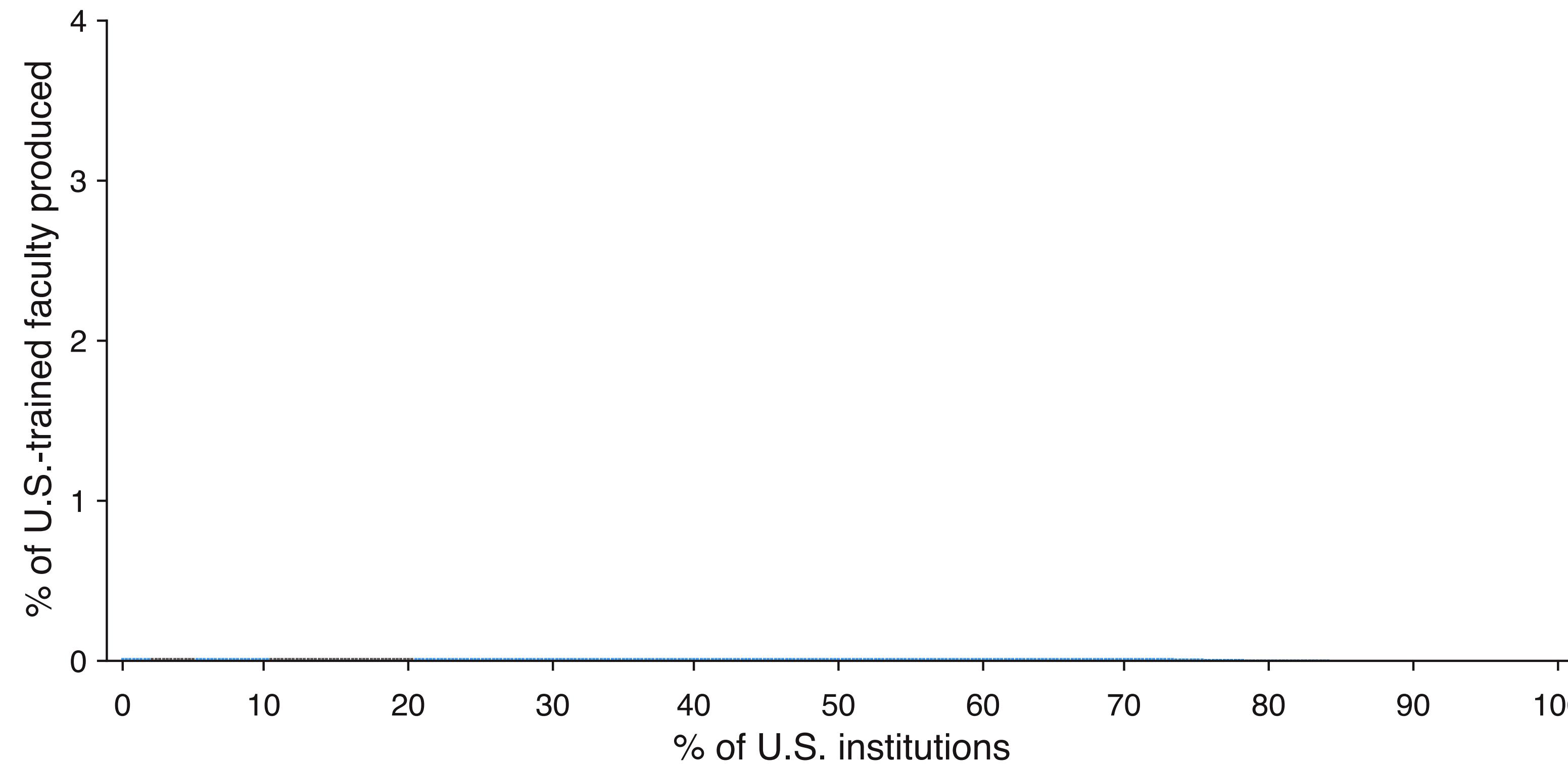


- ▶ how much does doctoral *prestige* matter?
- ▶ what implications for spread of ideas?



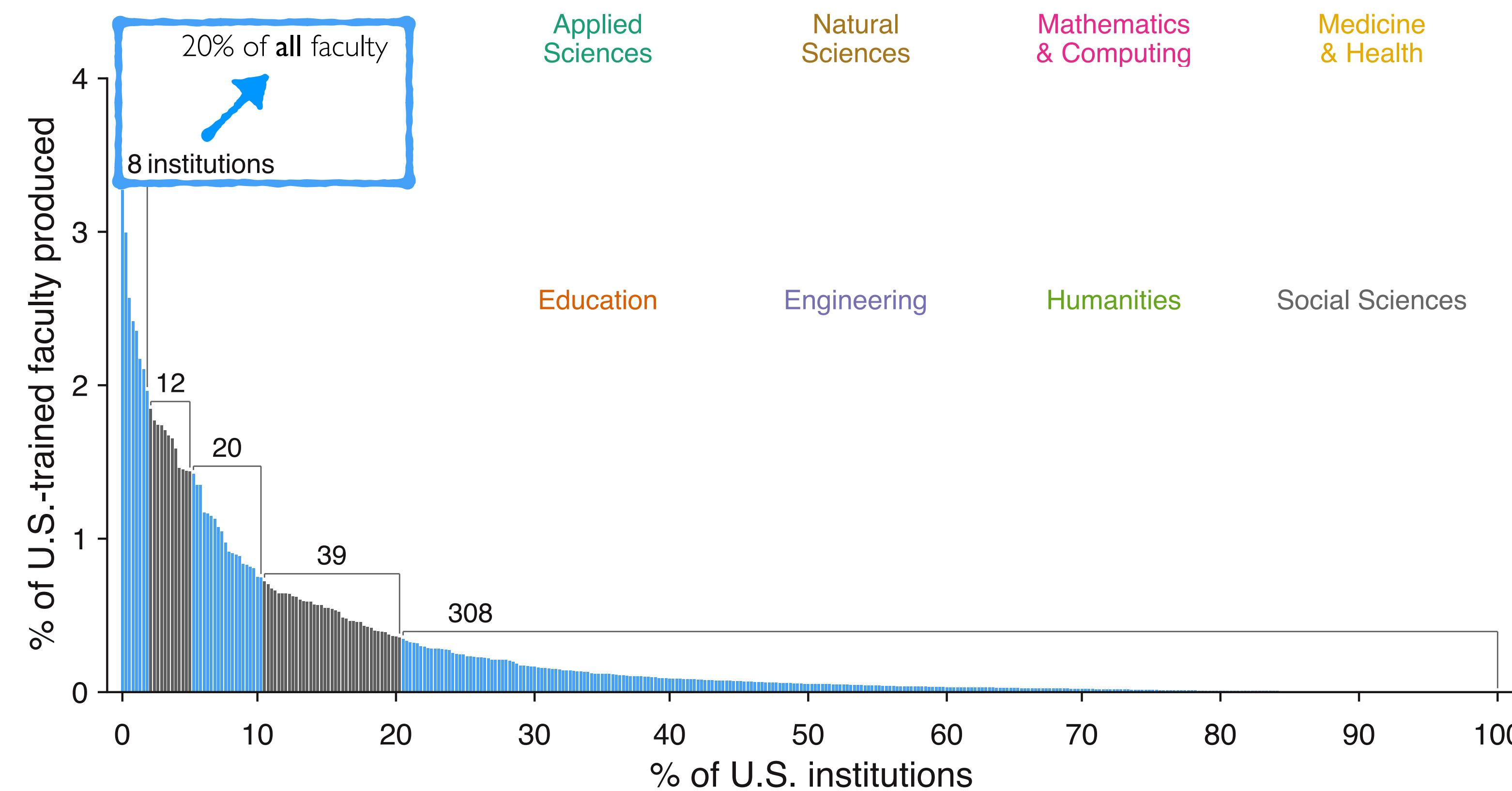
who hires whose graduates as faculty?

- ▶ sort 387 institutions by overall production of faculty



who hires whose graduates as faculty?

- ▶ faculty production is enormously *concentrated*



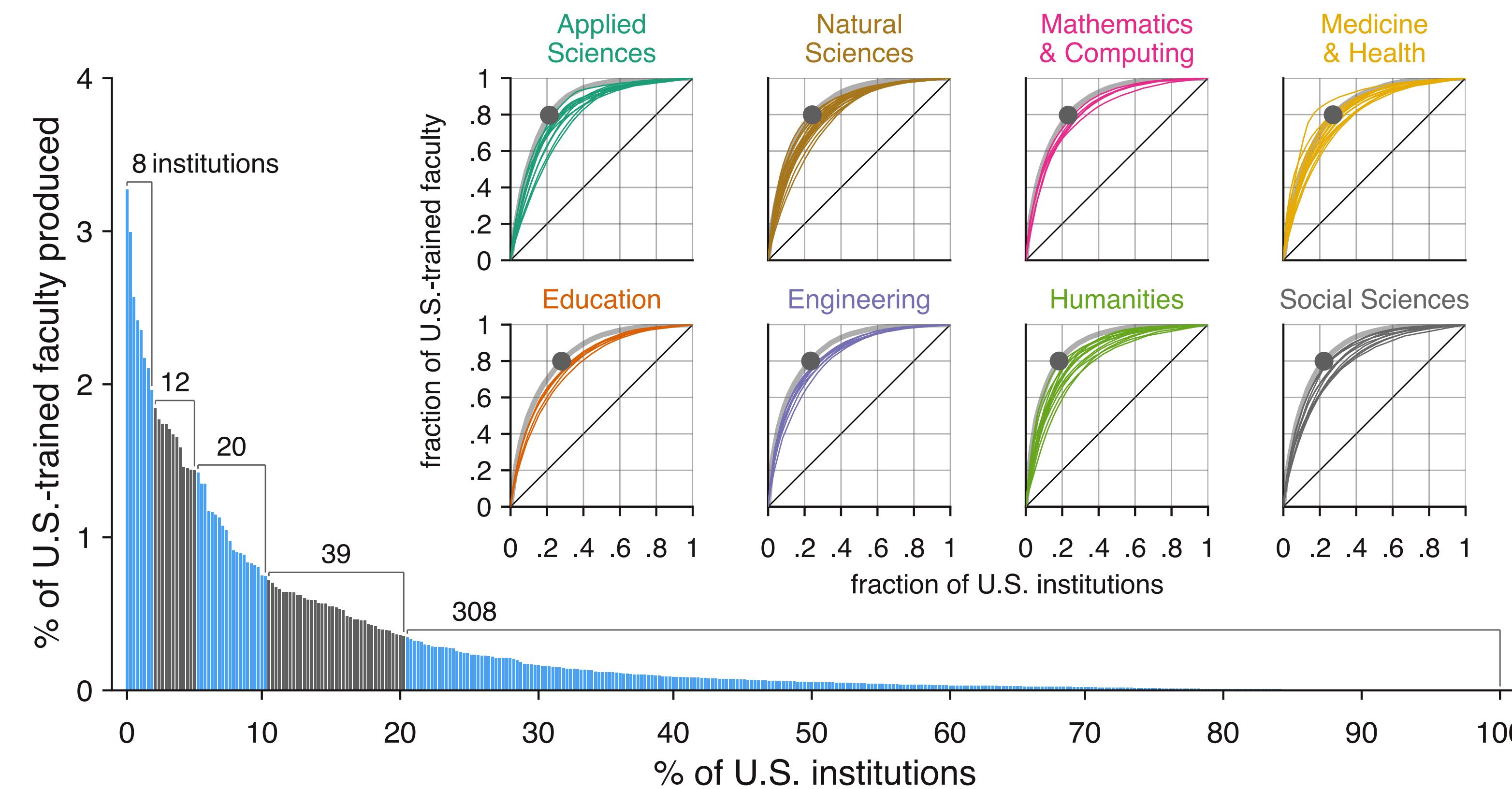
all-academia Gini = 0.75

the top 8: Berkeley, Harvard, Michigan, Wisconsin, Stanford, UIUC, MIT, UT Austin (note that only 3 of the 8 are private)

Wapman et al., "Quantifying hierarchy and dynamics in US faculty hiring and retention" (2022)

who hires whose graduates as faculty?

- ▶ faculty production is enormously *concentrated*
- ▶ recapitulated in all 86 fields (a roughly universal "80-20 rule")



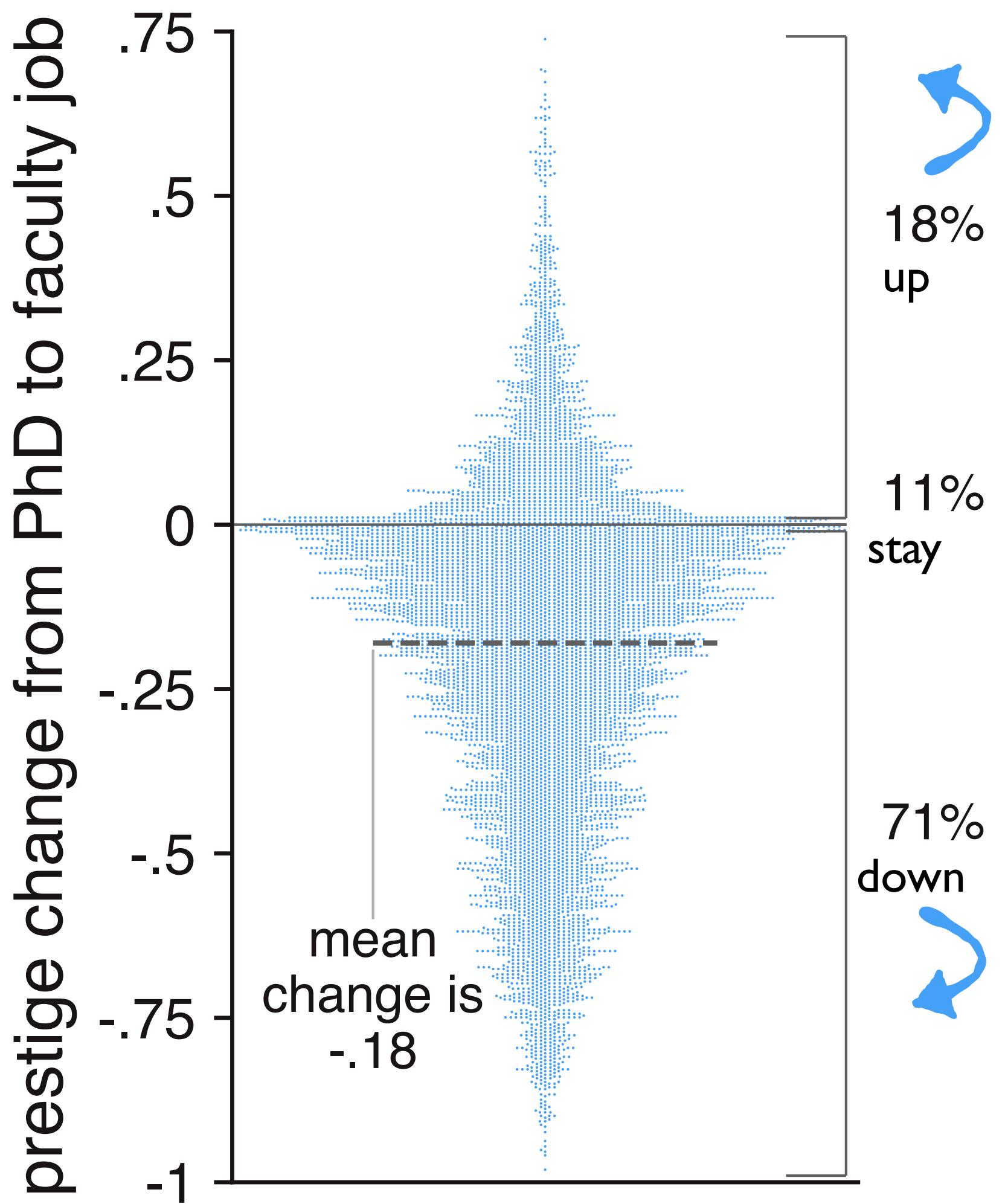
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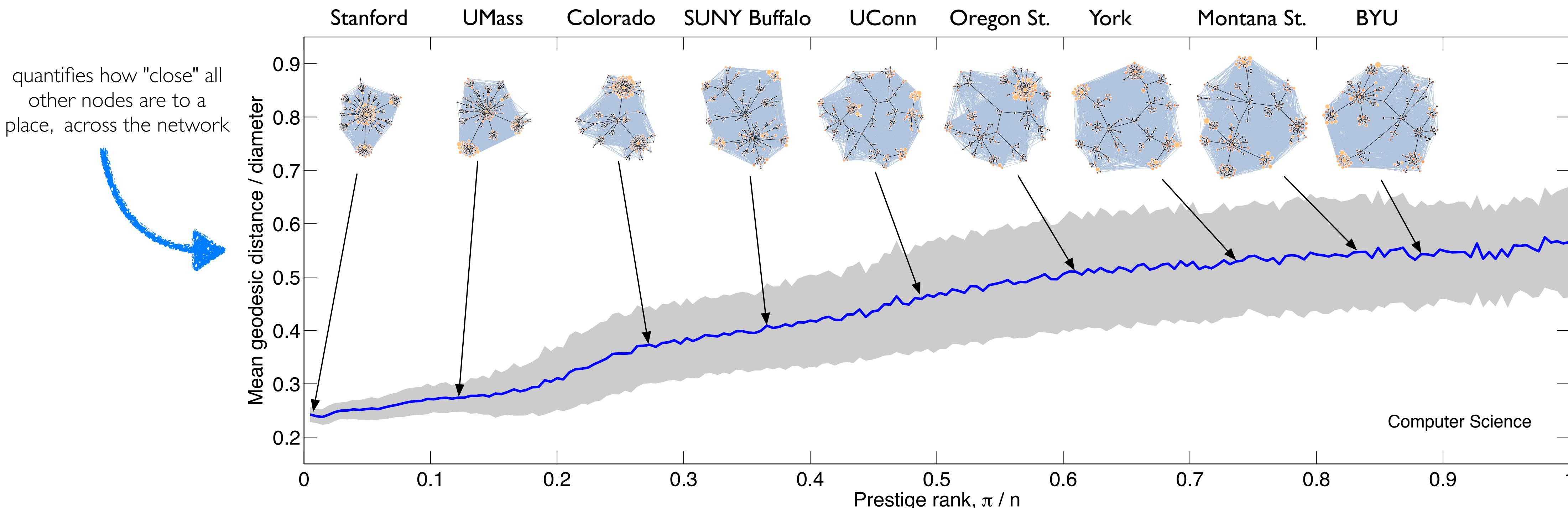
who hires whose graduates as faculty?

