How much of a meritocracy? Untangling the drivers of productivity and prominence among scientists

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science is not a meritocracy

good ideas do not always win out over mediocre ones 👎

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15 years of Alzheimer's research on Aß oligomers

Science **377**, (2022)

even if science is ultimately self-correcting, the great time and effort (and money) sometimes required to self-correct represents a substantial epistemic inefficiency.
and, that only covers the mediocre ideas that succeed, temporarily, without regard to the good ideas that fail to capture our attention.

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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

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Science **377**, (20

Scientific America

Science **164** (1969)

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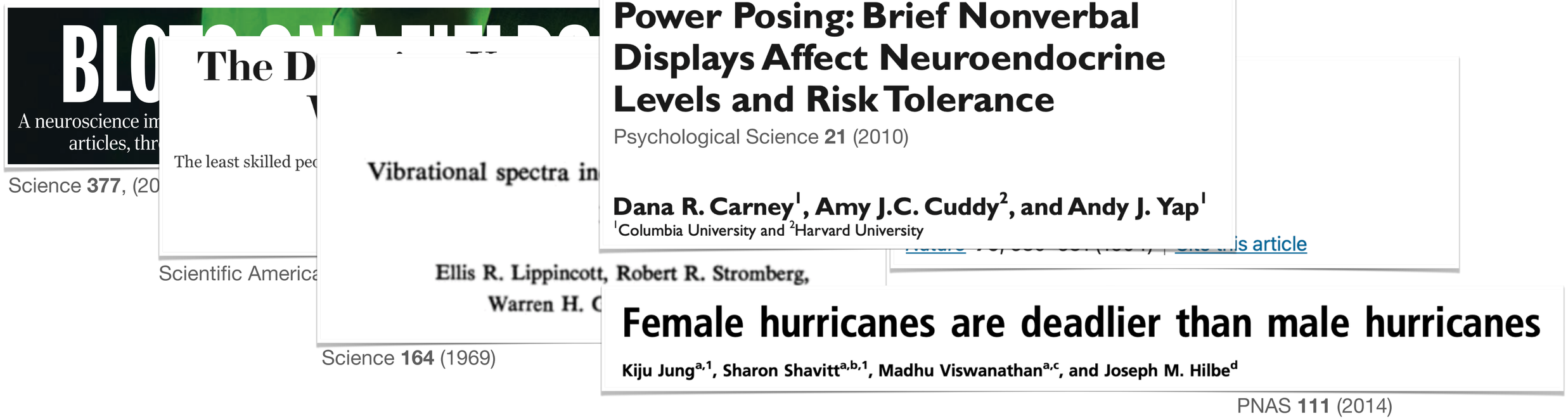
poor experimental design & causal misinterpretations



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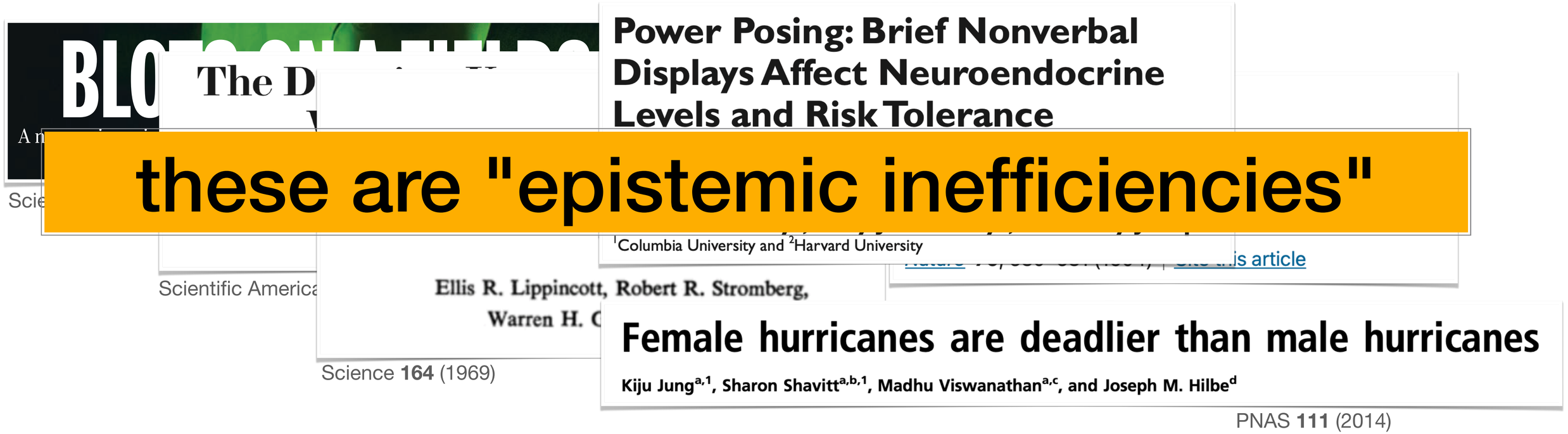

these are "epistemic inefficiencies"

Scientific America

Science **164** (1969)

PNAS **111** (2014)

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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 Samila[2], John-Paul Ferguson[3]

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**

** I am, somehow, less interested in the weight and convolutions of Einstein's brain than in the near certainty that people of equal talent have lived and died in cotton fields and sweatshops.* — Steven Jay Gould, The Panda's Thumb (1980)

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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)

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social biases

***drive* epistemic inefficiencies**

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ON*

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PNAS **117** (2020)

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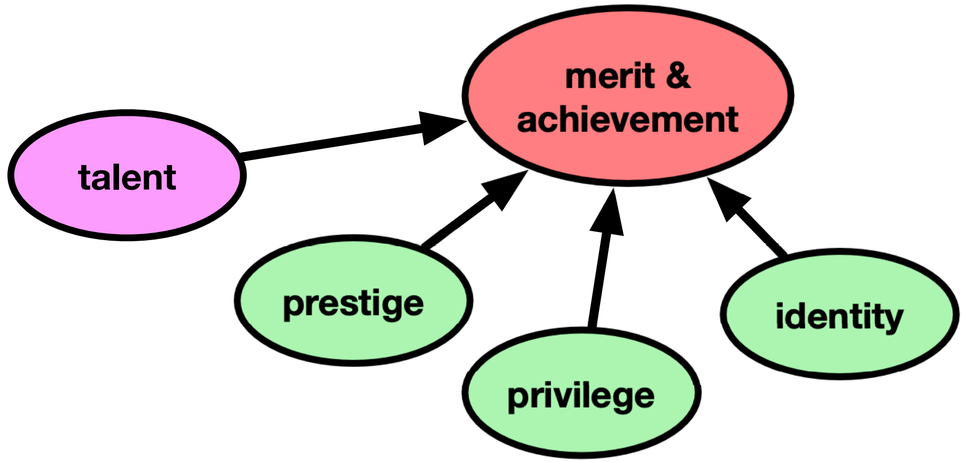
the best scientists are not reliably recognized

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?
- what *drives* scientific productivity and prominence?
- how important is *who* you work with?

 [jobs]

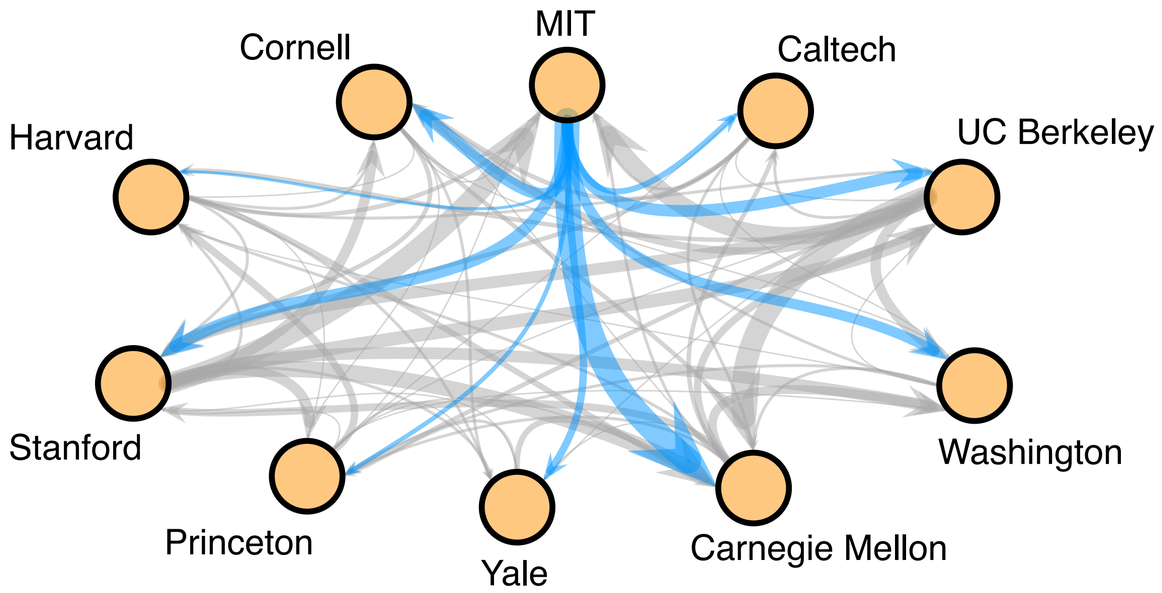
 [ideas]

 [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?



prestige in the sense of Burris (2004)
data generously provided by Academic Analytics Research Center, and carefully curated for data integrity

who hires whose graduates as faculty?

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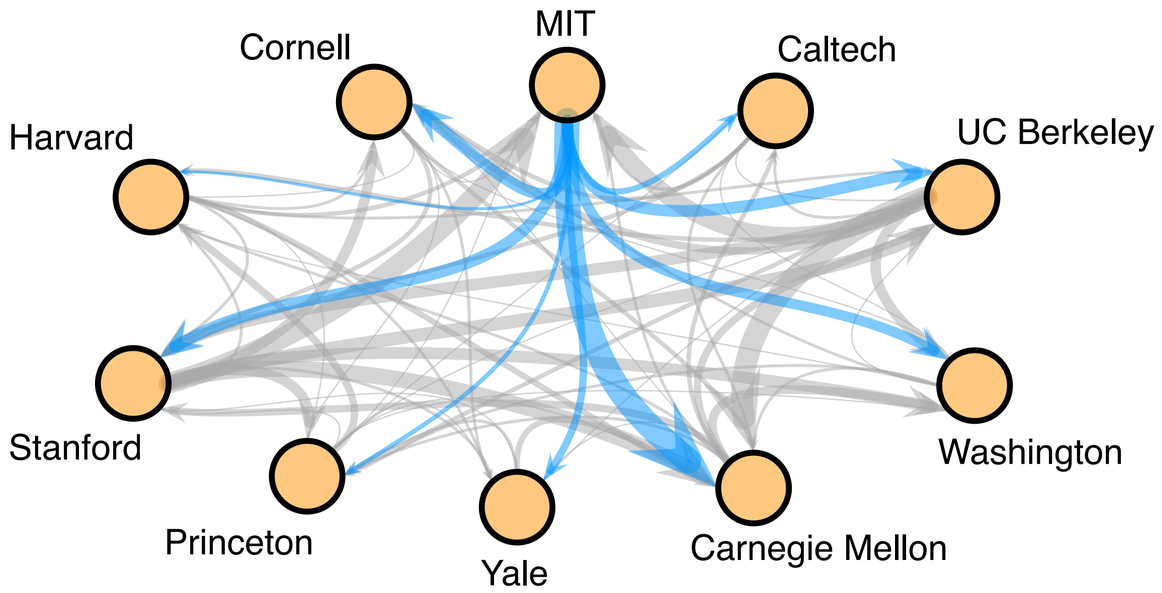
faculty hiring is a *network* → what does its shape tell us about academia?

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?



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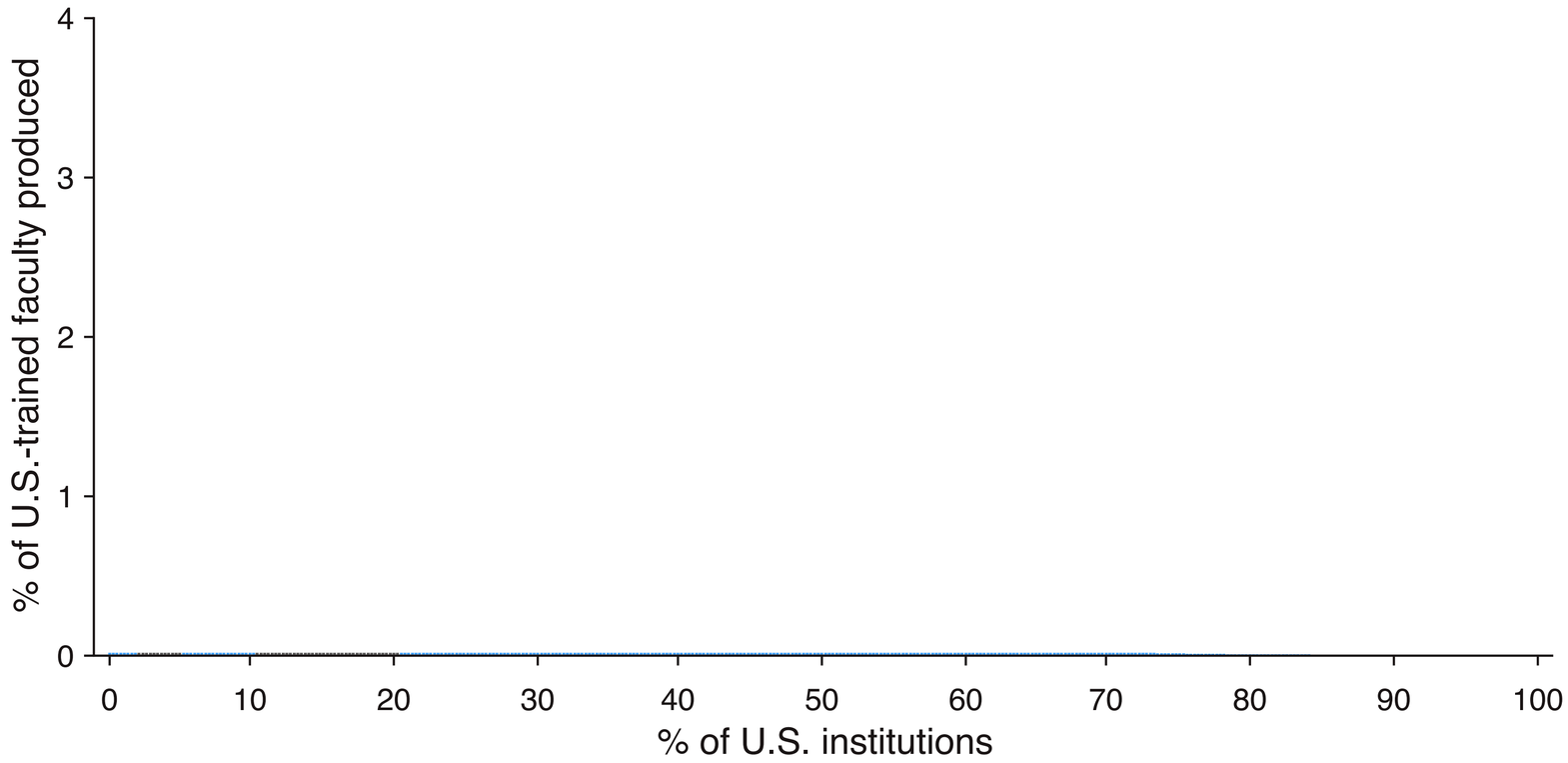
who hires whose graduates as faculty?

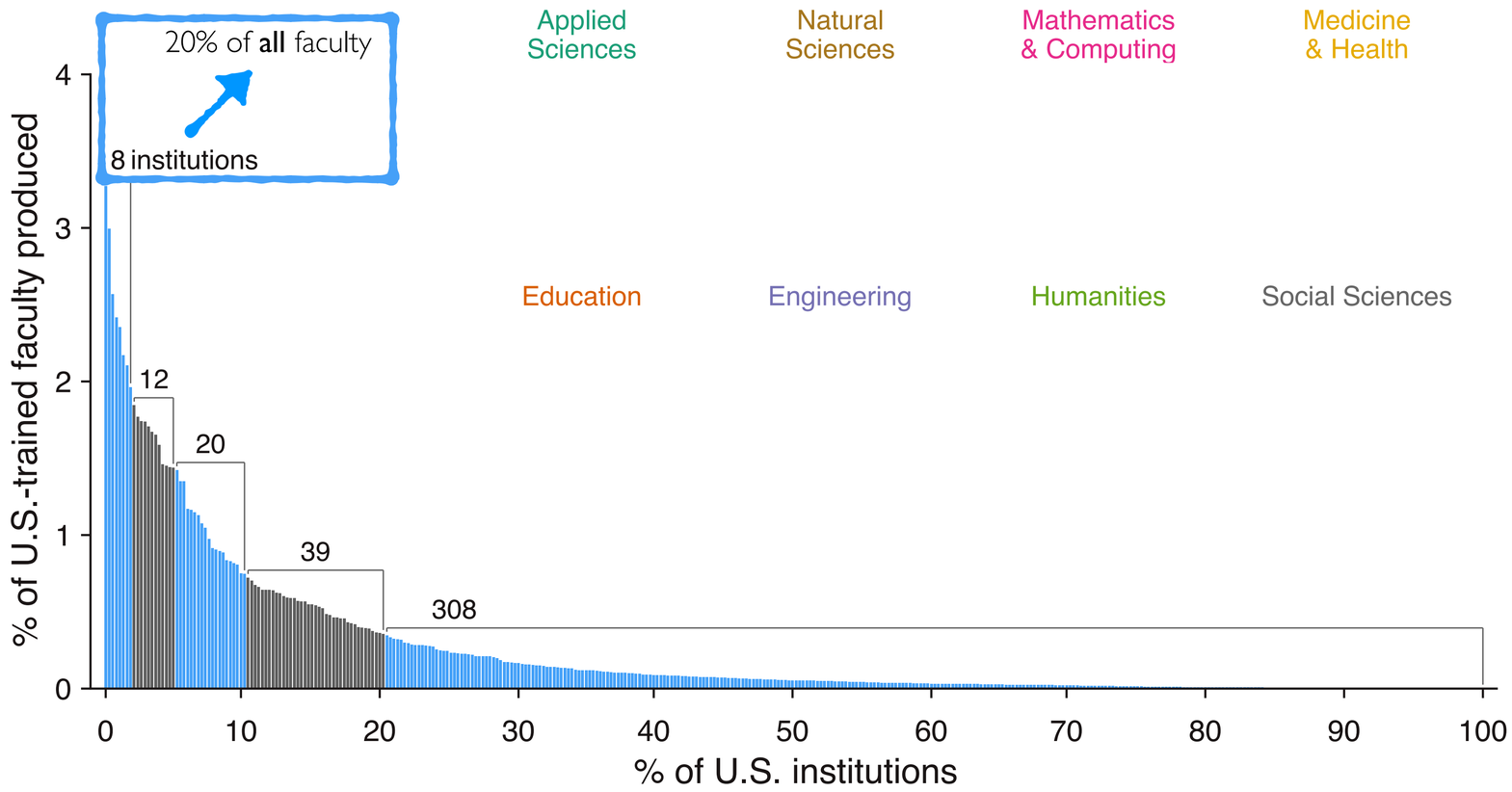
- sort 387 institutions by overall production of faculty