- ▶ prestige hierarchies are steep
- ▶ faculty placement mostly "down" (71%)
only 18% (mean) move "up"
- ▶ only 20% of departments have trained
more faculty than they've hired



who hires whose graduates as faculty?

hiring network has a core and periphery : high ranked nodes are more central

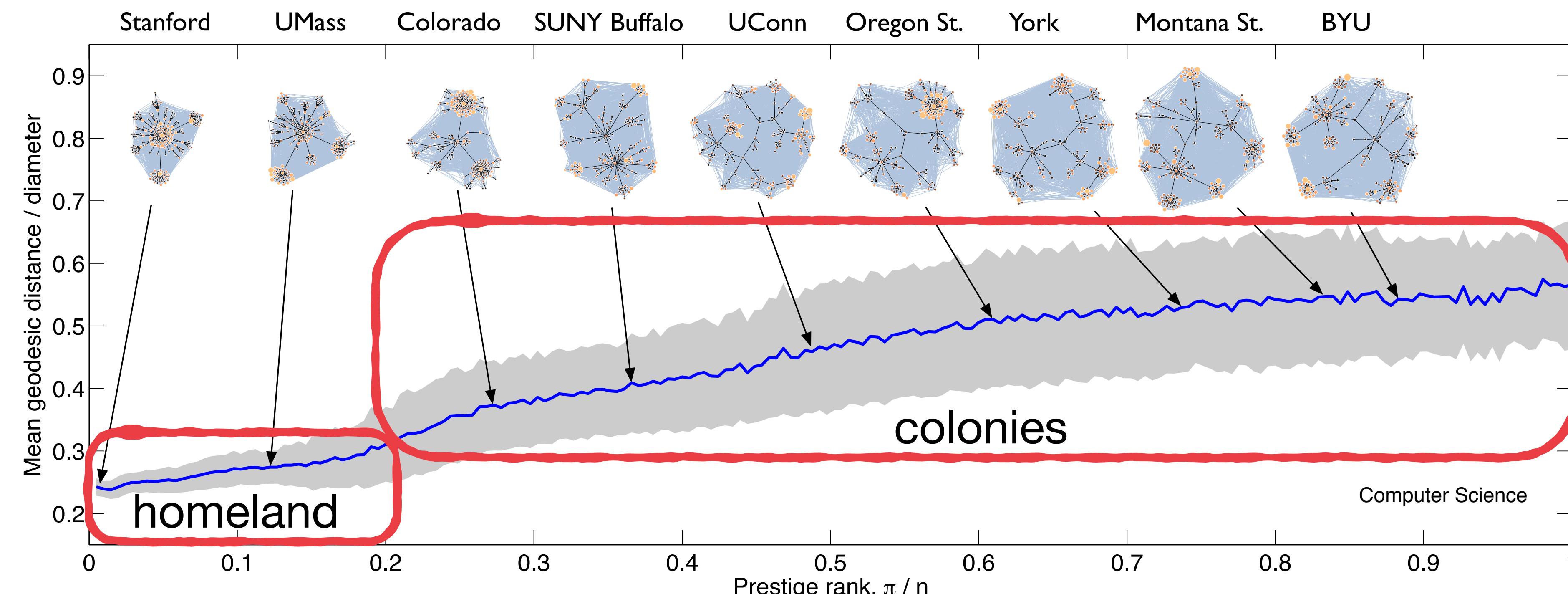


who hires whose graduates as faculty?

hiring network has a ~~core and periphery~~: high ranked nodes are more central

prestige → *influence* via doctoral placement

over research agendas, research communities, and departmental norms across a field



who hires whose graduates as faculty?

- ▶ prestige is a *structural variable* in the science of science
- reveals *core-periphery* structure of academia

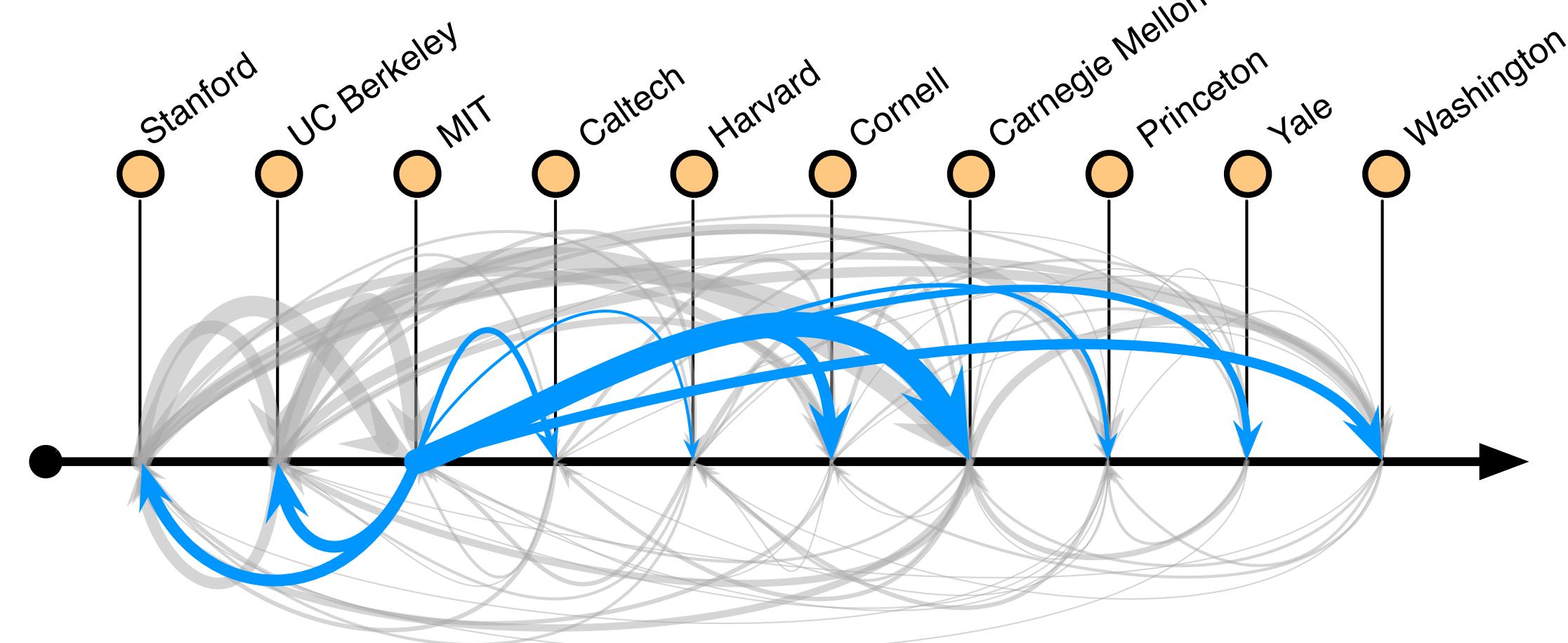
faculty flow from core → periphery ("the colonies")

modest fraction stays inside core ("homeland")

small fraction flows "upstream"

these hierarchies extremely stable over time*

- prestige → faculty production → hierarchy



* see Lee et al. "The dynamics of faculty hiring networks" (2022)
one might argue that these strong prestige hierarchies reflect true meritocratic differences, but I think that's a hypothesis that needs to be proved, rather than disproved

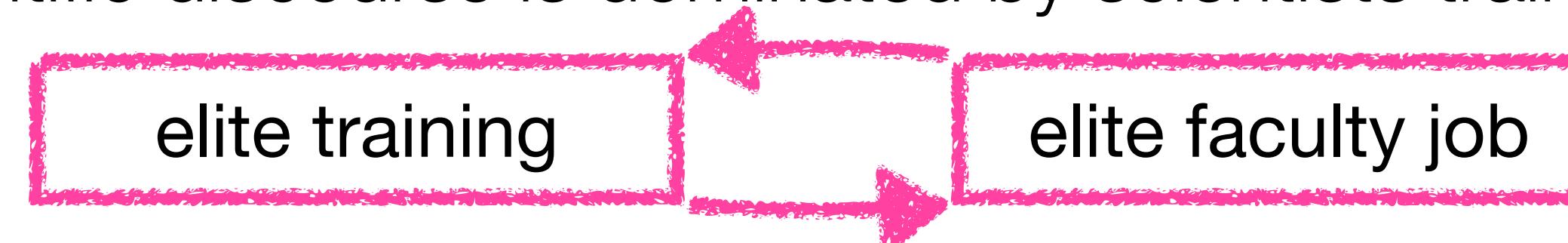
what drives productivity and prominence?

- ▶ scientific discourse is dominated by scientists trained + working at elite programs

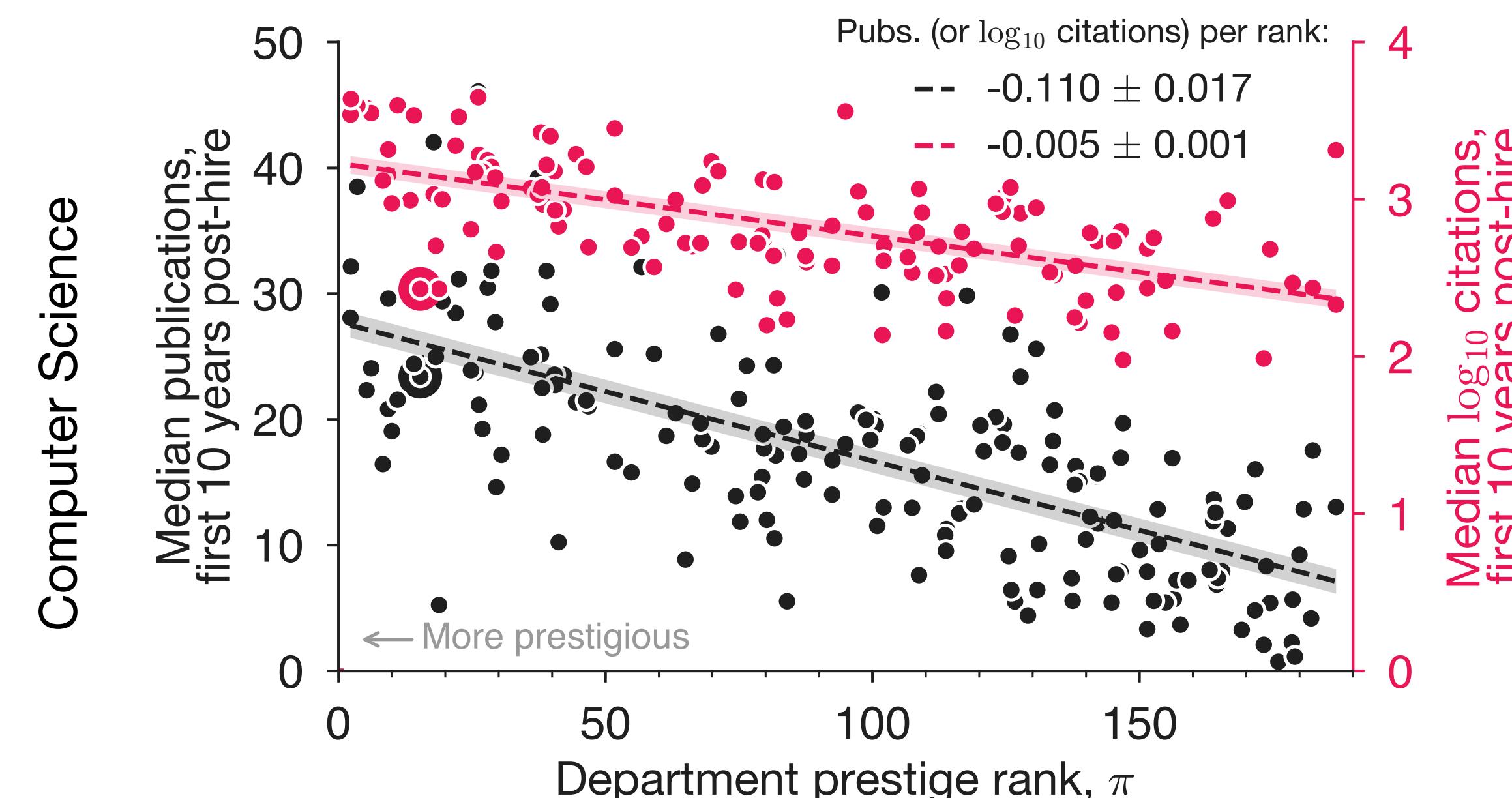
what drives productivity and prominence? 🧙

- ▶ scientific discourse is dominated by scientists trained + working at elite programs

but



endogenous cumulative advantage → past achievements correlate with future achievements



what drives productivity and prominence?

- ▶ scientific discourse is dominated by scientists trained + working at elite programs
- two possibilities explain this correlation
- idea 1: where a scientist trained.

what drives productivity and prominence?



- ▶ scientific discourse is dominated by scientists trained + working at elite programs

two possibilities explain this correlation

idea 1: where a scientist trained.

- skill, talent, training, temperament, etc.
- faculty hiring sorts people by their natural potential for good outcomes
- e.g., most productive scientists have elite pedigree, Harvard, Yale, Penn, Stanford, etc.

where you **train** causes future productivity and prominence

what drives productivity and prominence?

- ▶ scientific discourse is dominated by scientists trained + working at elite programs
- two possibilities explain this correlation
- idea 2: where a scientist works.

what drives productivity and prominence?

- ▶ scientific discourse is dominated by scientists trained + working at elite programs
two possibilities explain this correlation

idea 2: where a scientist works.

- environmental factors, resources, people, support
- beyond a basic training, a scientist's output is driven by local environment
- e.g., moving from poor to rich environments improves output, and vice versa

where you work causes future productivity and prominence

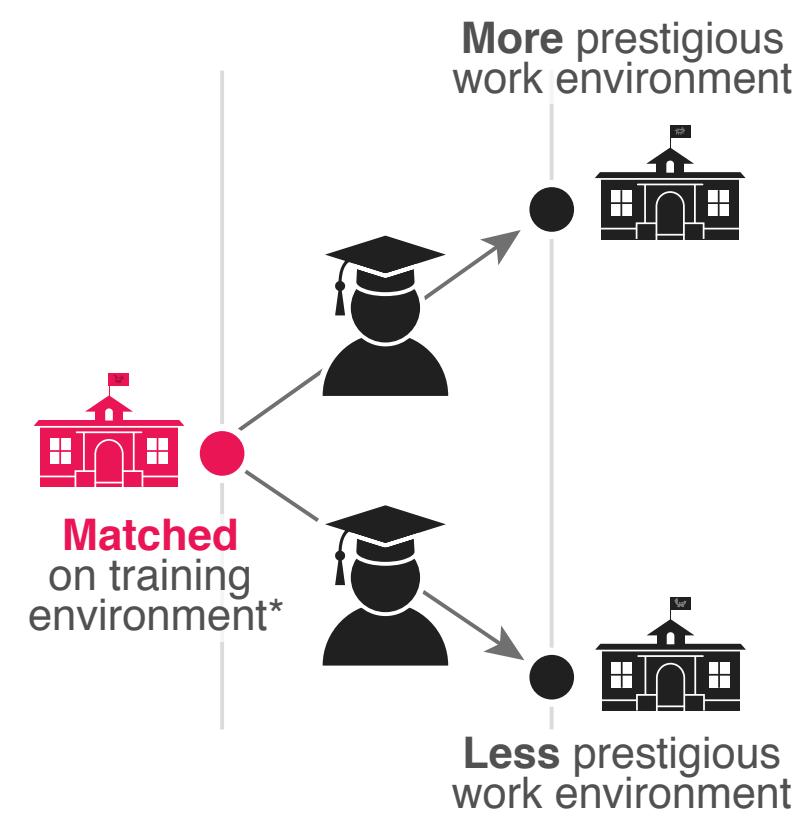


what drives productivity and prominence?