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

who hires whose graduates as faculty?

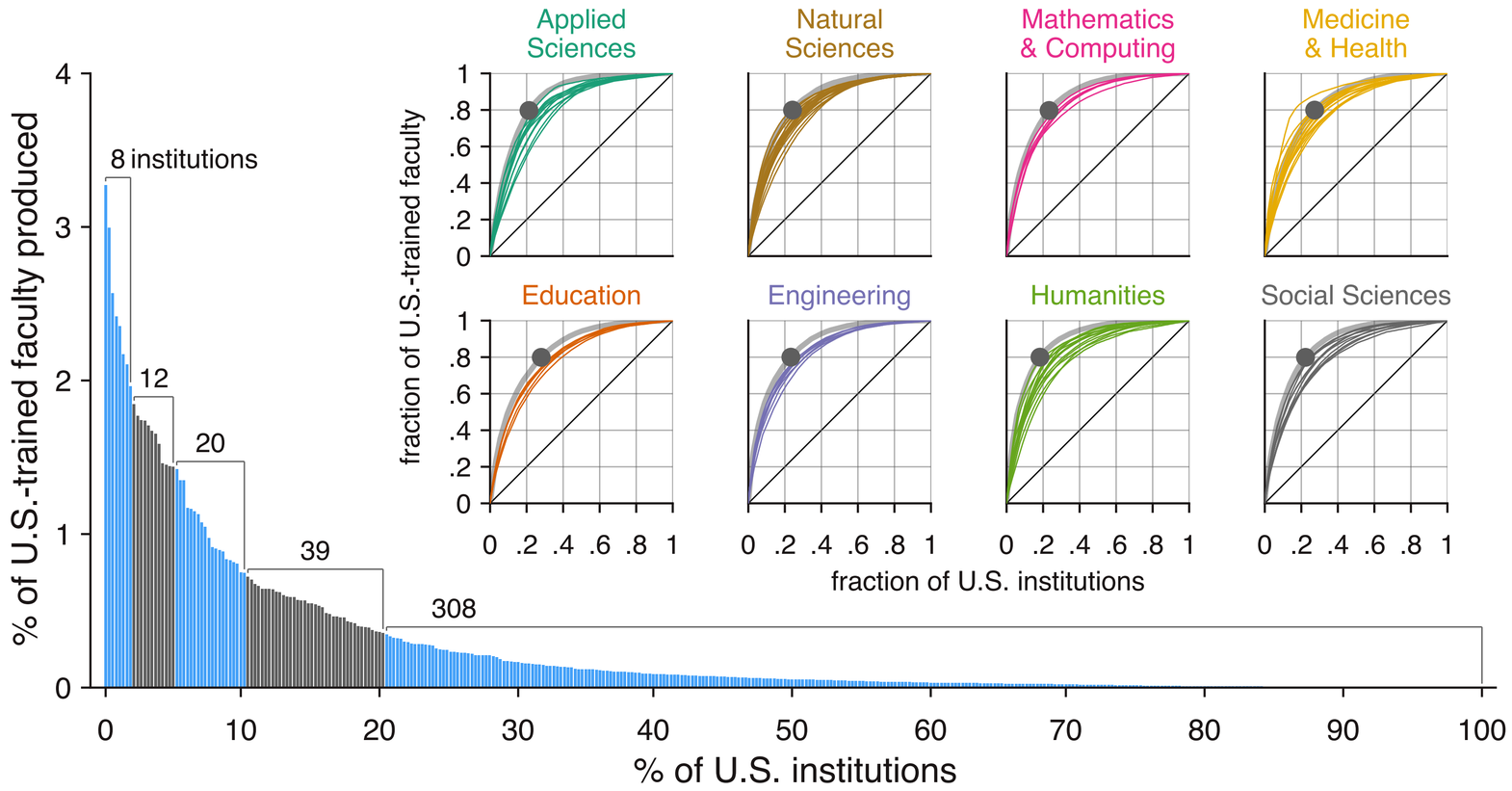
- faculty production is enormously *concentrated*



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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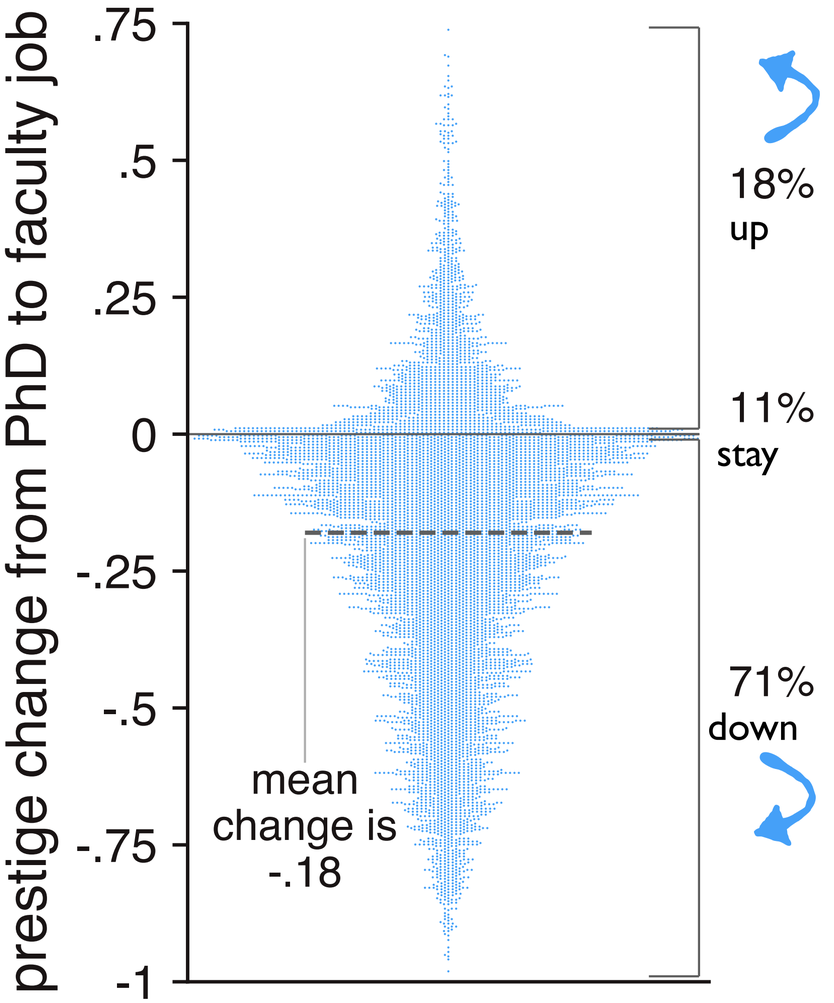
who hires whose graduates as faculty?