a test: faculty hiring is a quasi-natural experiment

2,453 early career CS faculty hires, and their 200,000 publications & 7.4M citations

match faculty pairs on *similar training, different placement*

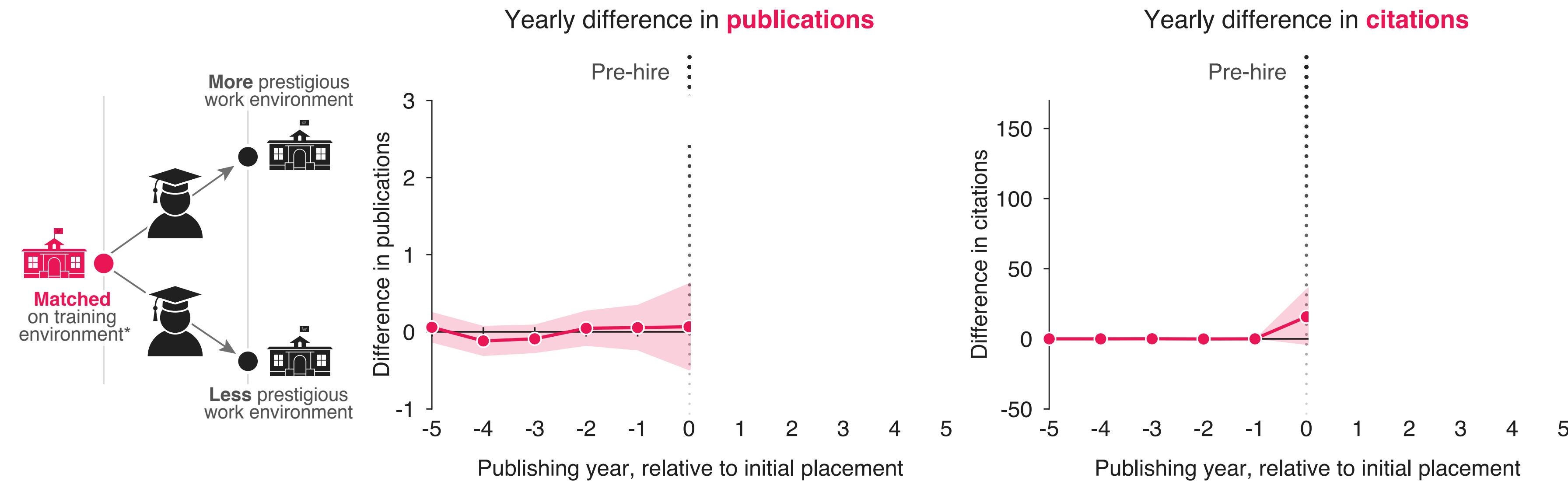


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caliper matched faculty on {gender, subfield, hiring prestige OR phd prestige, year of placement, postdoctoral training}. results robust to caliper variations

publications: N = 196 pairs, p < 0.005 (t-test); citations: N = 96 pairs, p < 0.005 (t-test)

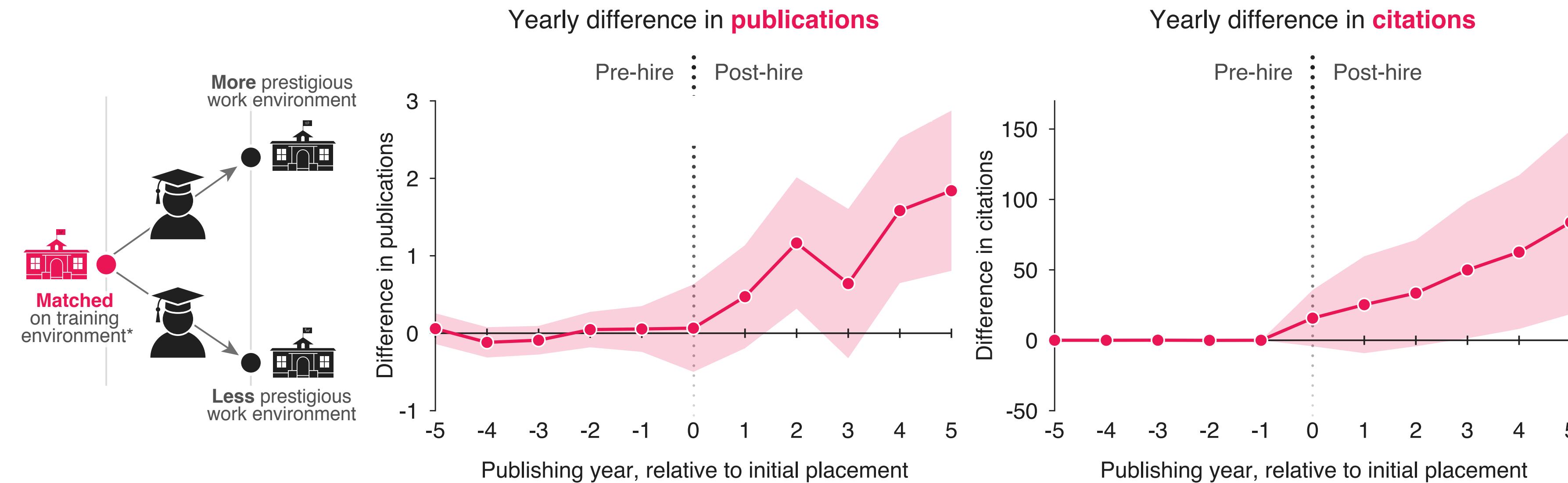
Way et al. "Productivity, prominence, and the effects of academic environment" (2019)

what drives productivity and prominence?

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match faculty pairs on similar training, different placement → *different productivity & prominence*



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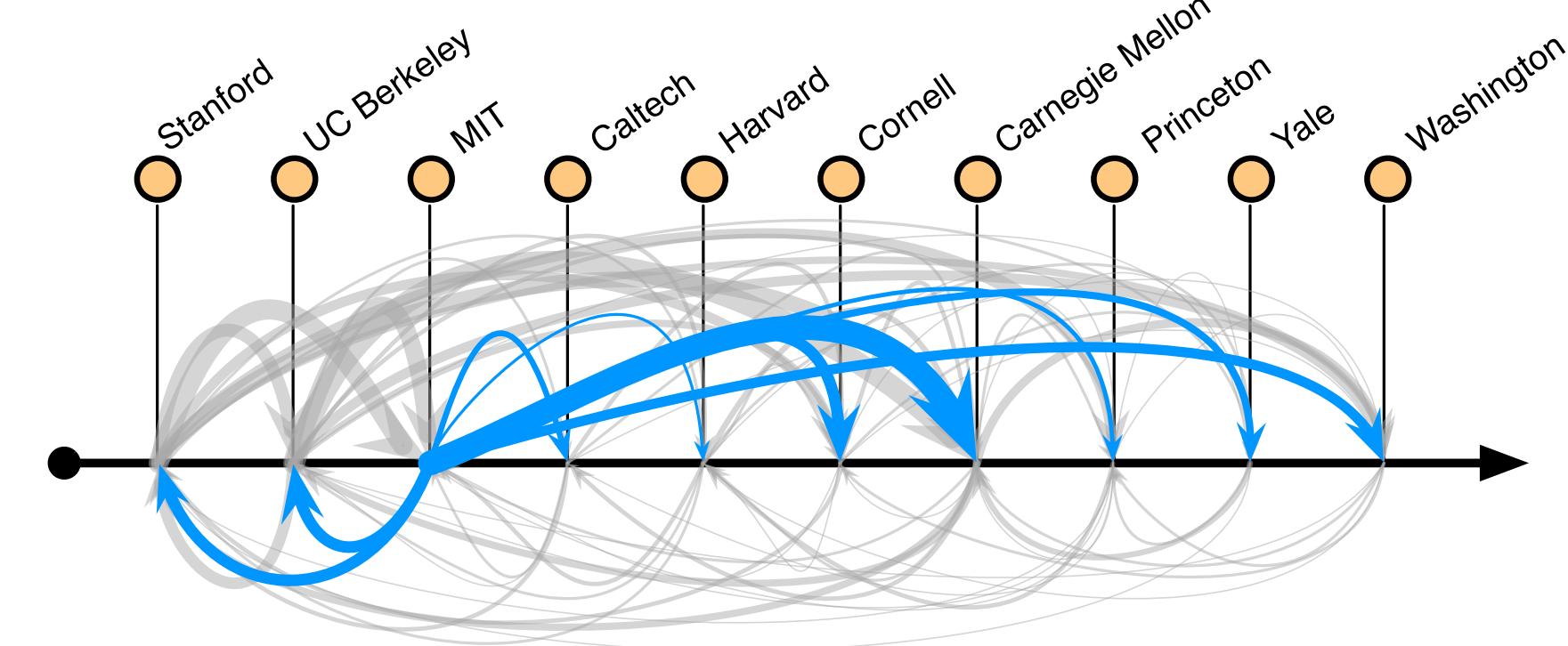
elite training does not drive scholarly productivity or prominence

working environment—not training—appears to drive scholarship

■ why do elite institutions dominate science?

doctoral prestige → faculty location

Clauset et al. (2015), Wapman et al. (2022)



what drives productivity and prominence?

- ▶ prestige is a *structural variable* in the science of science
 - elite training does not drive scholarly productivity or prominence*
 - working environment—not training—appears to drive scholarship

- why do elite institutions dominate science?

doctoral prestige → faculty location → scholarly impact

these results, Way et al. (2019)

- working environment causes higher impact (an environmental mechanism)

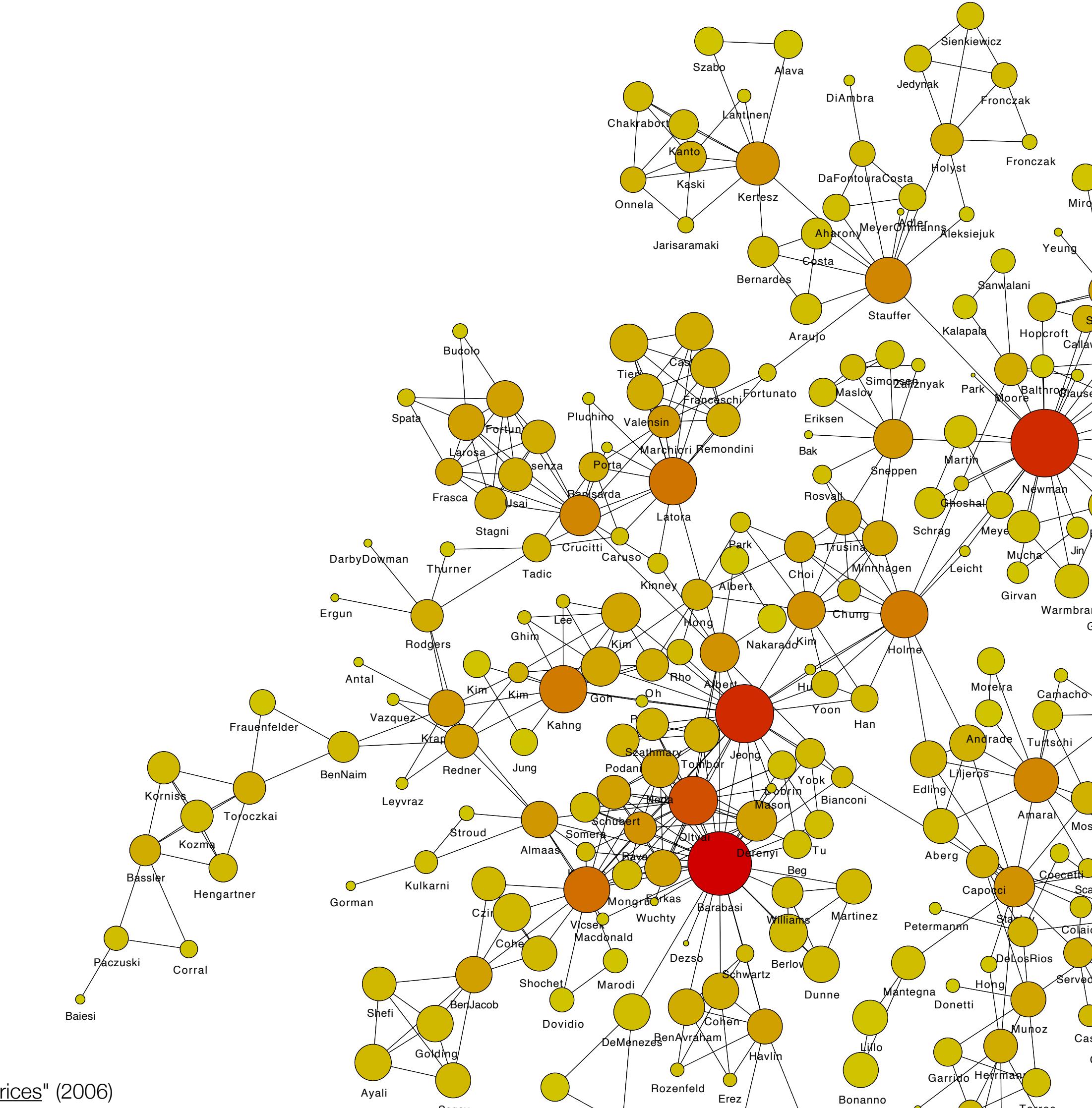
- ▶ Zhang et al. (2022) shows mechanism is a *labor advantage*
 - elite institutions = larger research groups

Labor advantages drive the greater productivity of faculty at elite universities

Sam Zhang^{1*}, K. Hunter Wapman², Daniel B. Larremore^{2,3}, Aaron Clauset^{2,3,4*}

how important is who you work with?

► networks mediate most scientific activities

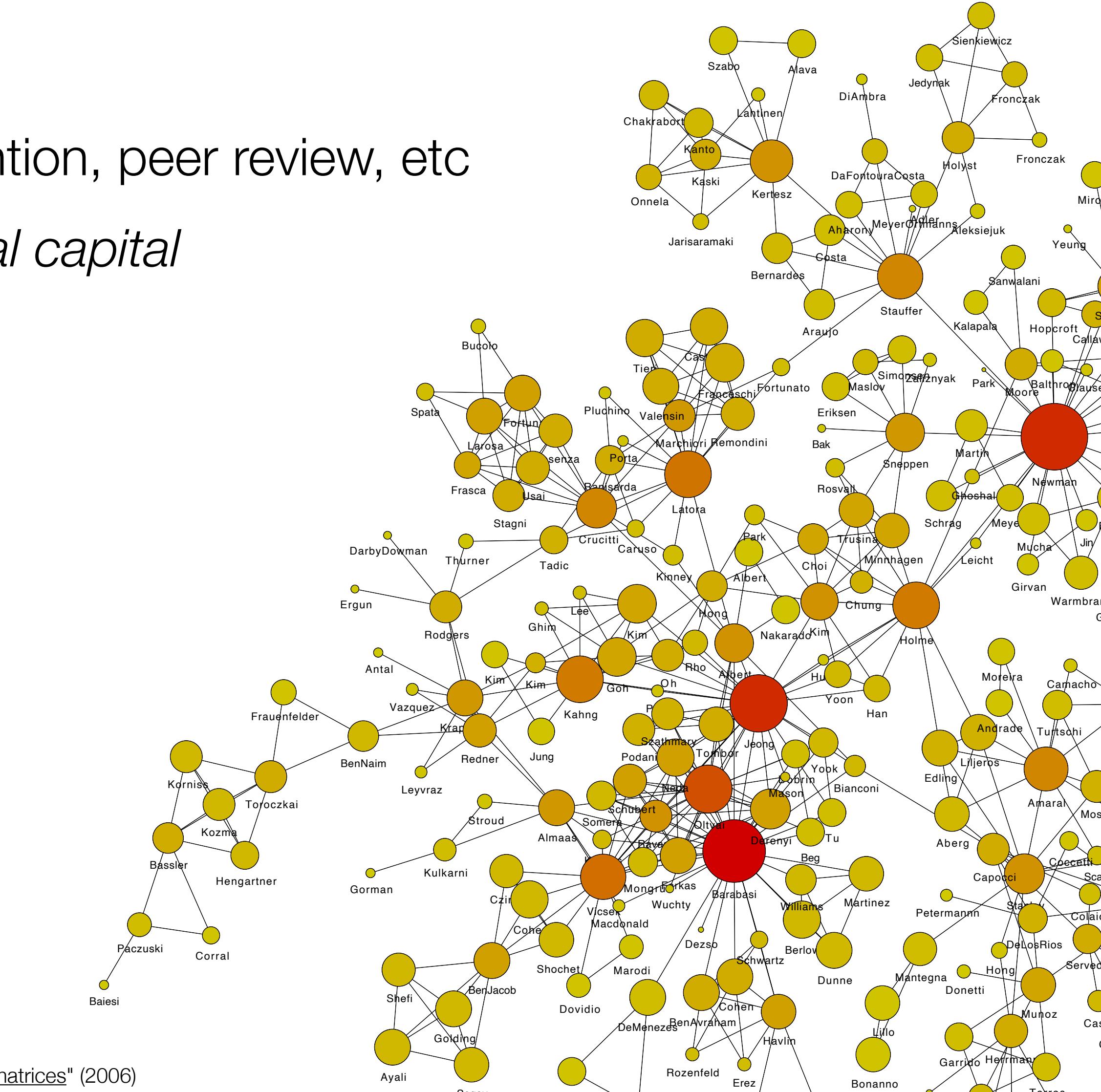


how important is who you work with?