- 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

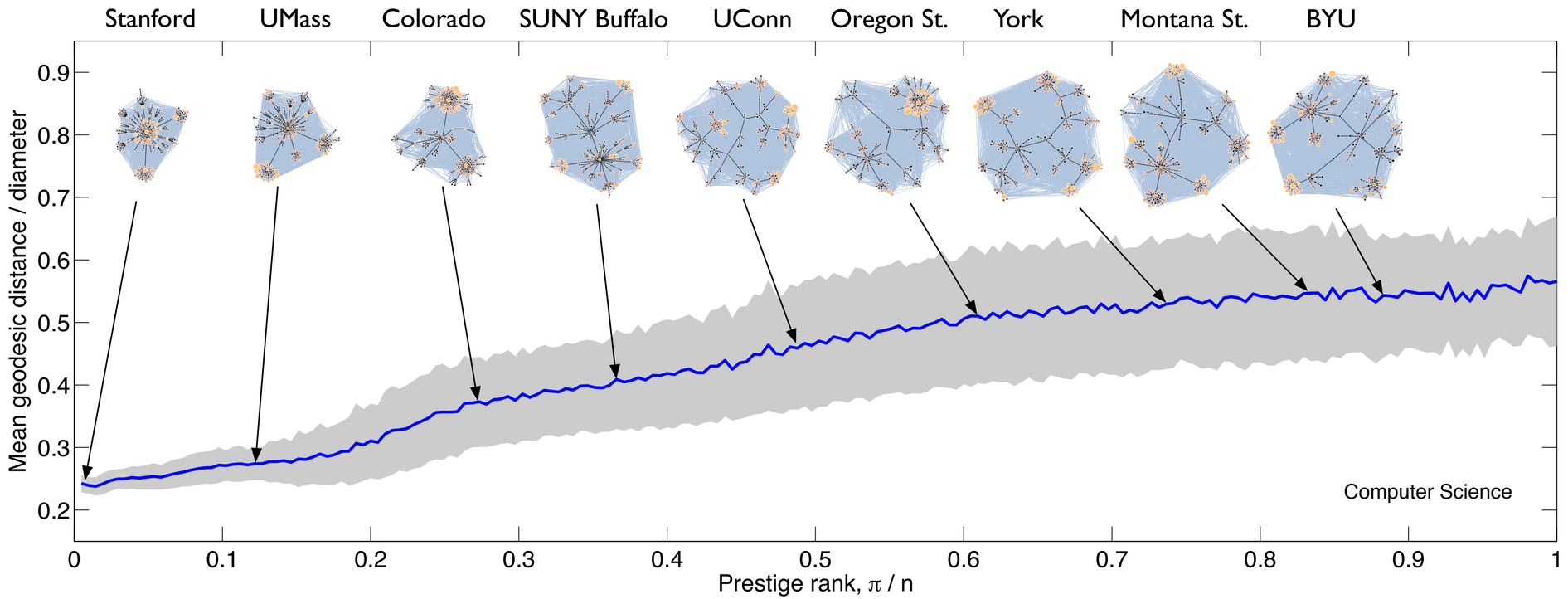


moreover: field-level hierarchies are steeper even than production inequalities predict — it's *not just about* production inequalities.
Wapman et al., "Quantifying hierarchy and dynamics in US faculty hiring and retention" (2022)

who hires whose graduates as faculty?

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

quantifies how "close" all other nodes are to a place, across the network

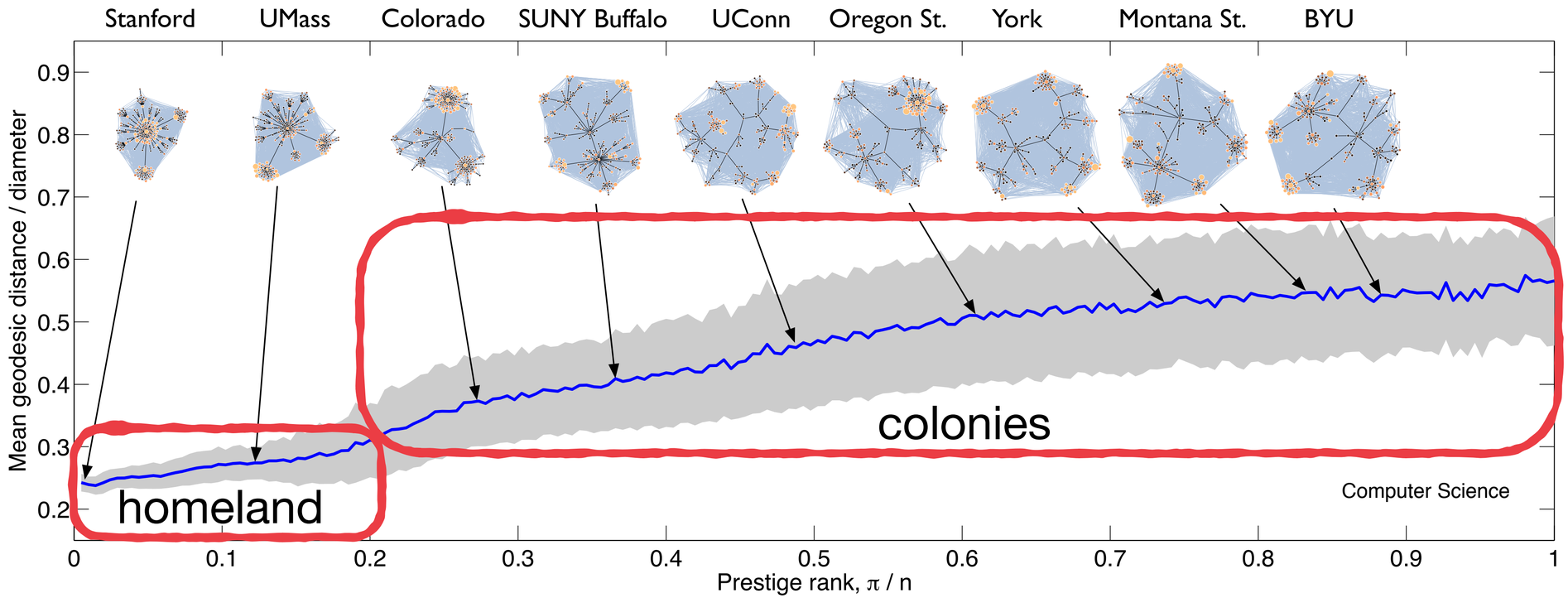


CS faculty hiring, from Clauset et al., "Systematic inequality and hierarchy in faculty hiring networks" (2015), but Wapman et al. (2022) shows the same pattern is universal

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



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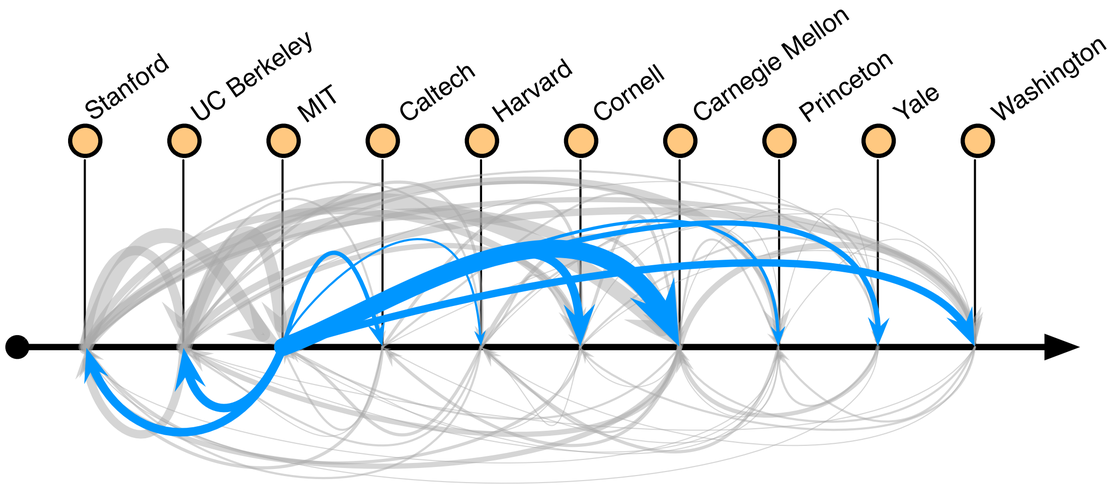
who hires whose graduates as faculty?

- **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? 🔮

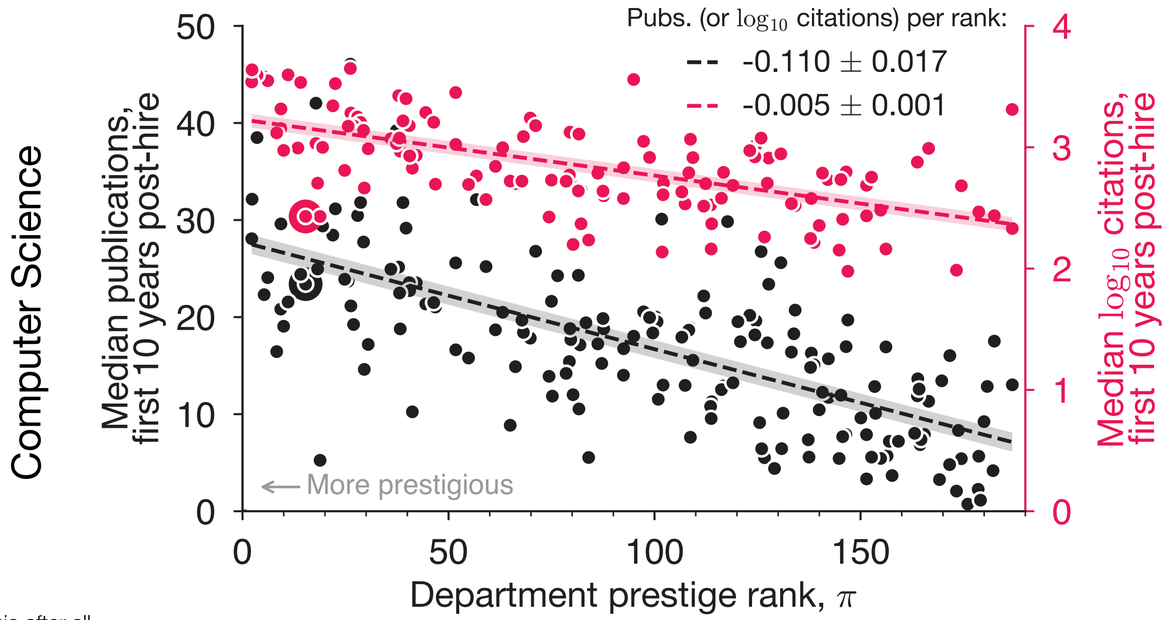
- scientific discourse is dominated by scientists trained + working at elite programs

what drives productivity and prominence? 🔮

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

but elite training ⇄ elite faculty job

endogenous cumulative advantage → past achievements correlate with future achievements



no reason to expect a different pattern in other fields — it's academia after all

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.