▶ networks mediate most scientific activities:

scientific training, hiring, collaboration, teaching, attention, peer review, etc

networks act like a form of *unequally distributed social capital*



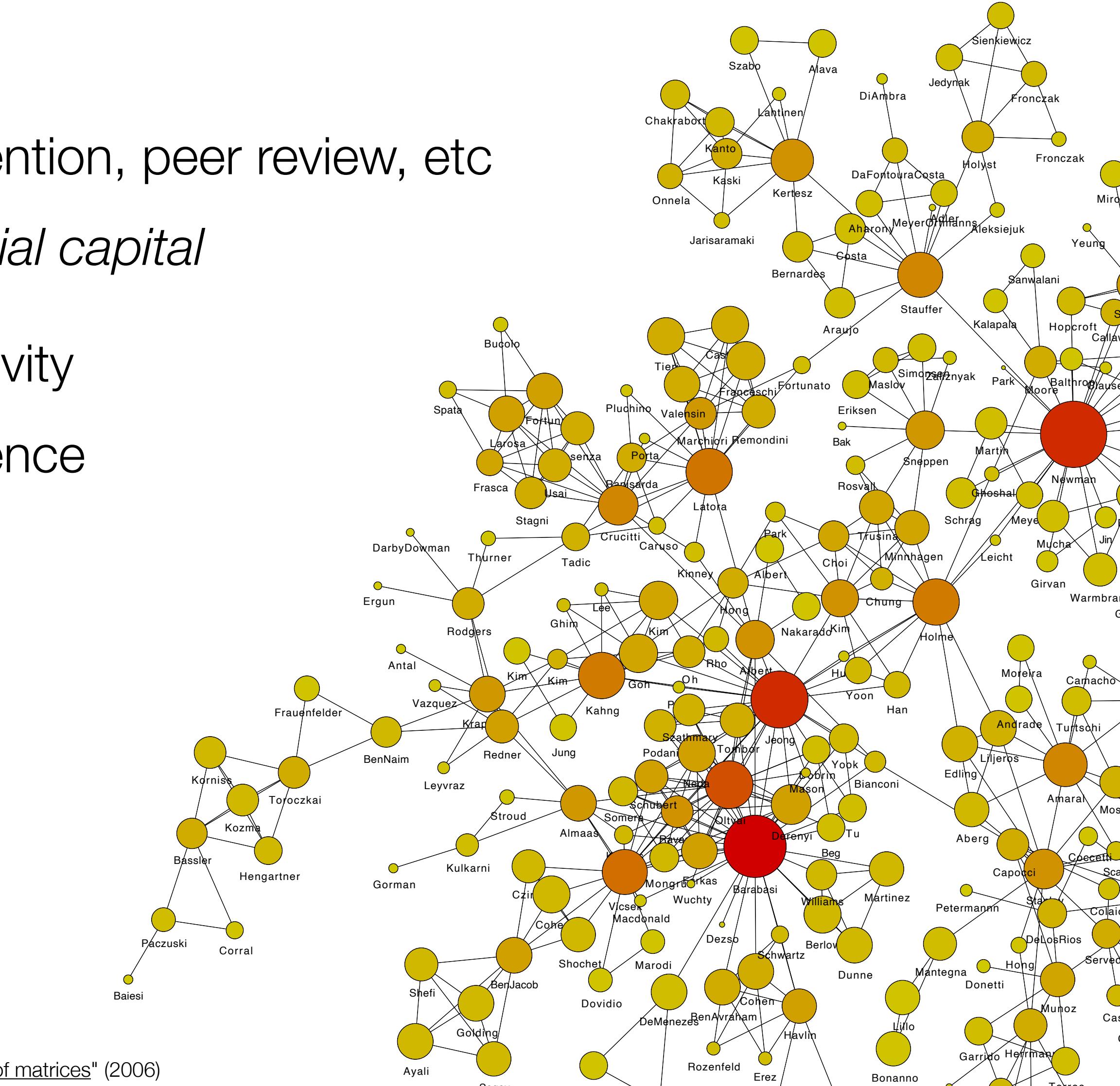
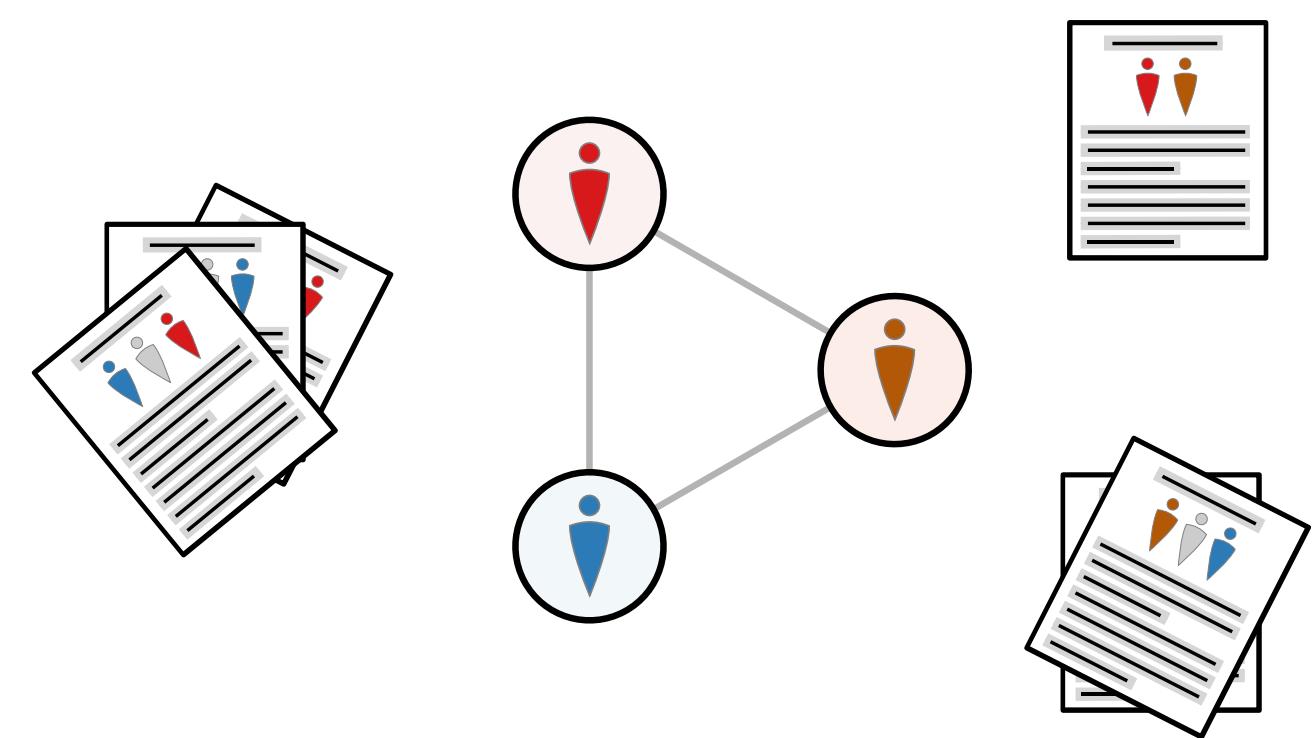
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- a productive collaborator → increases your productivity
- a prominent collaborator → increases your prominence



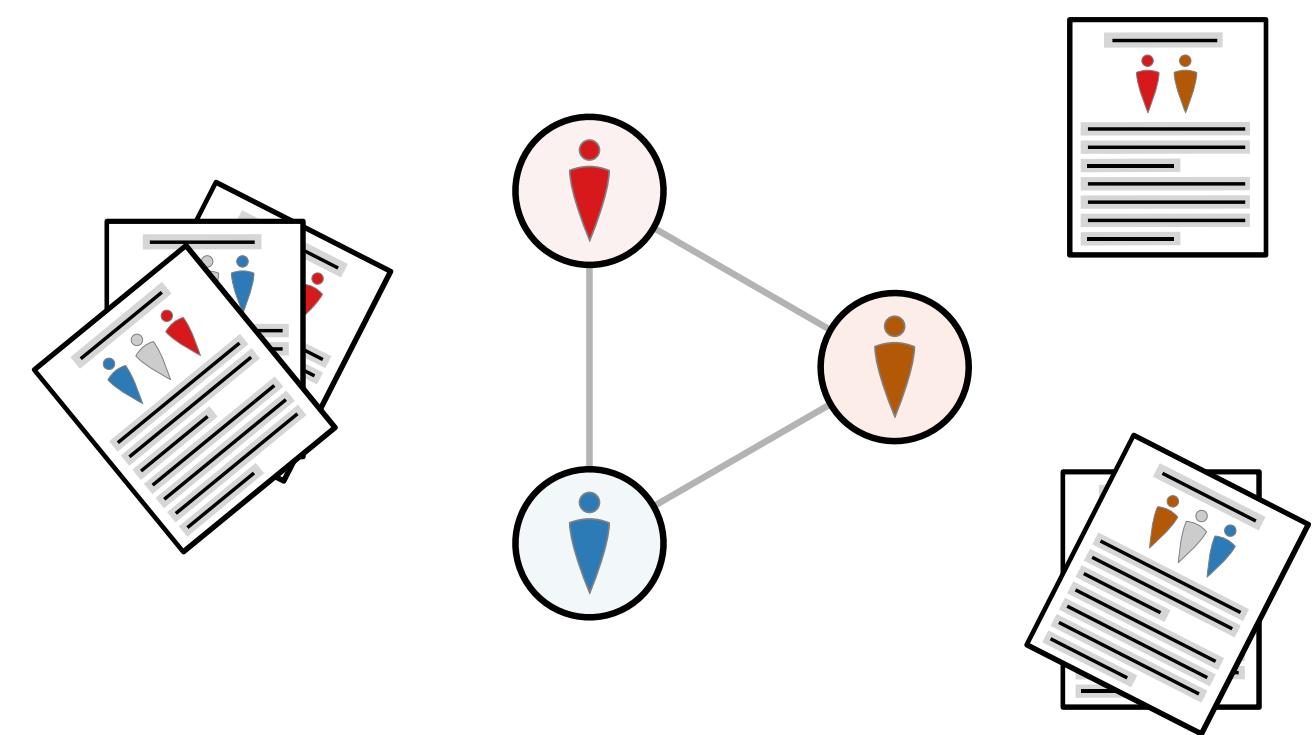
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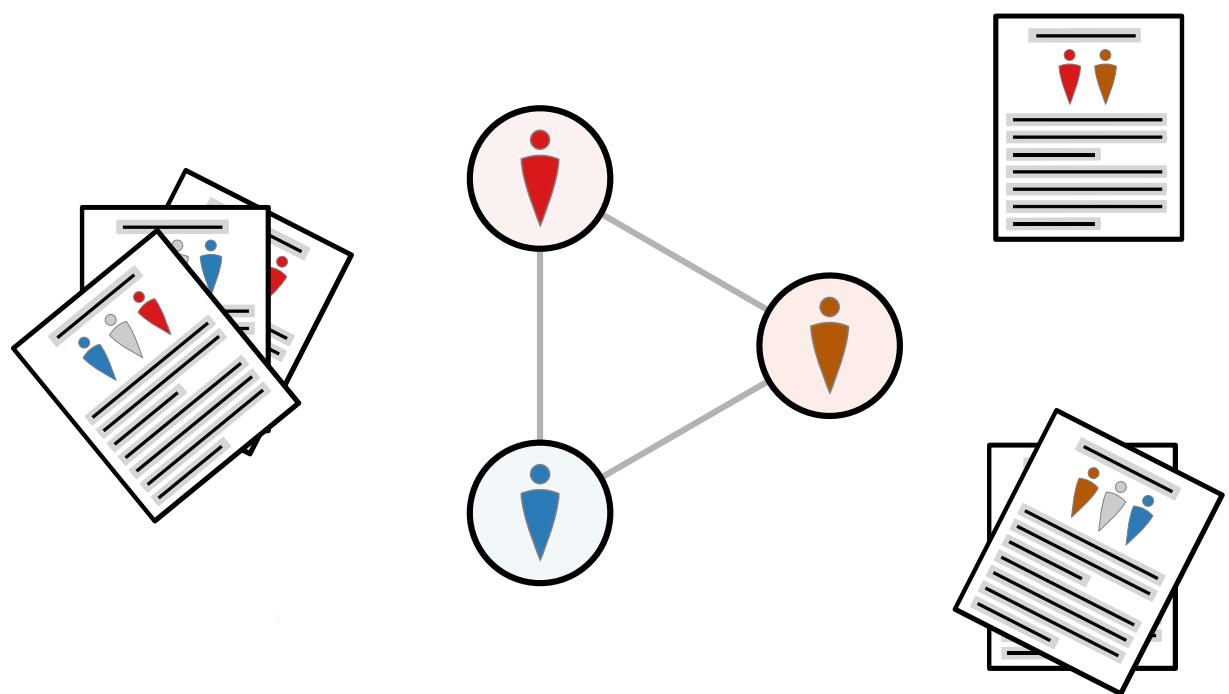


▶ how much do network effects (who you work with) drive your productivity and prominence?



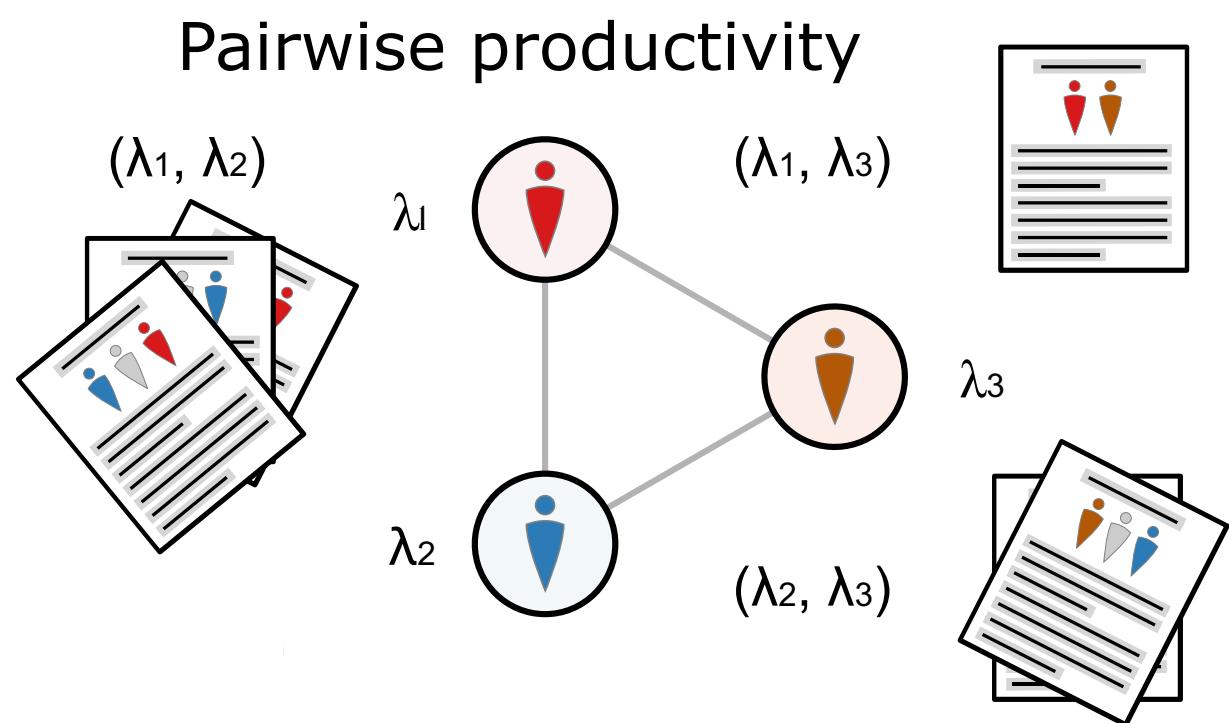
untangling the network's effects

▶ probability model of pairwise *productivity* and of pairwise *prominence* → infer *individual* parameters



untangling the network's effects

- ▶ probability model of pairwise *productivity* and of pairwise *prominence* → infer *individual* parameters
 - productivity of a pair i, j is a linear function $\lambda_i + \lambda_j$ of their (unknown) individual productivities



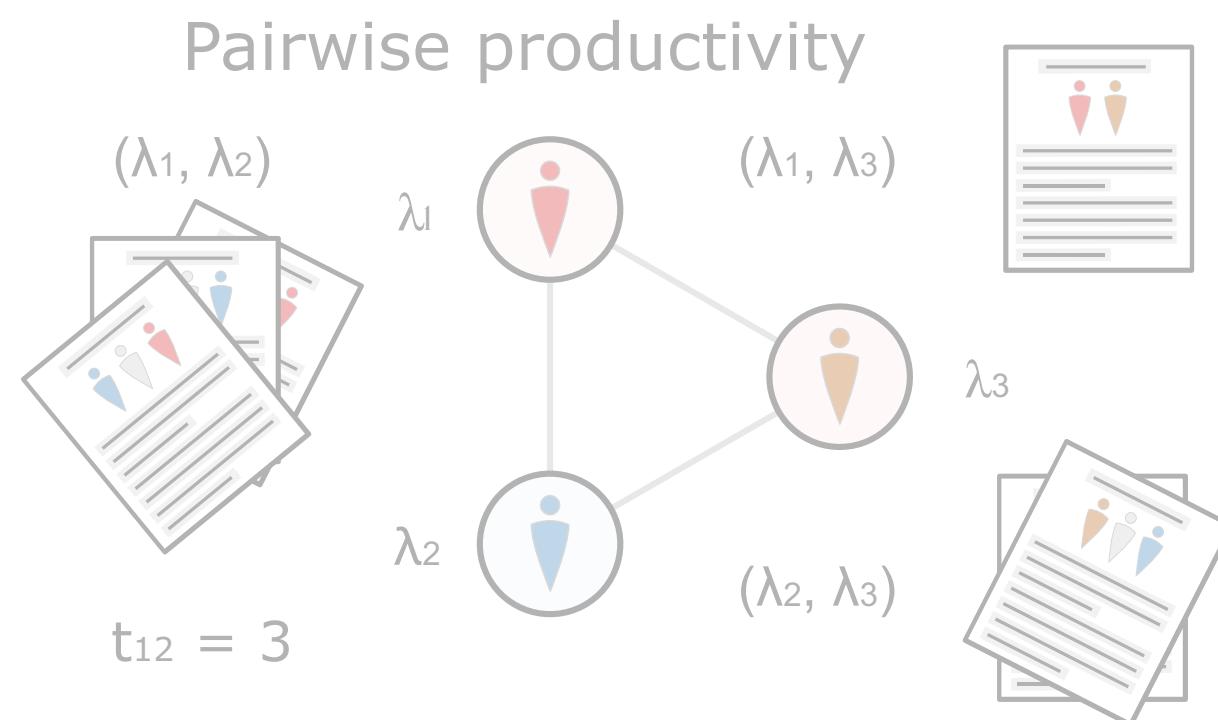
number (i, j) -coauthored papers

$$\Pr(N_{ij}, t_{ij} | \lambda_i, \lambda_j) = \text{Poisson}([\lambda_i + \lambda_j]t_{ij})$$

given time period

untangling the network's effects

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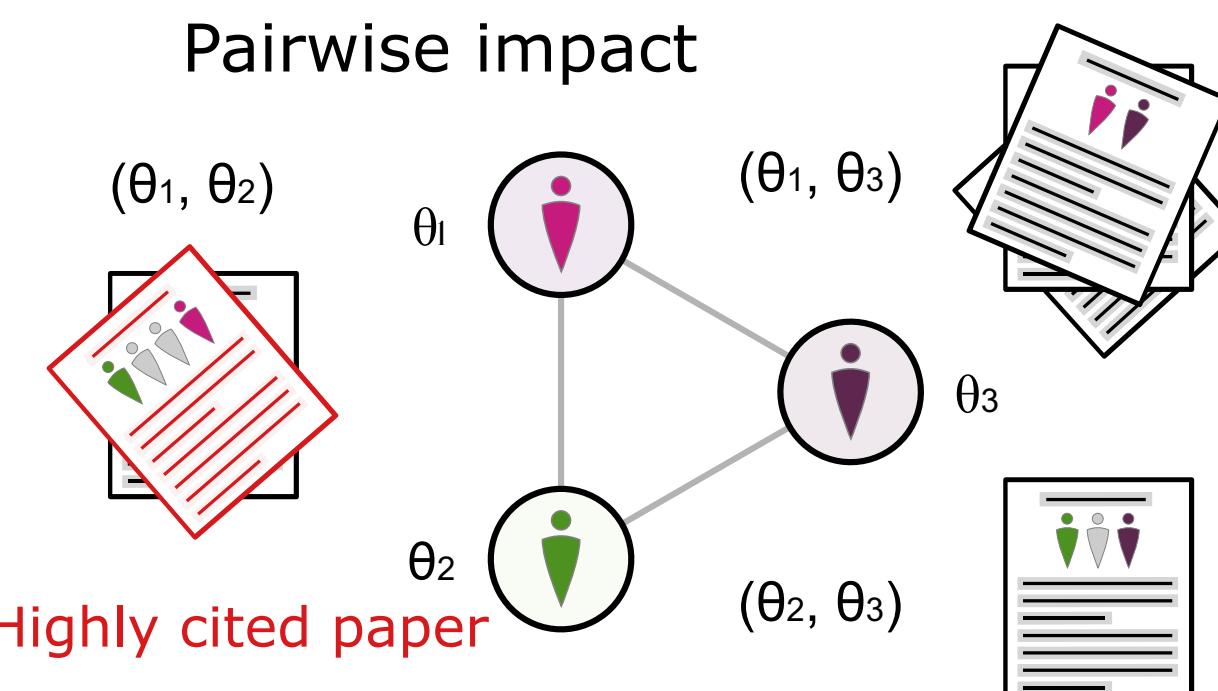


number (i, j) -coauthored papers

$\Pr(N_{ij}, t_{ij} | \lambda_i, \lambda_j) = \text{Poisson}([\lambda_i + \lambda_j]t_{ij})$

given time period

- prominence of a pair i, j is linear function $\theta_i + \theta_j$ of their (unknown) individual prominences



number (i, j) -coauthored papers

$\Pr(N_{ij}, m_{ij} | \theta_i, \theta_j) = \text{Binomial}(N_{ij}, [\theta_i + \theta_j])$

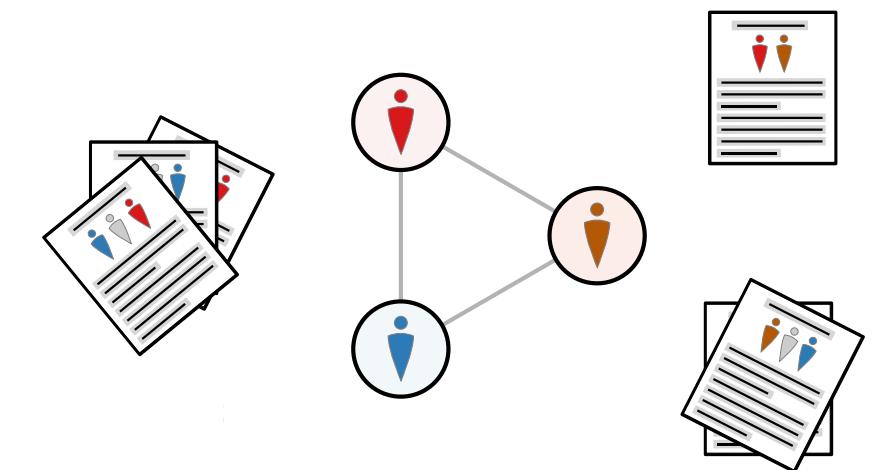
number of "high impact" papers

untangling bibliographic data

Microsoft Academic Graph (MAG) 1950–2019



- 198,202 mid-career researchers, with 10+ papers by 15th year of publishing history
- spanning 6 STEM fields (biology, chemistry, CS, math, medicine, physics)
- analyze only first-last author pairs (mitigates middle-author effects)
- define 'highly cited' — in upper 8% for given year-field

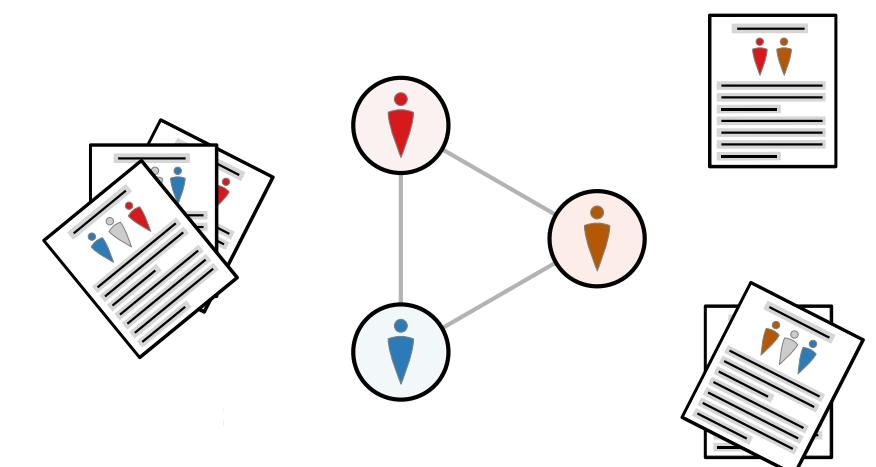


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Estimate individual (λ_i, θ_i) parameters for each scientist

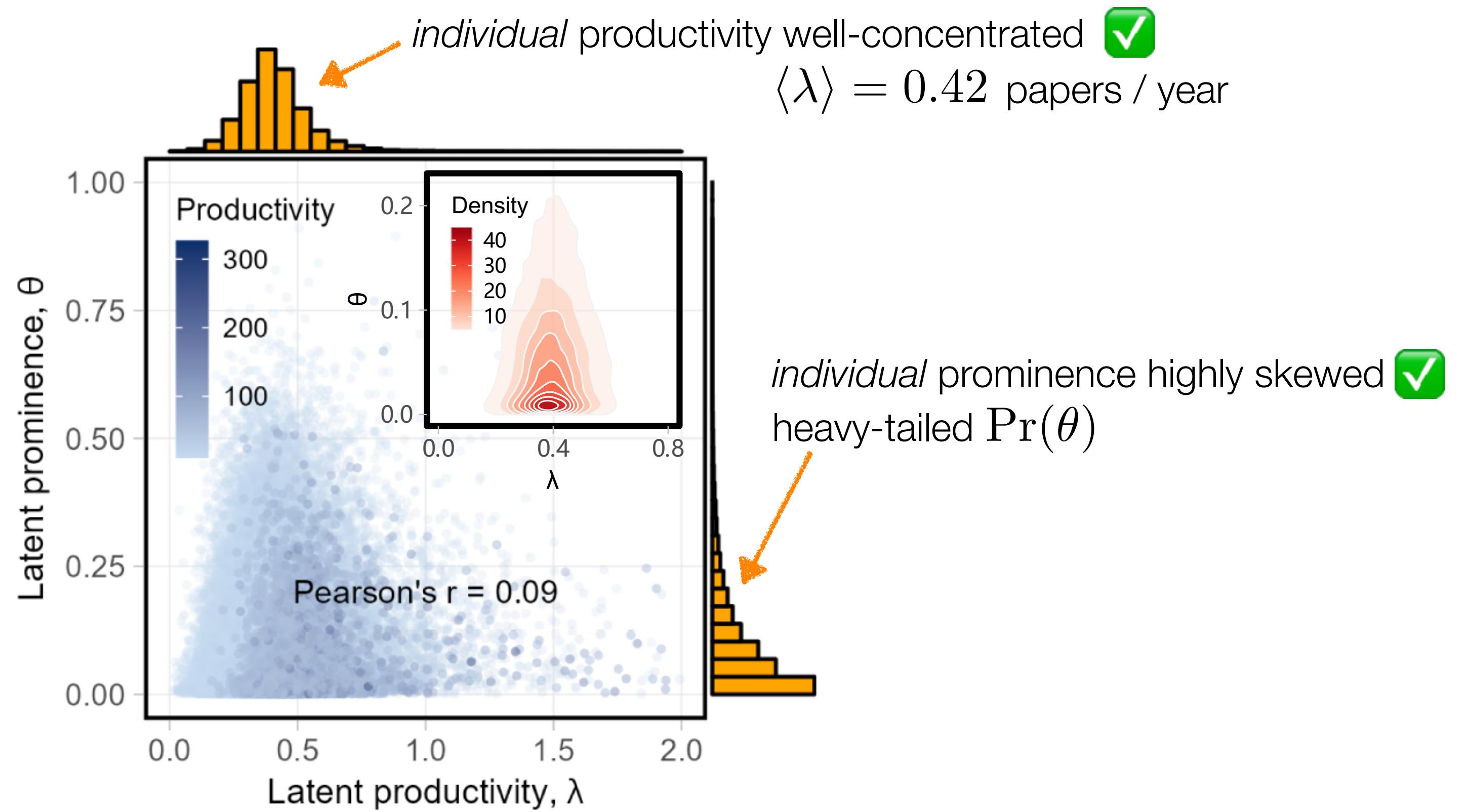
- estimate using network 1950– T , for variable T in [1975,2017]
- bootstrapped convex optimization, then record mean λ_i and θ_i
- investigate how (λ_i, θ_i) covary with gender, prestige, etc.

model checking

- ▶ applied to 198,202 mid-career STEM researchers 1975-2017

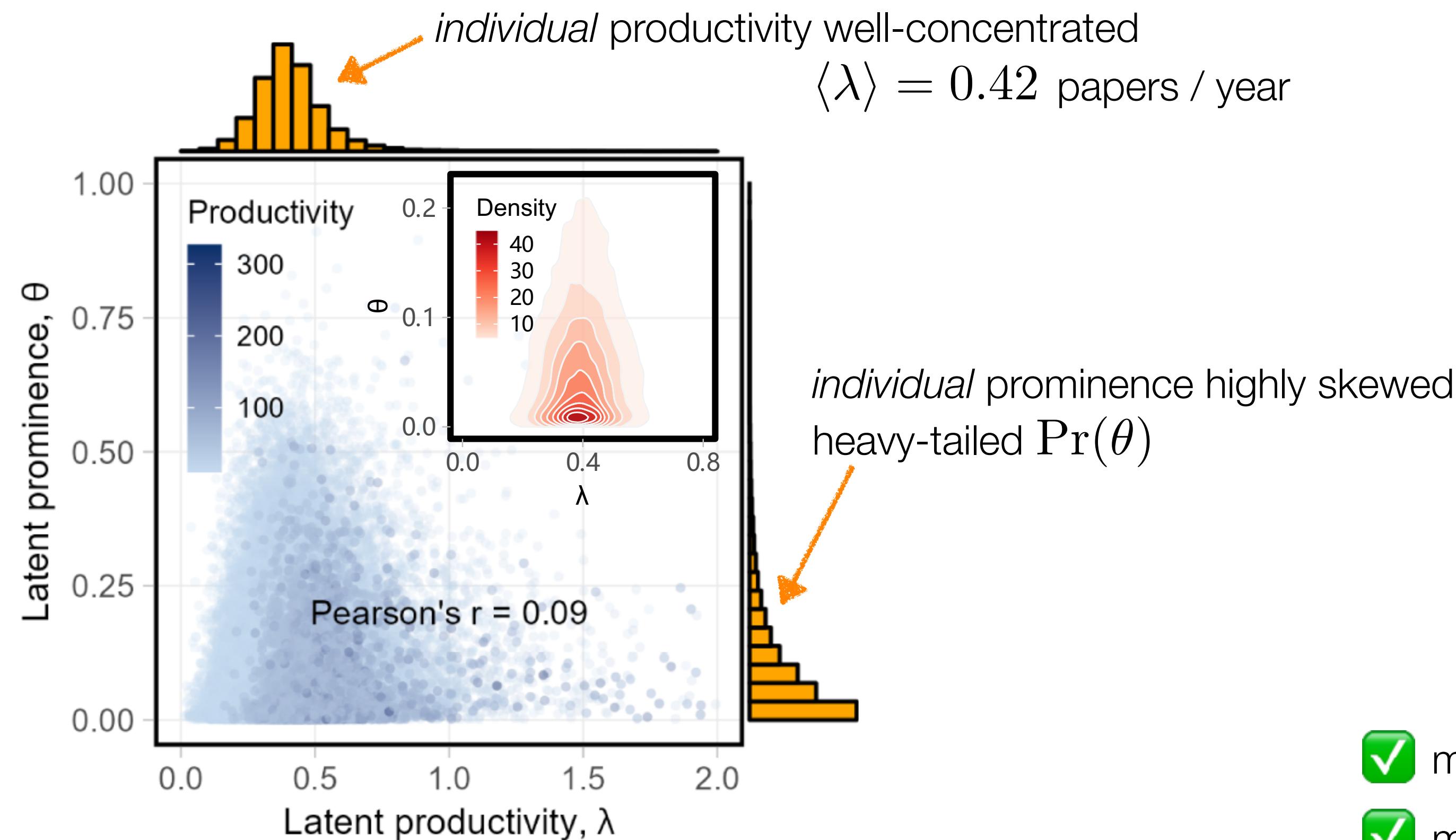
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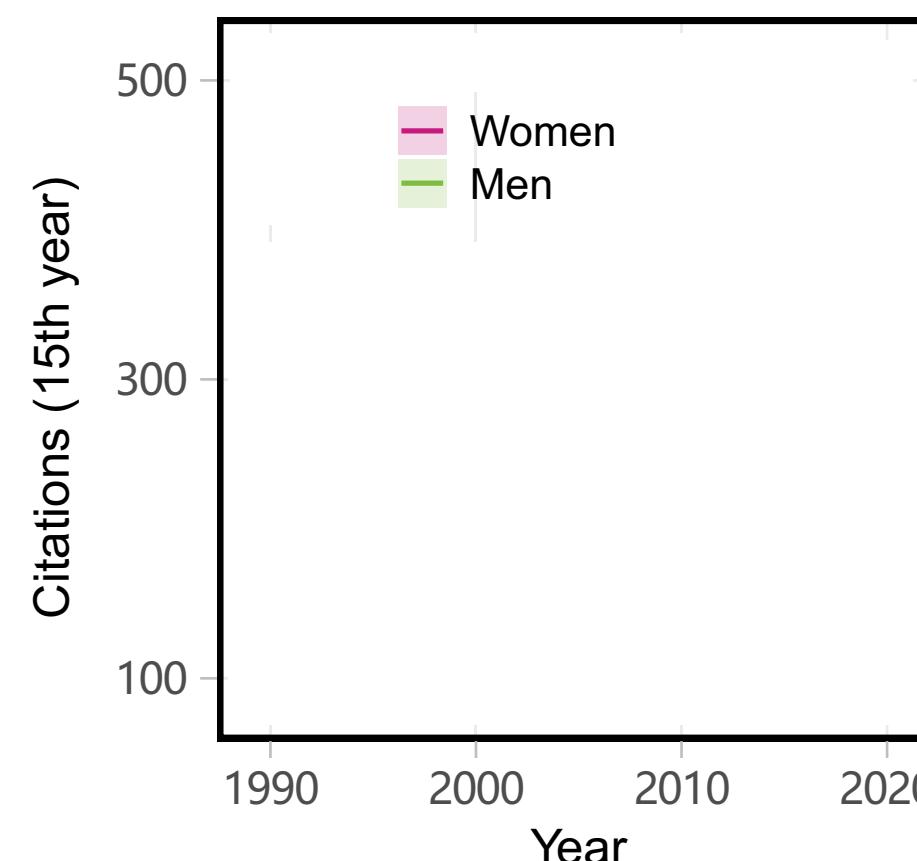
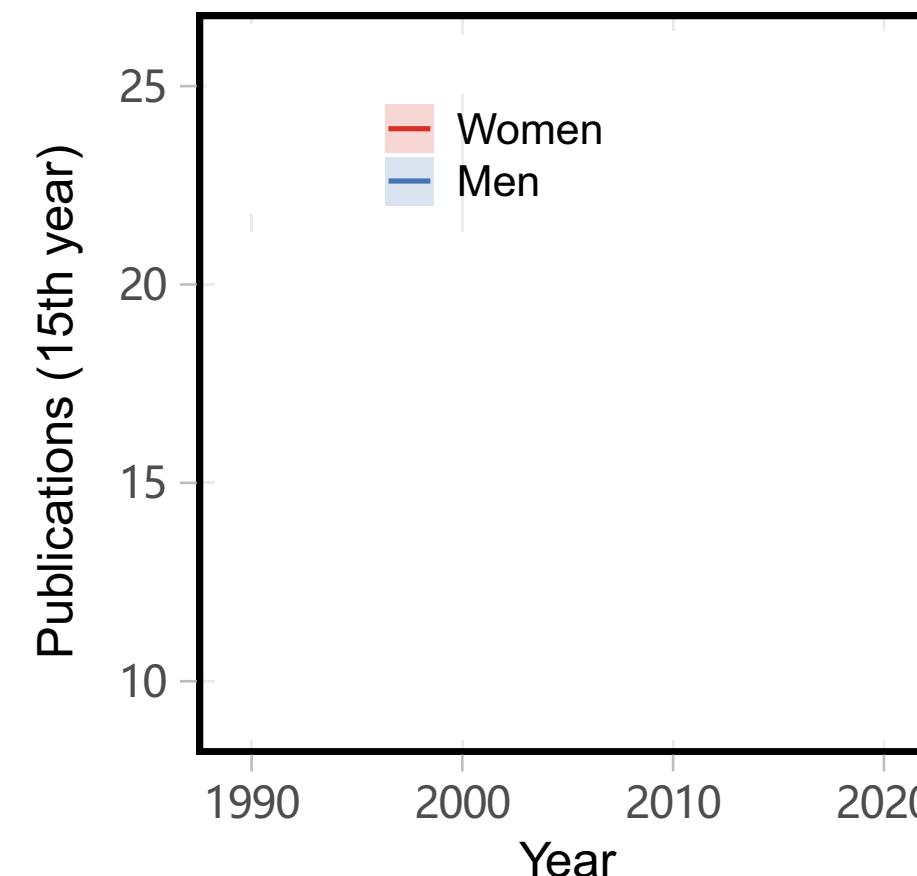
individual prominence highly skewed
heavy-tailed $\Pr(\theta)$