  - 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

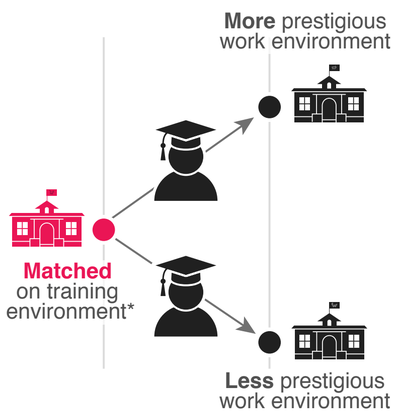
Allison & Long, "Departmental Effects on Scientific Productivity" (1990)

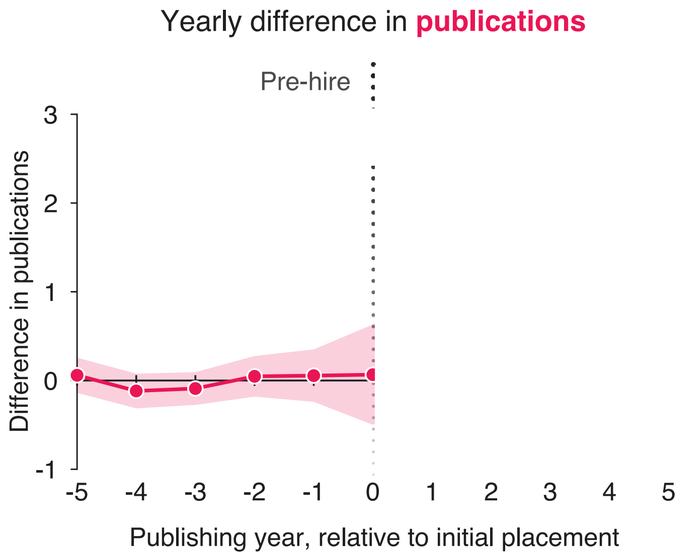
what drives productivity and prominence?

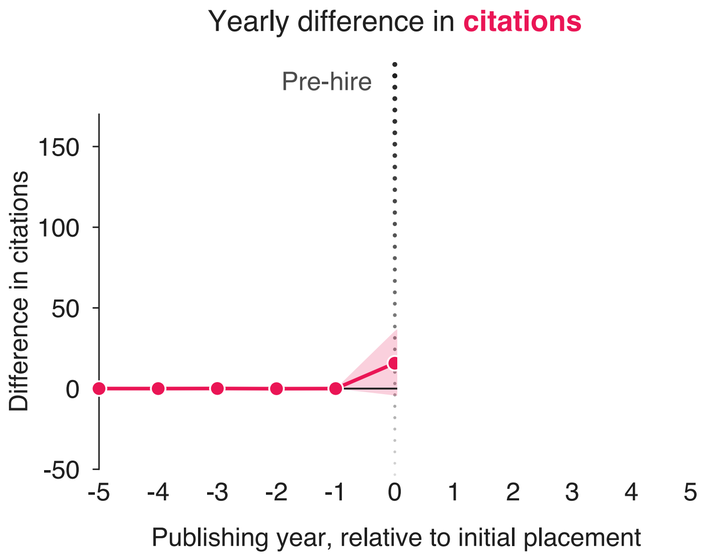
a test: faculty hiring is a quasi-natural experiment

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

match faculty pairs on *similar training, different placement*







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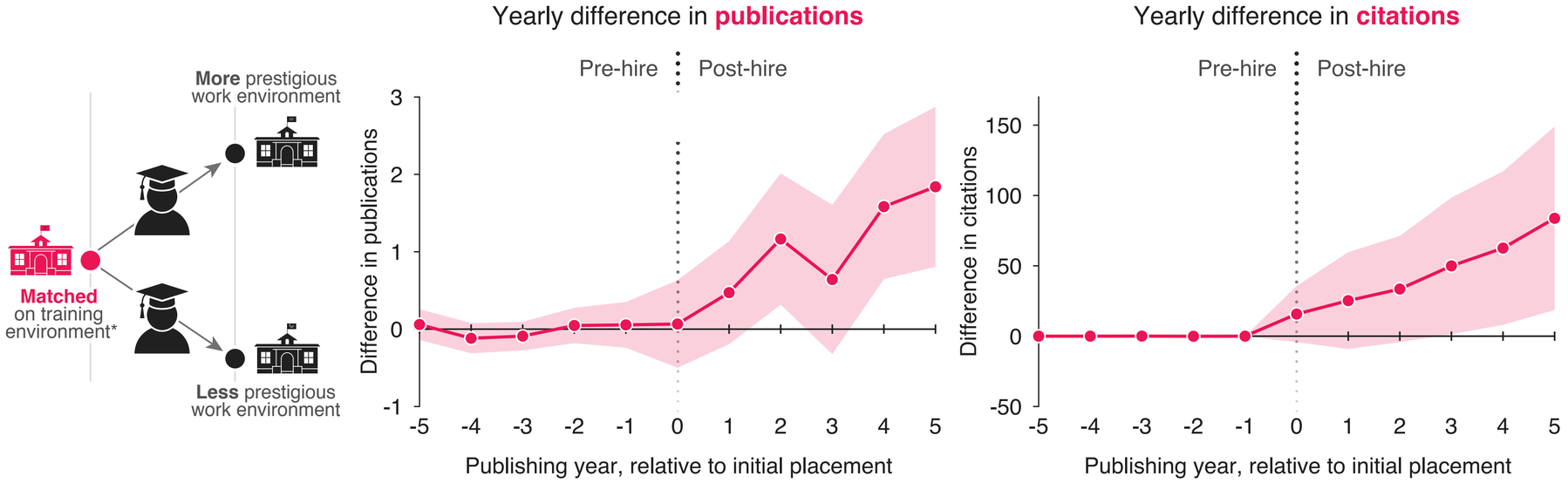
match faculty pairs on similar training, different placement → *different productivity & prominence*



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what drives productivity and prominence?

- **prestige** is a *structural variable* in the science of science

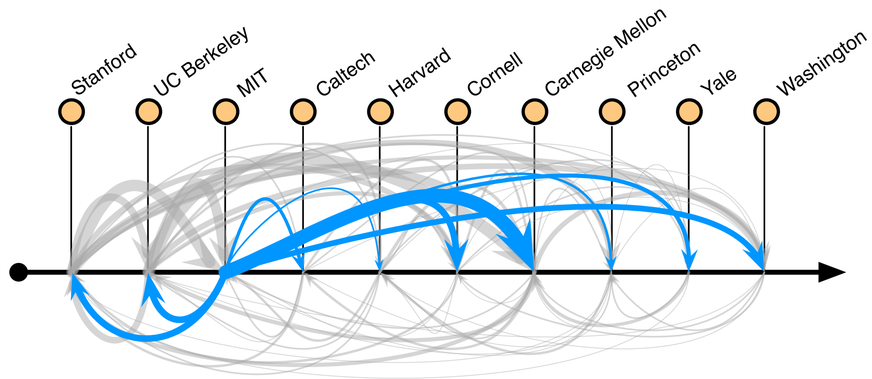
  elite training does not drive scholarly productivity or prominence

  working environment—not training—appears to drive scholarship

- why do elite institutions dominate science?

  doctoral prestige → faculty location

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



we couldn't control for recommendation letters, job talk quality, charisma, future funding prospects, etc., which may correlate with greater future productivity / prominence. however, these should correlate with pre-hire productivity, which we control for. further, research on mid-career moves supports our finding (see Allison & Long 1990)

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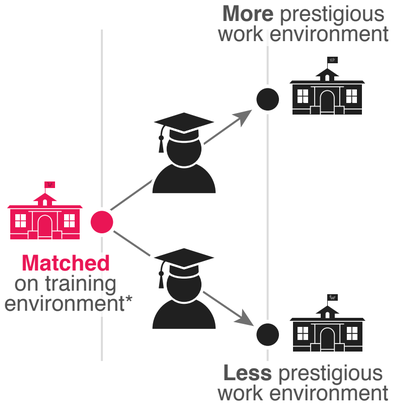
  doctoral prestige → faculty location → scholarly impact

  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 Wapman[2], Daniel B. Larremore[2,3], Aaron Clauset[2,3,4]*

Science Advances **8**, eabq7056 (2022)

Zhang et al. "Labor advantages drive the greater productivity of faculty at elite universities" (2022)
the mechanism is not selection or retention of more productive faculty, and not norms of higher productivity — see paper for those tests
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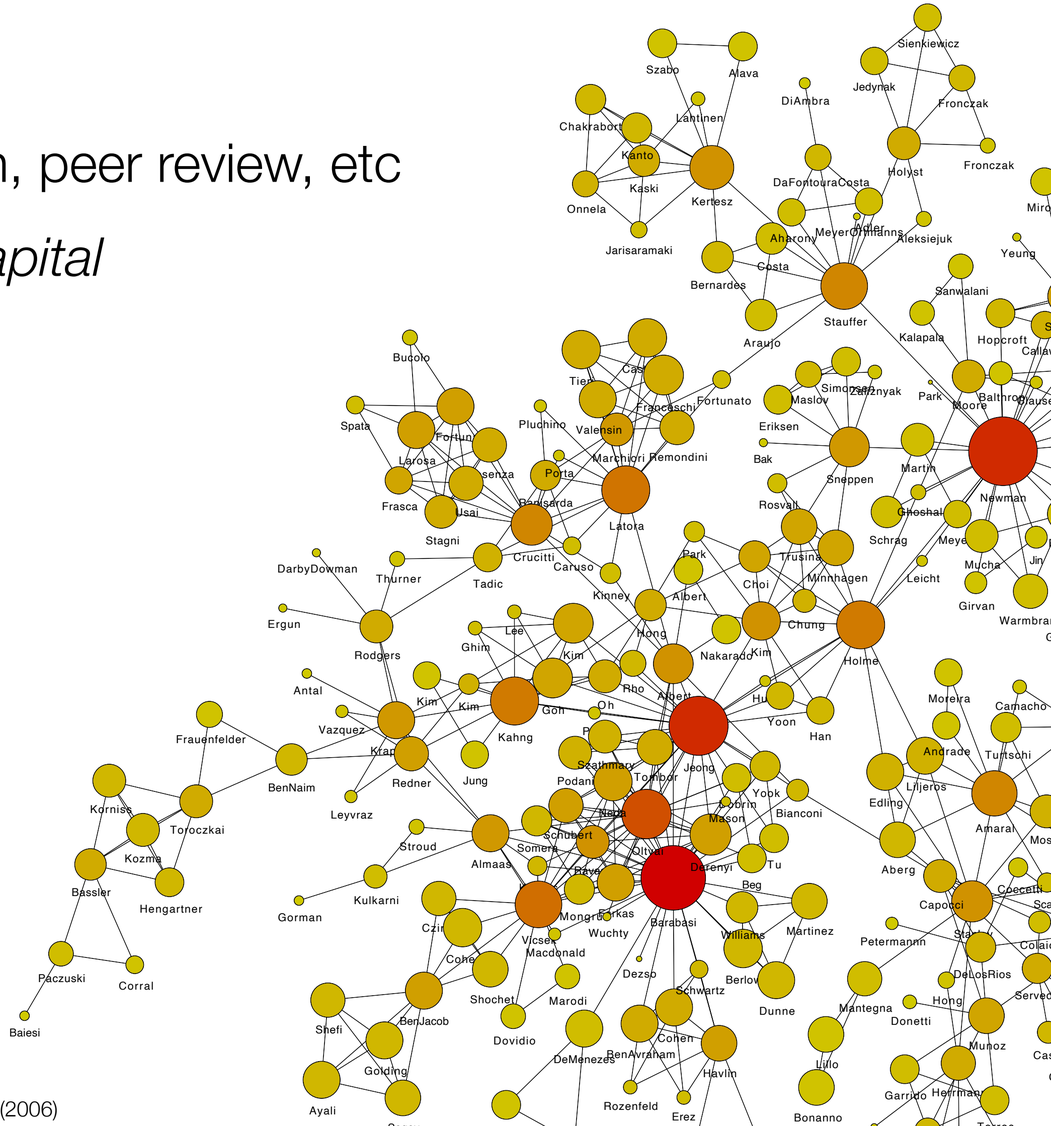
however, these should correlate with pre-hire productivity, which we control for. further, research on mid-career moves supports our finding (see Allison & Long 1990)

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*



partial figure of 379 network scientists in 2006 and their collaborations, from Newman "Finding community structure in networks using the eigenvectors of matrices" (2006)

how important is who you work with?

- *networks* mediate most scientific activities:

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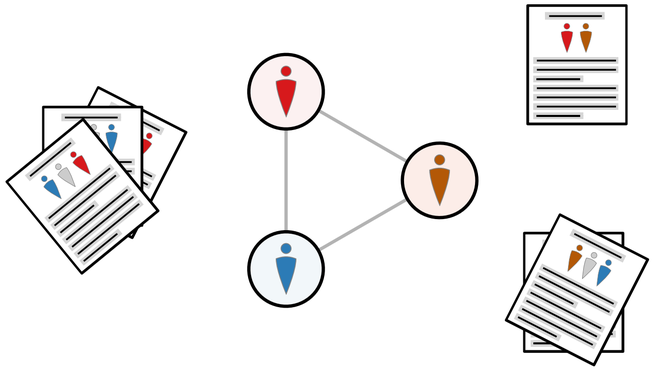
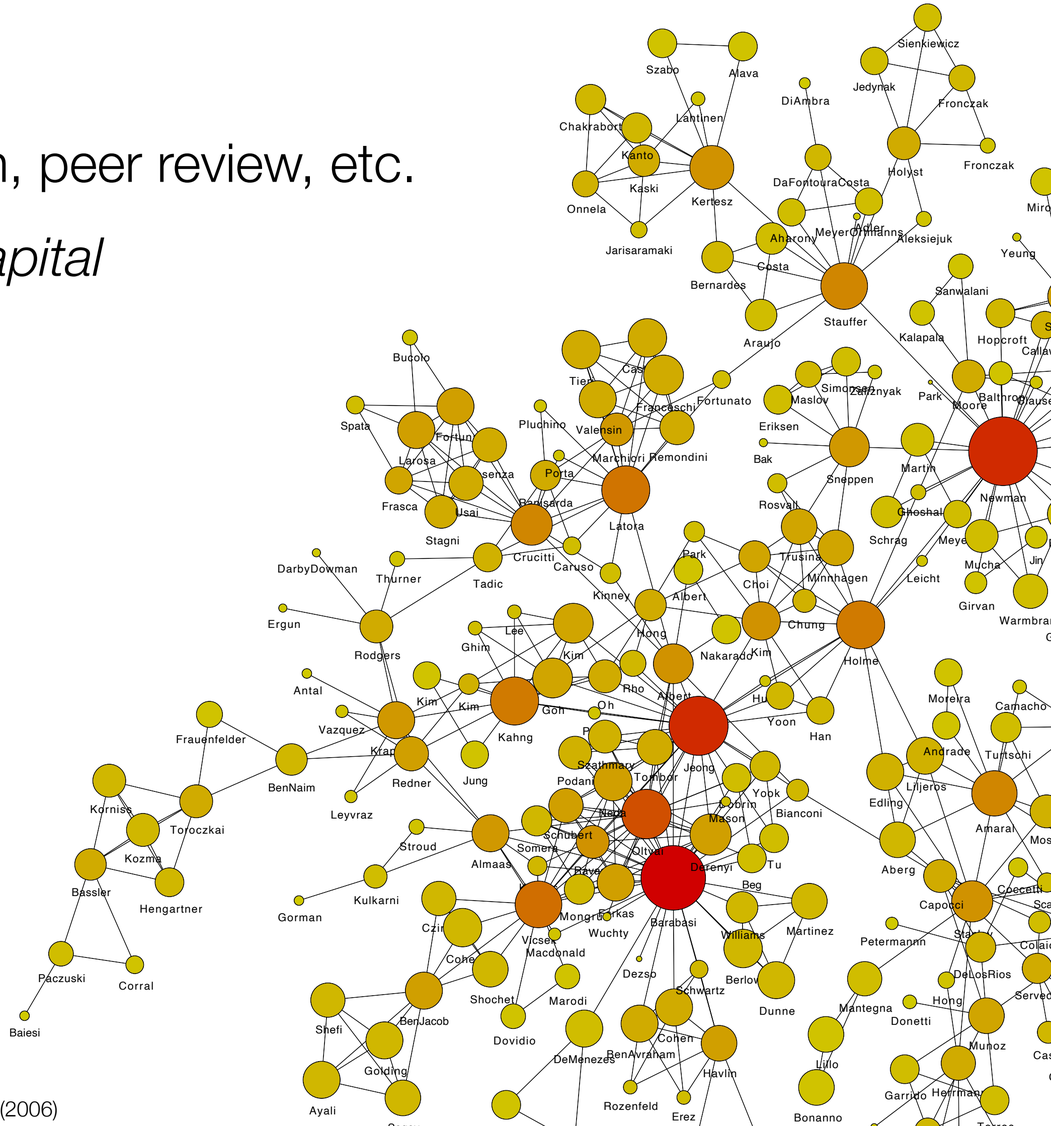
  networks act like a form of *unequally distributed social capital*