	Prestige	Papers	Citations	λ	θ	High λ coauthors	High θ coauthors
Prestige		0.06	0.15	0.02	0.15	0.04	0.13
Papers	0.06		0.4	0.21	-0.02	0.7	0.44
Citations	0.15	0.4		0.12	0.38	0.27	0.49
λ	0.02	0.21	0.12		0.15	0.31	0.14
θ	0.15	-0.02	0.38	0.15		0.06	0.25
High λ coauthors	0.04	0.7	0.27	0.31	0.06		0.43
High θ coauthors	0.13	0.44	0.49	0.14	0.25	0.43	

- ✓ my paper count = highly correlated with high λ coauthors
- ✓ my citations = well correlated with high λ & θ coauthors

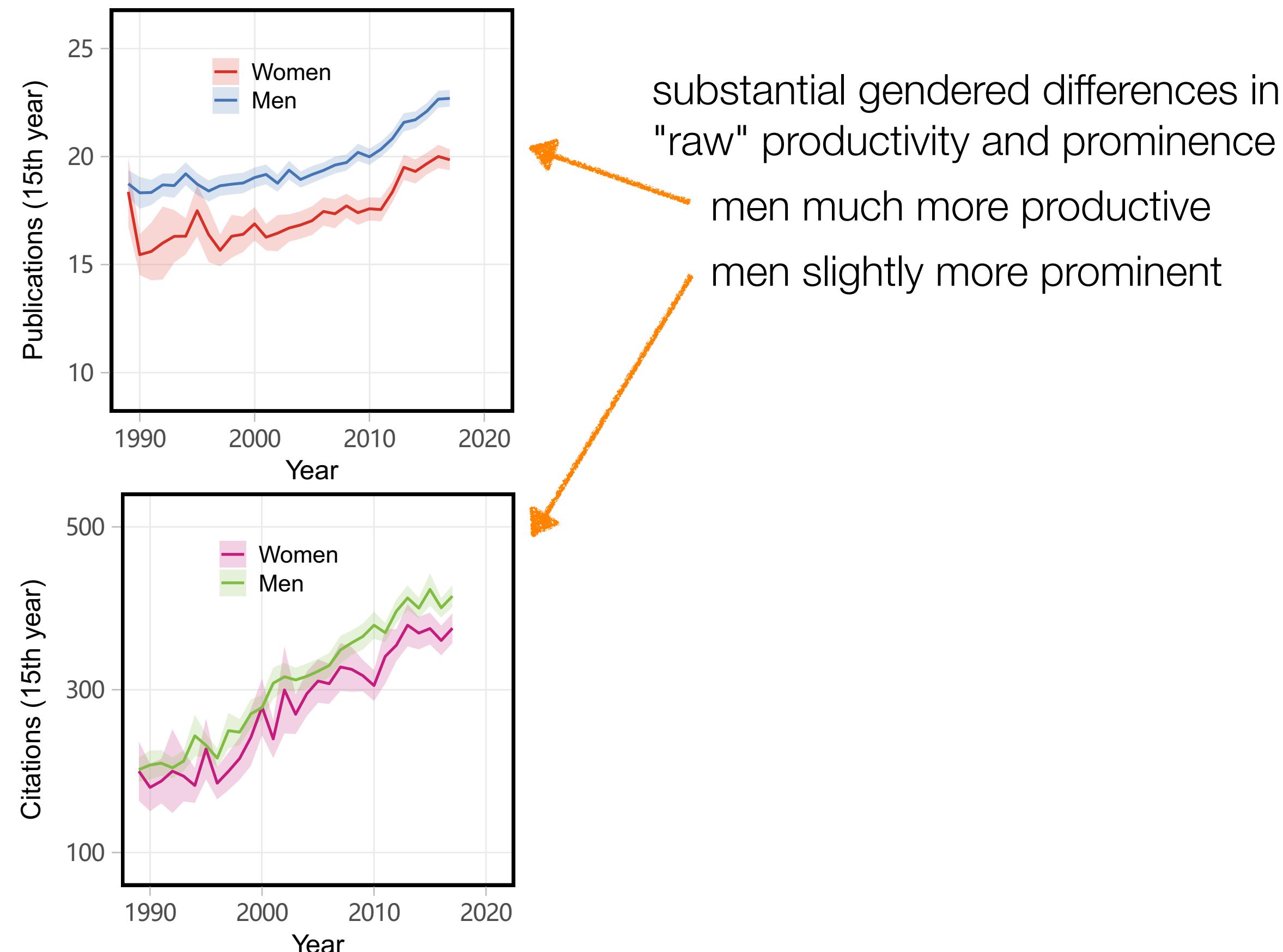
gender vs. productivity & prominence

- ▶ past work : men publish more papers than women & receive more citations
 - compare (λ_i, θ_i) over time, for men and women



gender vs. productivity & prominence

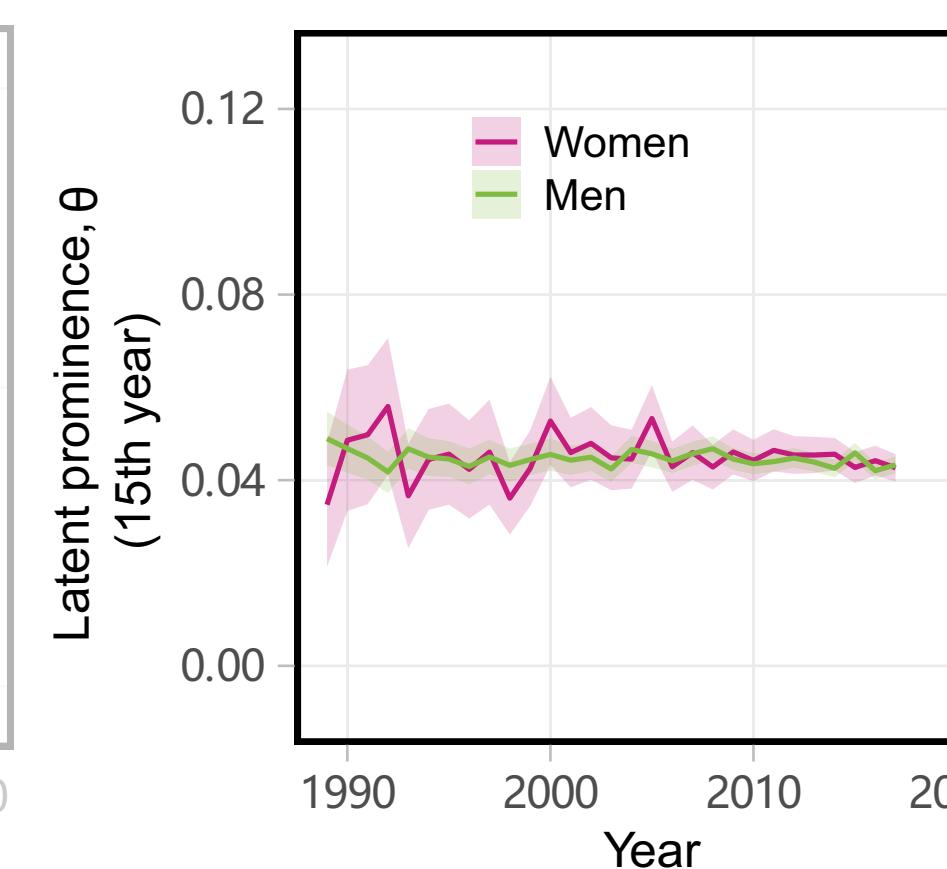
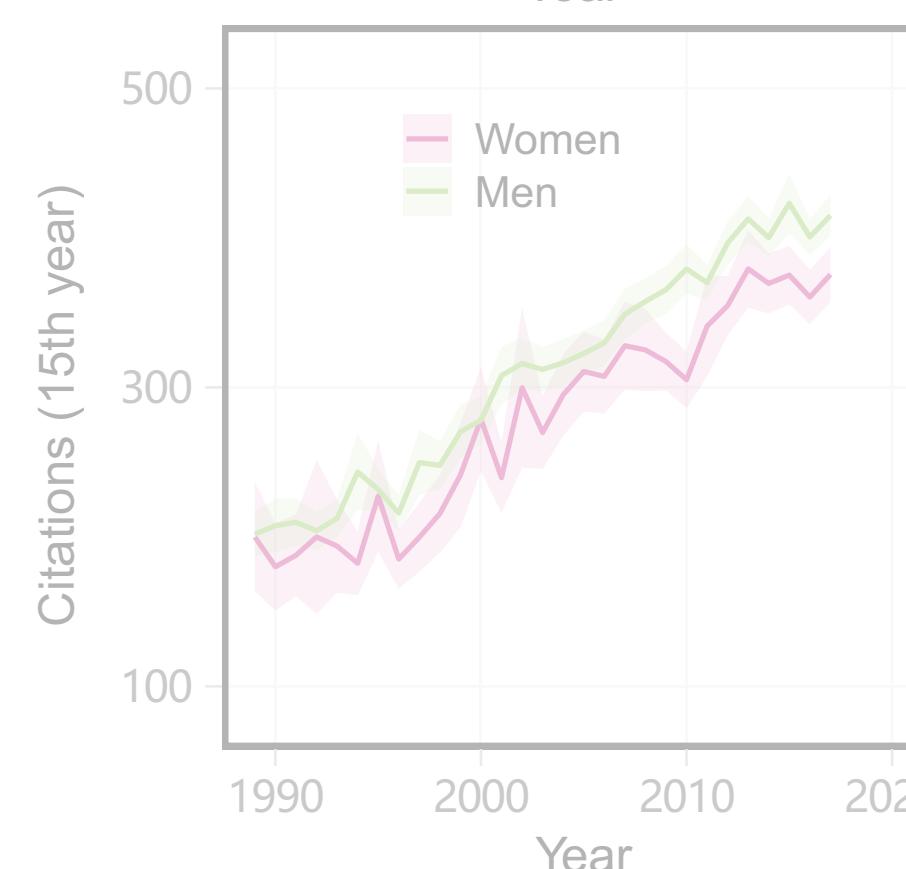
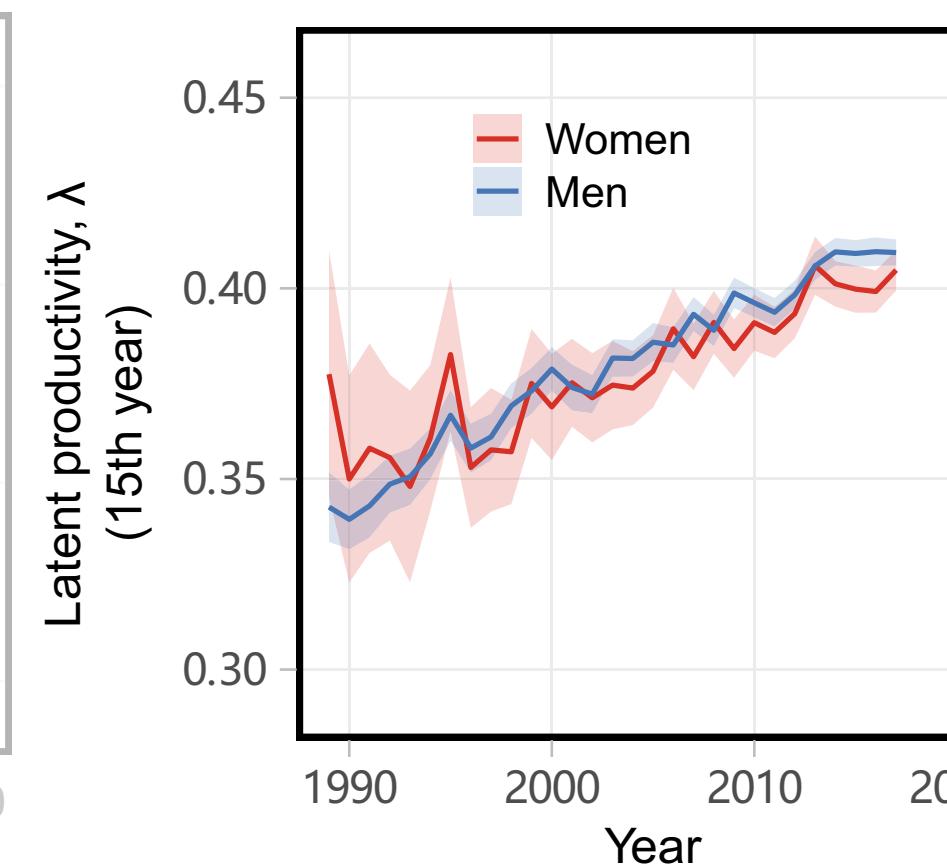
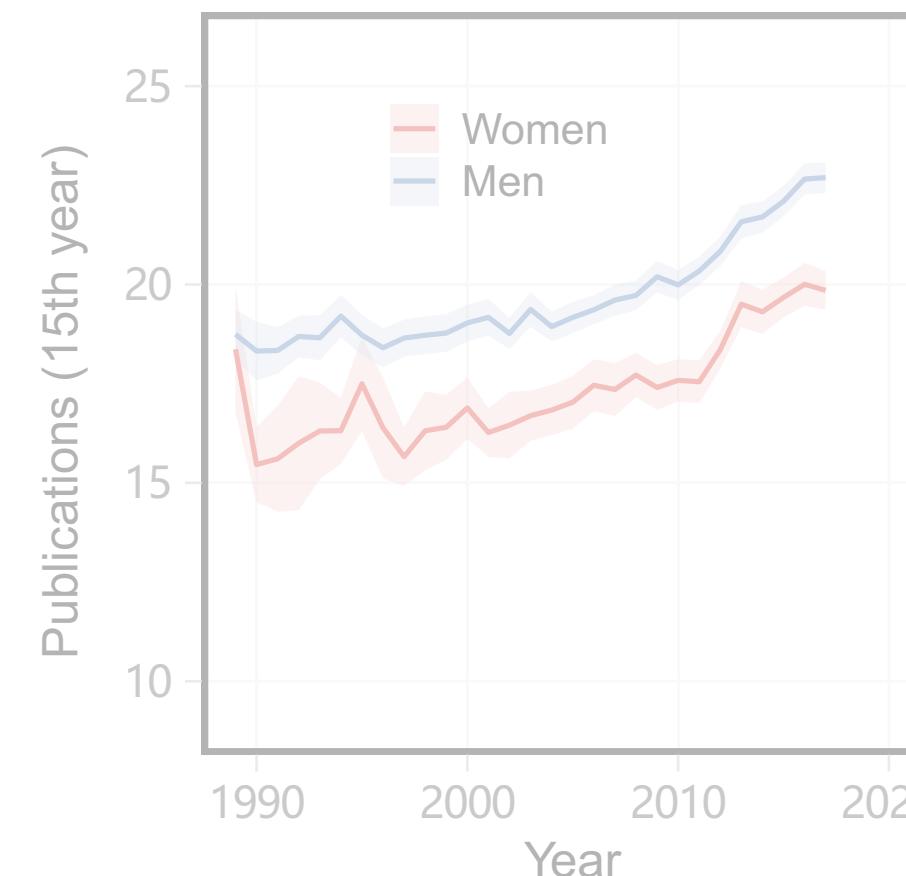
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shaded areas are 95% confidence intervals

gender vs. productivity & prominence

- ▶ past work : men publish more papers than women & receive more citations
- compare (λ_i, θ_i) over time, for men and women → their networks are different