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



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



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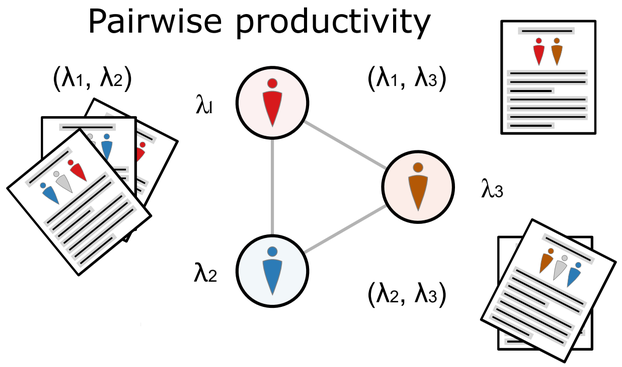
untangling the network's effects

- 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

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

given time period

Li et al., "Untangling the network effects of productivity and prominence among scientists" (2022)

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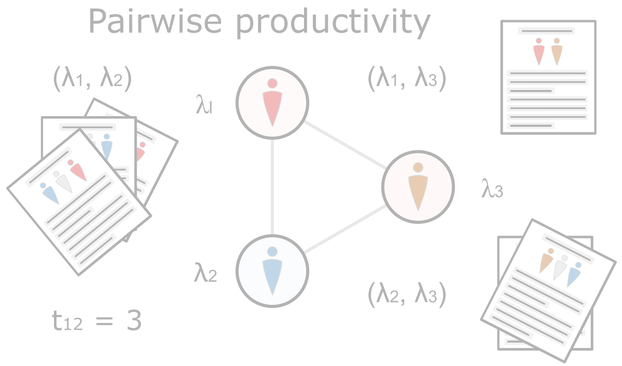

number (i, j)-coauthored papers

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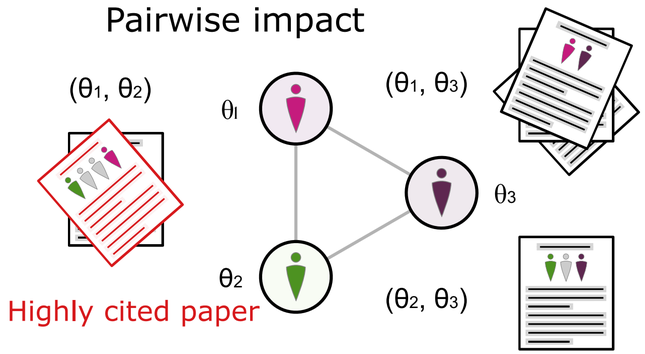
given time period

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



number (i, j)-coauthored papers

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

number of "high impact" papers

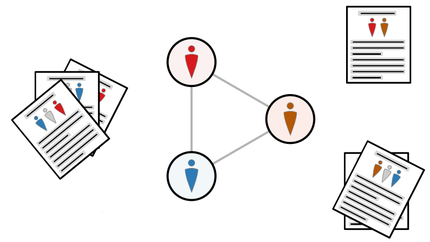
Li et al., "Untangling the network effects of productivity and prominence among scientists" (2022)

untangling bibliographic data

Microsoft Academic Graph (MAG) 1950—2019

Microsoft Research

- 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



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.

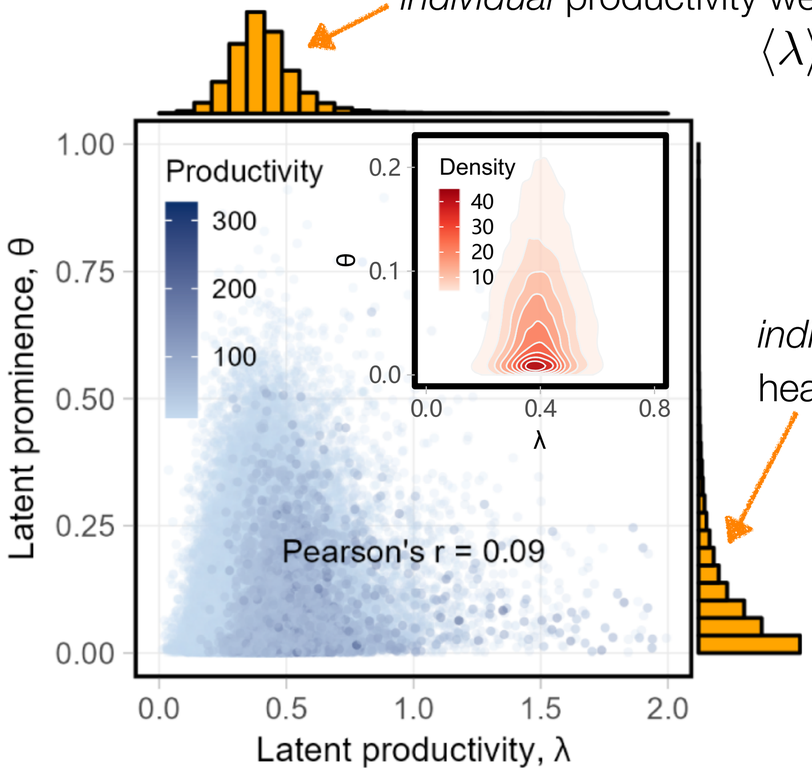
"field" is given by MAG's level-0 classification — there are 19 of these, 6 of which we select
prestige measure must be international, and production of highly cited papers generally correlates well with other national measures of prestige — define "elite" as top 10 institutions under z-score of total highly cited papers over time period
prior to estimation, prune all subtrees of collaboration network — model parameters are non-identifiable on trees; robustness analysis indicates prestige (lower) but no gender correlation with dropped authors

model checking

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

individual productivity well-concentrated ✅

$\langle \lambda \rangle = 0.42$ papers / year



individual prominence highly skewed ✅

heavy-tailed $\Pr(\theta)$

dots omitted if $\hat{\theta} < 10^{-3}$ (researchers with no highly cited papers)

model checking

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

individual productivity well-concentrated

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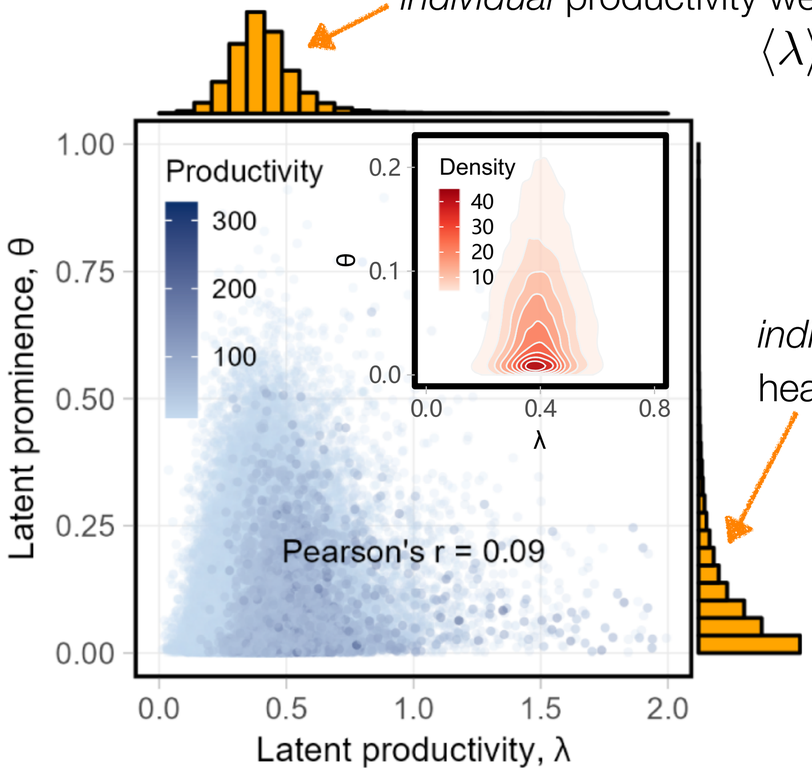