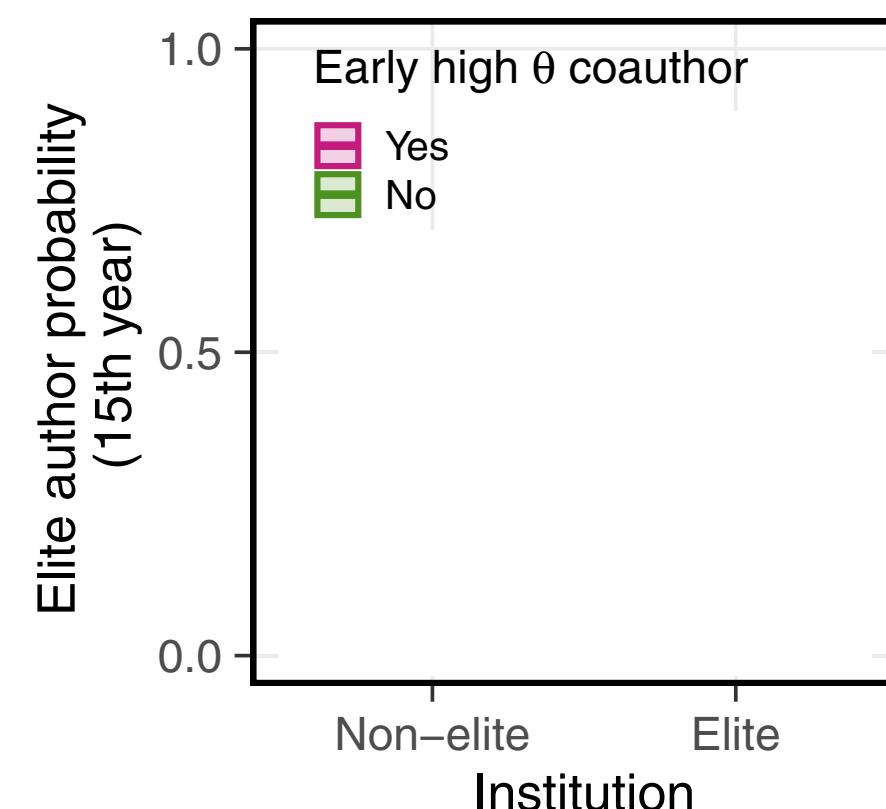
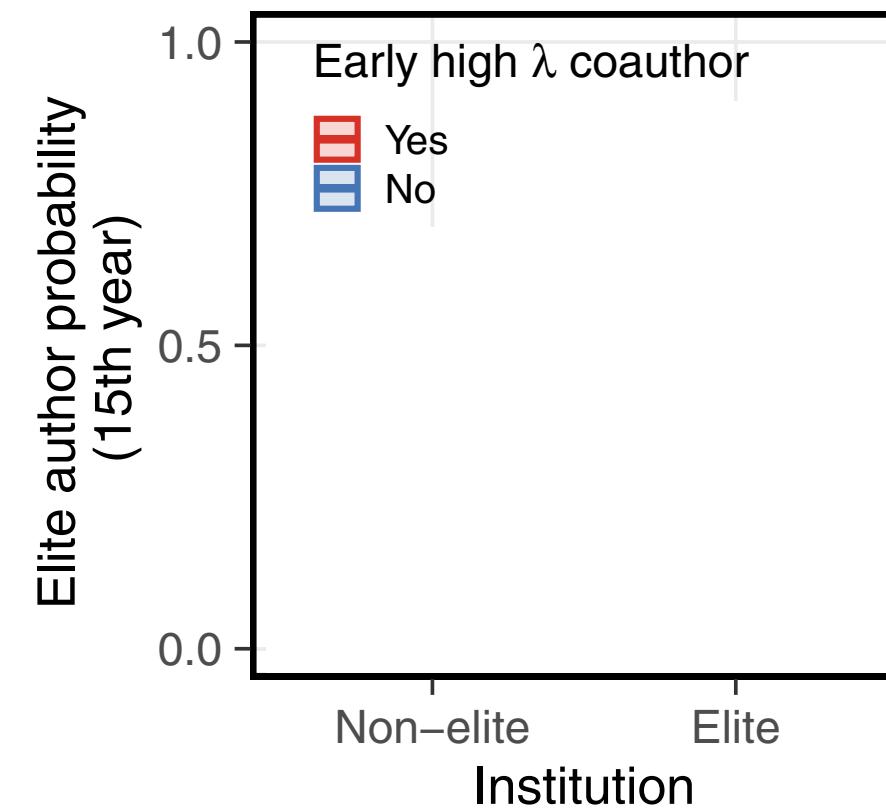
but: latent productivity and prominence
is *not* gendered

- ▶ size and composition of collaboration networks is gendered
- ▶ latent productivities increase steadily
- ▶ latent prominence stable over time

*not causal, but implies effects of known gendered causal factors on productivity (eg, parenthood) may operate by reshaping collaborating networks

effects of elite collaborators

- ▶ how much does an early-career collaboration with an elite senior researcher influence you?
 - elite senior researches with high λ or high θ

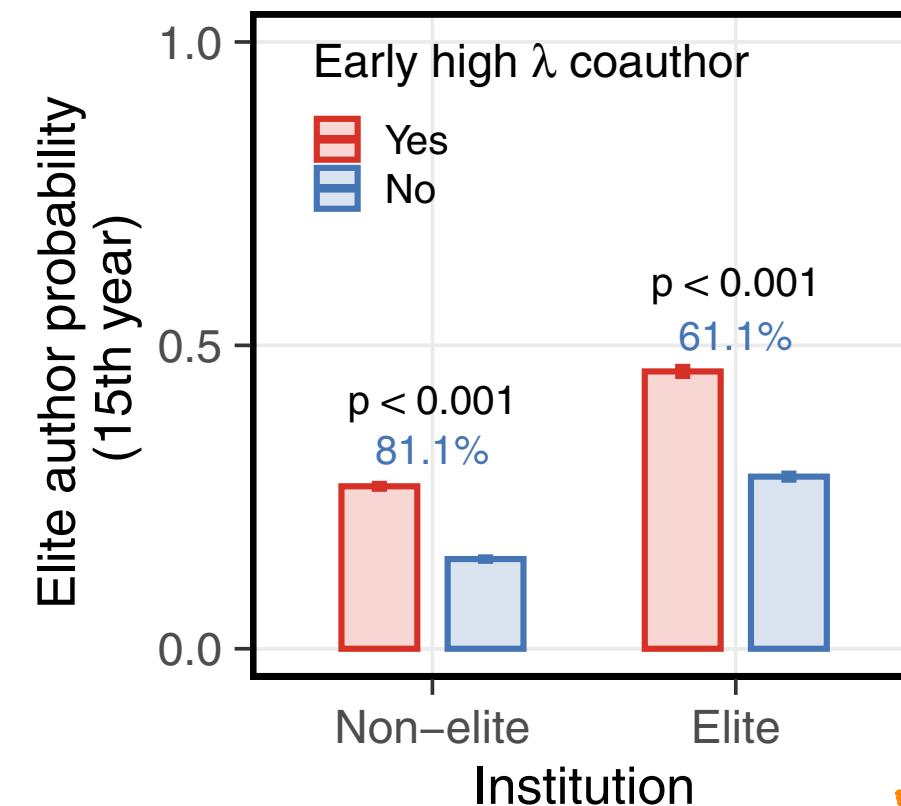


elite institutions = top 10 by z-score of high impact papers
early-career collaboration = within first 5 years of publishing history
"elite author" = upper 5% of citations among authors in a given field-year
shaded areas are 95% confidence intervals

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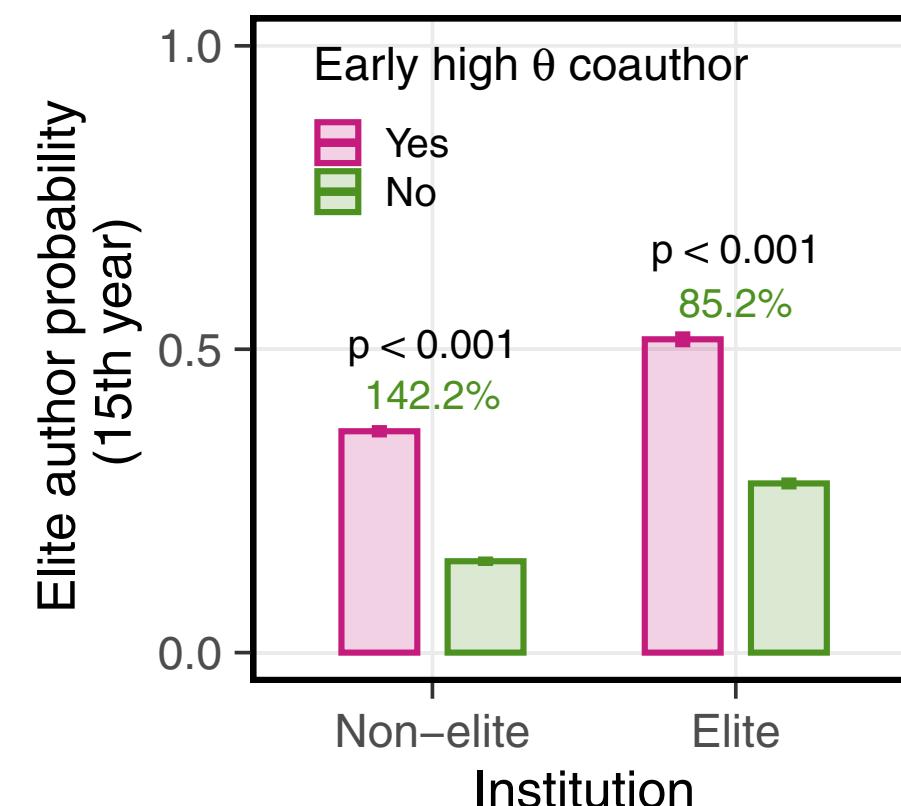
high- λ or early high- θ early collaborator substantially increases likelihood of high prominence in mid-career

▶ common at elite institutions

▶ effect appears at non-elite institutions too ✓

Pr. of high- λ early collab = 0.18 (elite) & 0.15 (non-elite)

Pr. of high- θ early collab = 0.14 (elite) & 0.07 (non-elite)

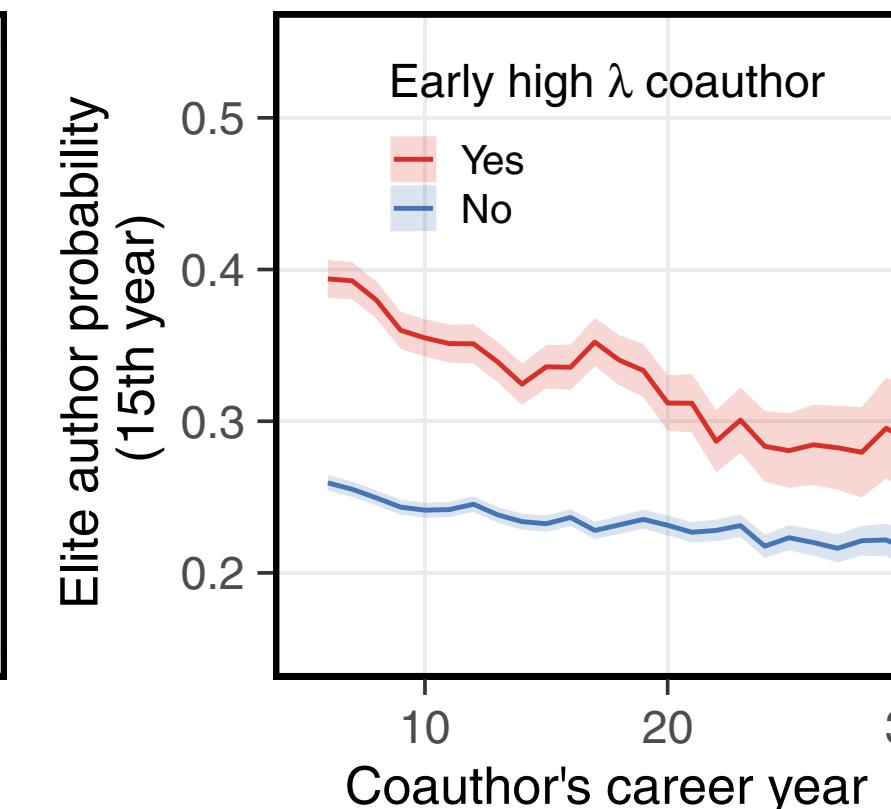
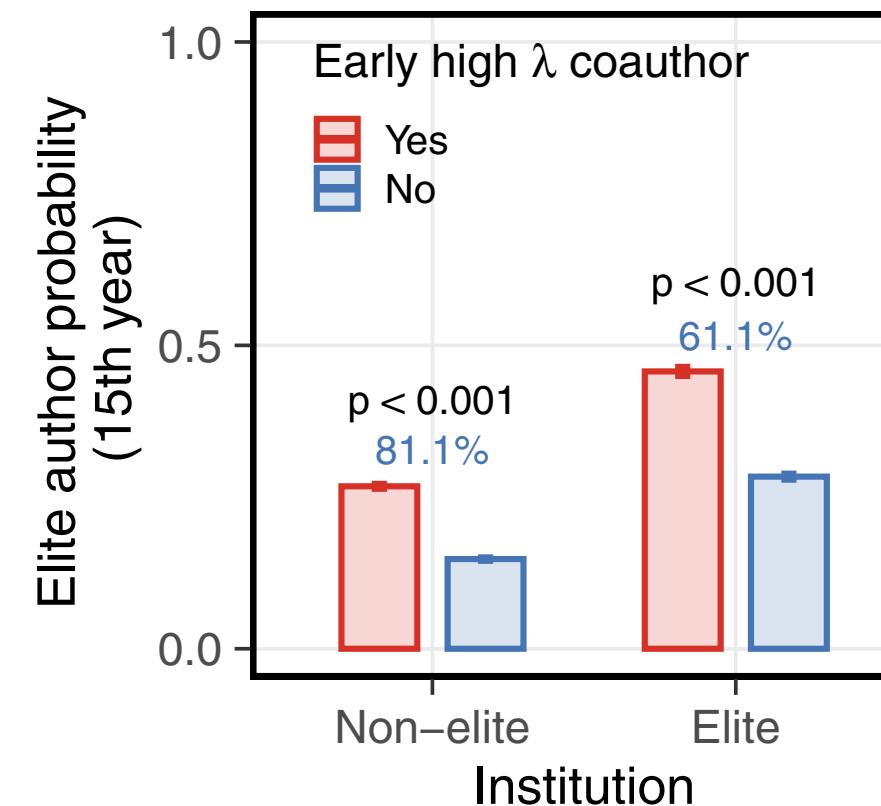


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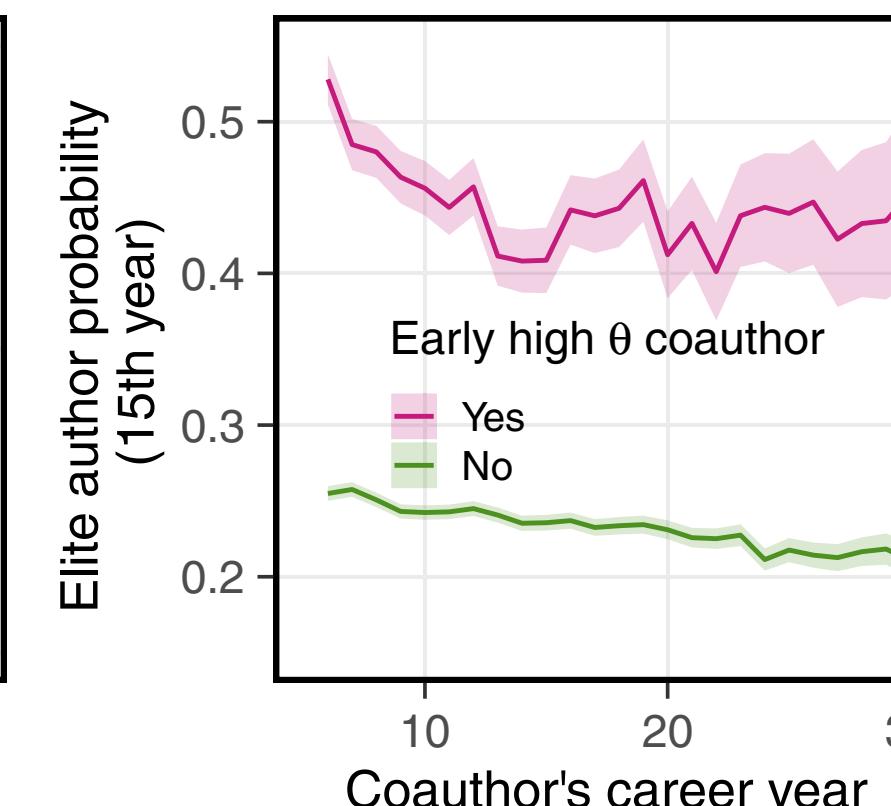
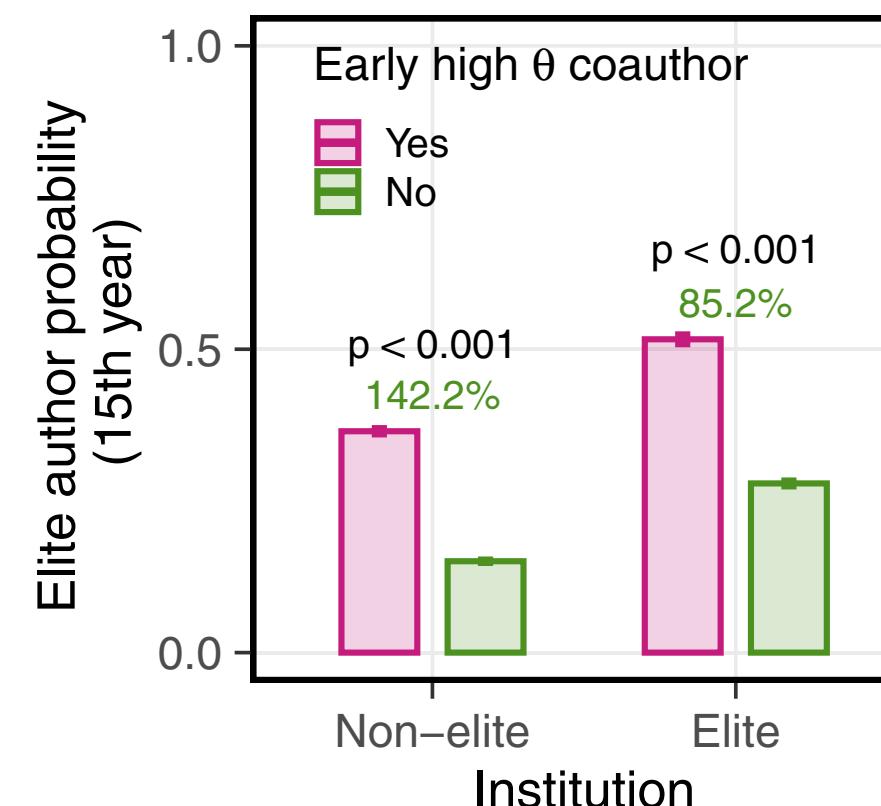
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the 'benefits' are substantial regardless of coauthors career age

- ▶ slight decrease for most senior coauthors
- ▶ collaboration networks act like a partially transferrable form of *social capital* in science

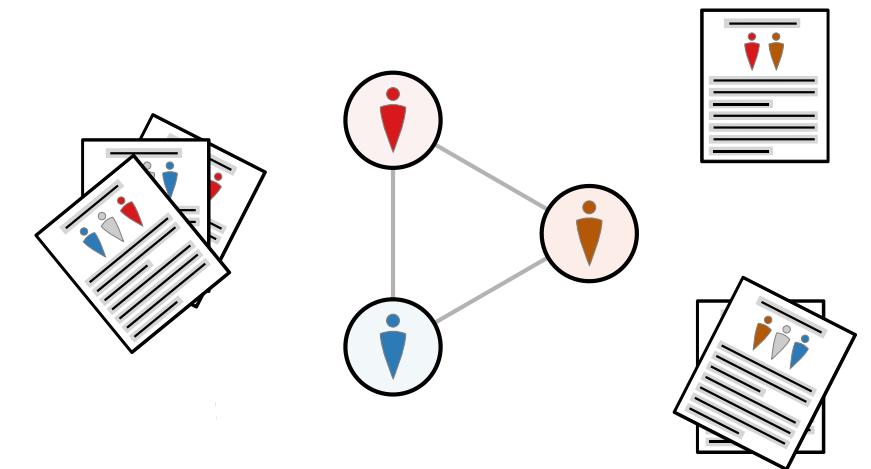


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how important is who you work with?

networks act like unequally distributed social capital in science

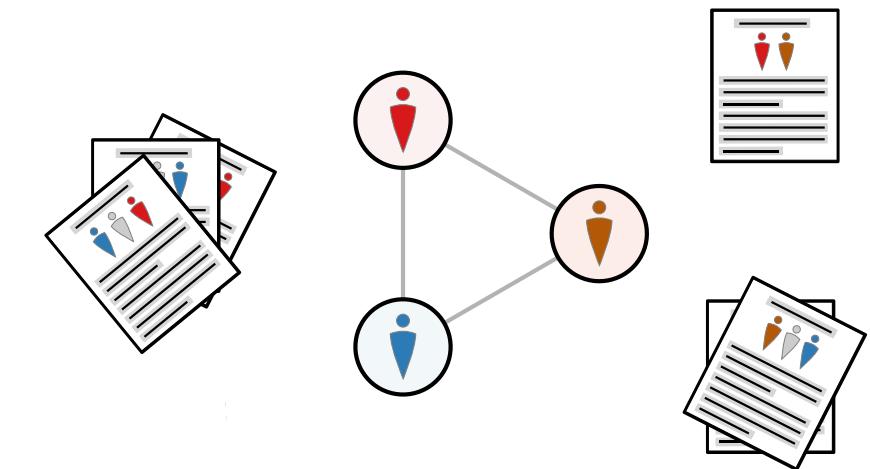
- *they mediate our scientific attention, evaluation, and collaboration*



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- *they mediate our scientific attention, evaluation, and collaboration*



differences in collaboration networks can explain

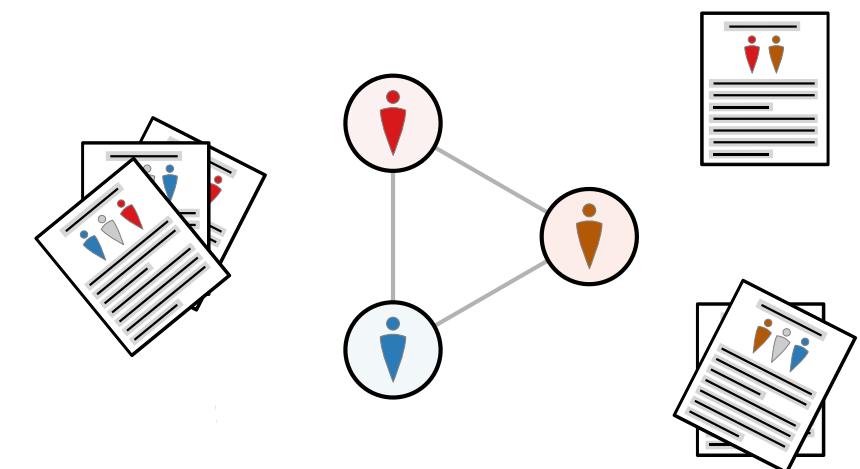
- gendered differences in productivity & prominence →
 - no difference in *latent* productivity & prominence (λ_i, θ_i)
 - but men do publish more and are more prominent, implying the difference is due to their networks
 - hence, should not compare *unadjusted* measures of productivity & prominence (the network confounds)



how important is who you work with?

networks act like unequally distributed social capital in science

- *they mediate our scientific attention, evaluation, and collaboration*



differences in collaboration networks can explain

- gendered differences in productivity & prominence
- early-career productivity & prominence

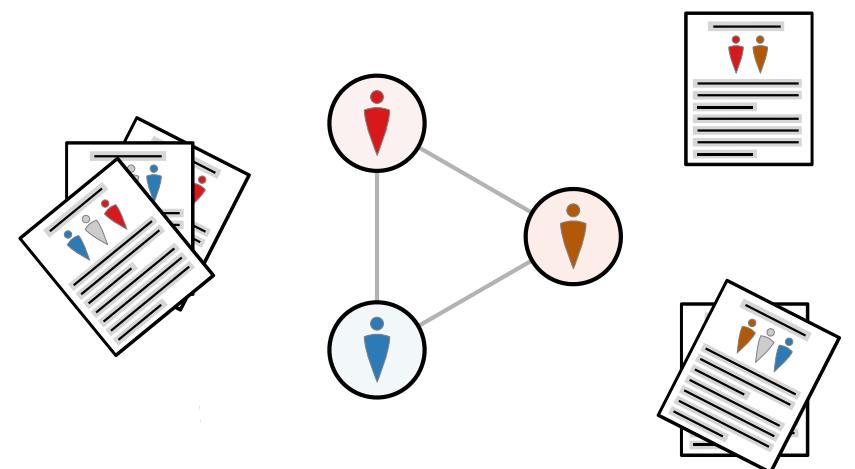
- ➔ • elite senior coauthors bequeath some of their networks to junior coauthors — inter-generational transfers
- this effect is independent of institutional prestige
- but junior scholars have greater access to elite coauthors at elite institutions



how important is who you work with?

networks act like unequally distributed social capital in science

- *they mediate our scientific attention, evaluation, and collaboration*



differences in collaboration networks can explain

- gendered differences in productivity & prominence
- early-career productivity & prominence
- what else?

can we intervene in these networks to mitigate inequalities? 🤔

- funds for new collaborations, eg, after parenthood?
- early-career fellowships to work with elite senior coauthors?

study limitations:

- none of these analyses are causal, although they do suggest specific mechanisms that can be tested
- no data on race/ethnicity in our bibliographic analyses, although literature suggests under-represented minorities may have similar or larger network differences as women
- we focus only on STEM fields, which tend to have strong collaboration norms; unclear what results might be for fields with different collaboration norms

how much of a meritocracy?

"little in academia makes sense except in the light of prestige"



- ▶ prestige pervades and structures the scientific ecosystem

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"little in academia makes sense except in the light of prestige"



- ▶ prestige pervades and structures the scientific ecosystem
 - shapes who gets faculty jobs and where
 - shapes how much scholarship is produced & academic labor
 - shapes composition of collaboration networks

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} individual placement, productivity, and prominence cannot be separated from one's place in the academic system

▶ your environment matters! (physical and social)

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} individual placement, productivity, and prominence cannot be separated from one's place in the academic system

▶ how can we accelerate science?

- deprioritize prestige signals
- deconcentrate academic labor
- targeted collaboration support, eg, for women & URM scholars

▶ your environment matters!
(physical and social)

references & collaborators

Productivity, prominence, and the effects of academic environment

Samuel F. Way^{a,1}, Allison C. Morgan^a, Daniel B. Larremore^{a,b,2}, and Aaron Clauset^{a,b,c,1,2}

^a Department of Computer Science, University of Colorado, Boulder, CO, USA; ^b BioFrontiers Institute, University of Colorado, Boulder, CO, USA; ^c Santa Fe Institute, Santa Fe, NM, USA

PNAS 116(22), 10729–10733 (2019)

Quantifying hierarchy and dynamics in US faculty hiring and retention

<https://doi.org/10.1038/s41586-022-05222-x> K. Hunter Wapman¹, Sam Zhang², Aaron Clauset^{1,3,4} & Daniel B. Larremore^{1,3}

Nature 610, 120–127 (2022)

Labor advantages drive the greater productivity of faculty at elite universities

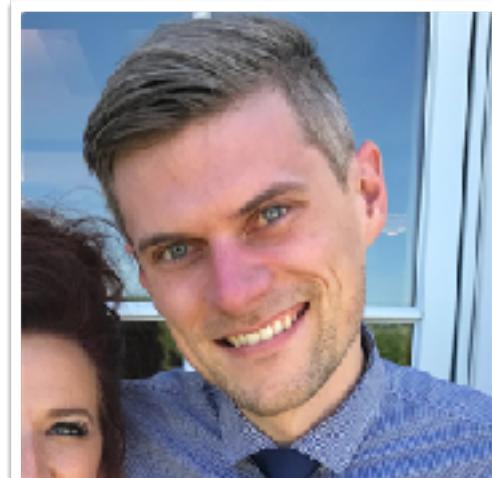
Sam Zhang^{1*}, K. Hunter Wapman², Daniel B. Larremore^{2,3}, Aaron Clauset^{2,3,4*}

Science Advances 8, eabq7056 (2022)

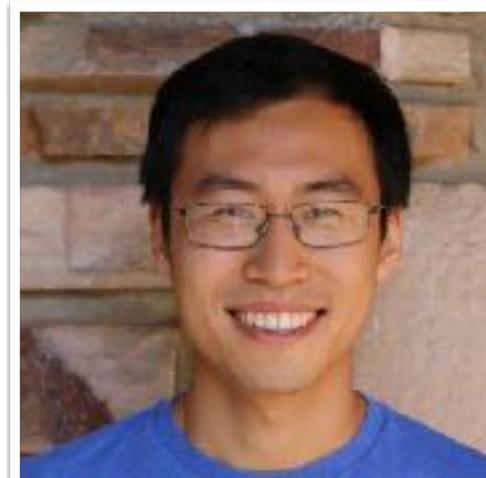
Untangling the network effects of productivity and prominence among scientists

Weihua Li^{1,2,3,4}, Sam Zhang⁵, Zhiming Zheng^{1,2,3,4}, Skyler J. Cranmer⁶ & Aaron Clauset^{1,7,8,9}

Nature Communications 13, 4907 (2022)



Dr. Samuel F Way
(now: Spotify)



Sam Zhang
(Colorado)



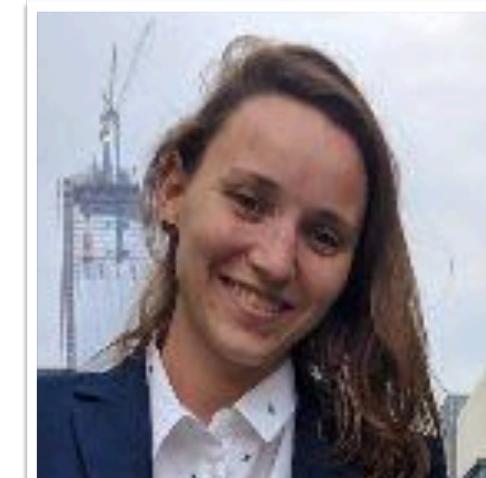
Dr. K. Hunter Wapman
(Colorado)



Prof. Weihua Li
(Beihang)



Prof. Zhiming Zhang
(Beihang)



Dr. Allison Morgan
(now: Code for America)



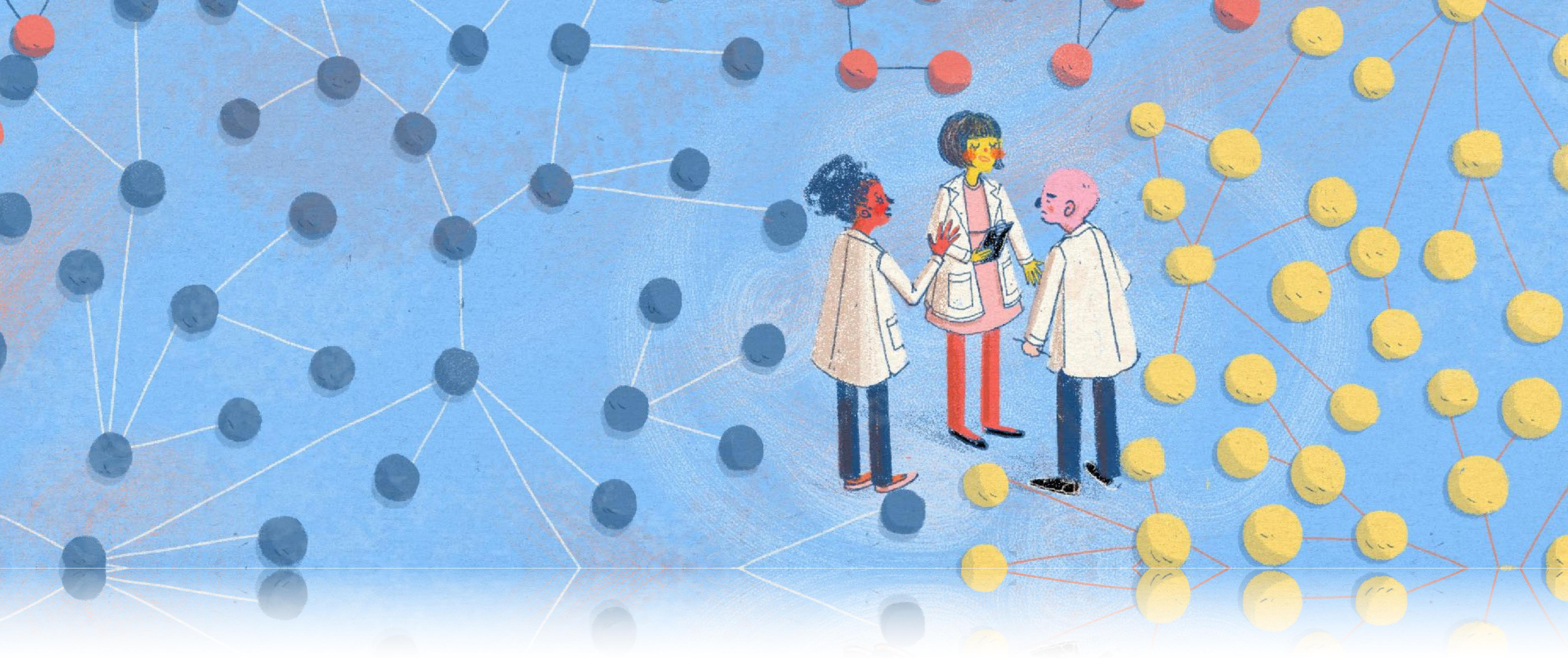
Prof. Skyler Cranmer
(Ohio State)



Prof. Daniel Larremore
(Colorado)

Funding:





fin



papers, code, data

<https://aaronclauset.github.io>