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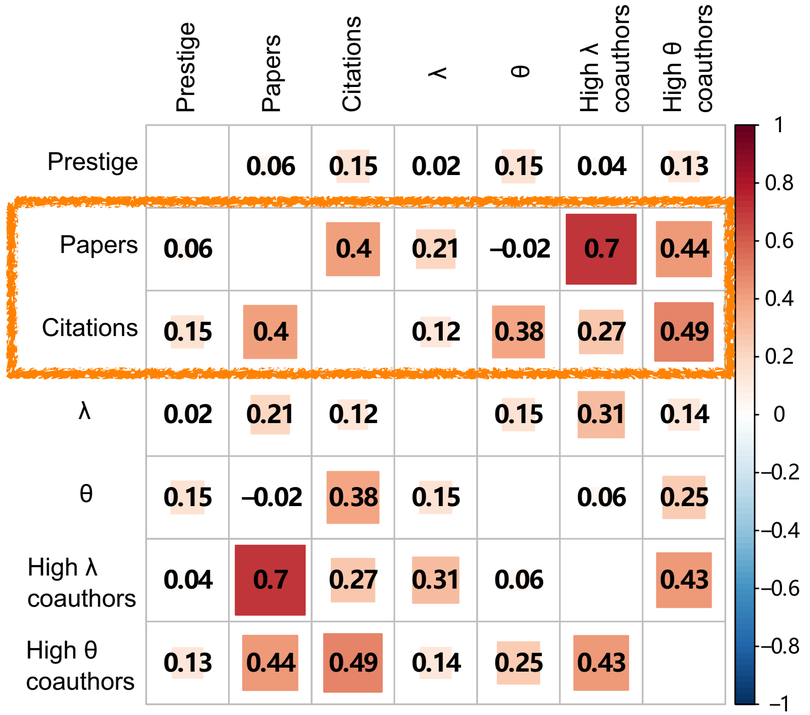


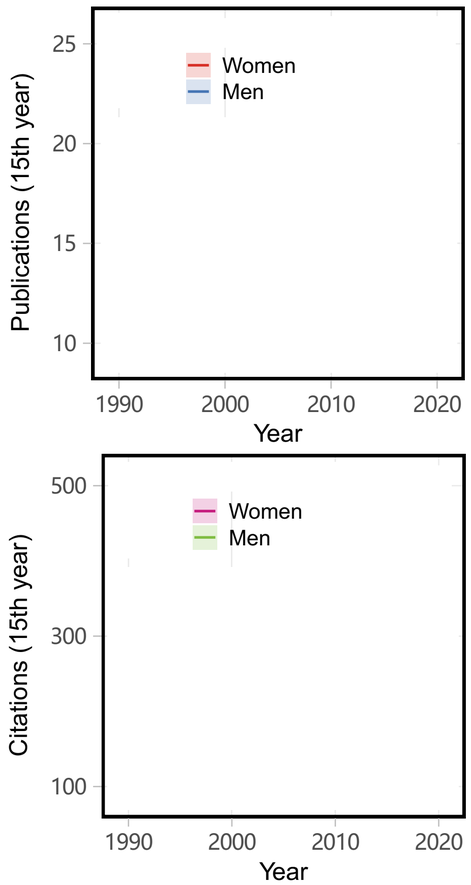
✅ my paper count = highly correlated with high λ coauthors

✅ my citations = well correlated with high λ & θ coauthors

dots omitted if $\hat{\theta} < 10^{-3}$ (researchers with no highly cited papers)

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



eg, Madsen et al., "Author-level data confirm the widening gender gap in publishing rates during COVID-19" (2022)

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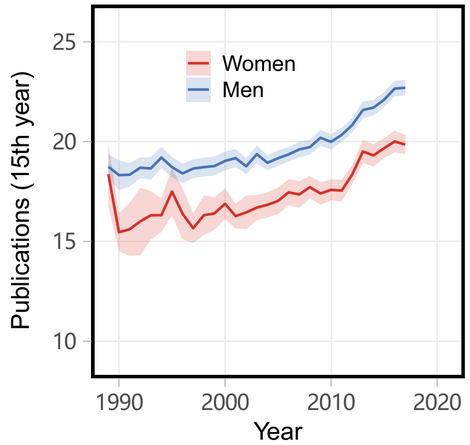
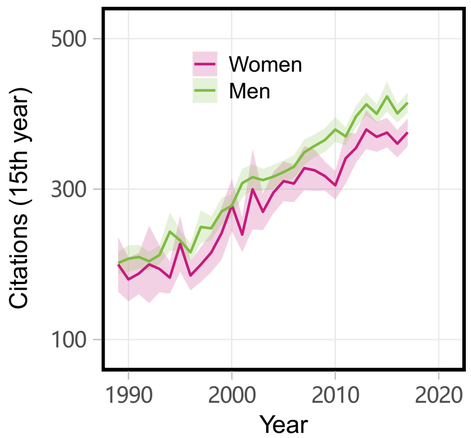




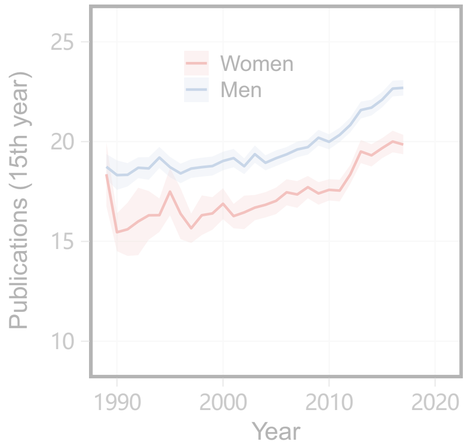
substantial gendered differences in "raw" productivity and prominence

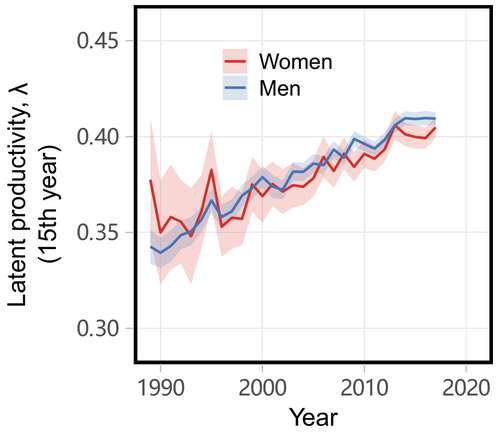
- men much more productive
- men slightly more prominent

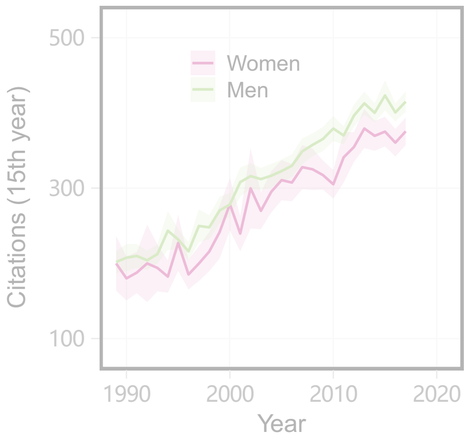
shaded areas are 95% confidence intervals

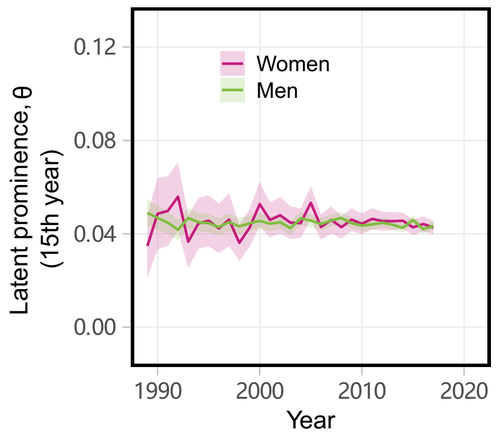
gender vs. productivity & prominence

- 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* ✅

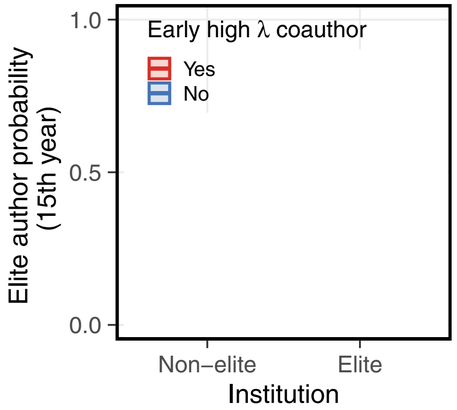
- size and composition of collaboration networks is gendered
- latent productivities increase steadily
- latent prominence stable over time

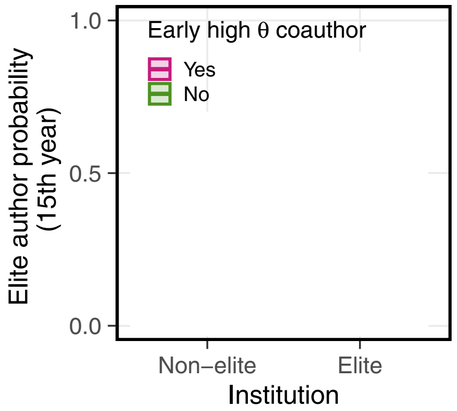
*not causal, but implies effects of known gendered causal factors on productivity (eg, parenthood) may operate by reshaping collaborating networks

see Morgan et al. "The unequal impact of parenthood in academia." (2021)

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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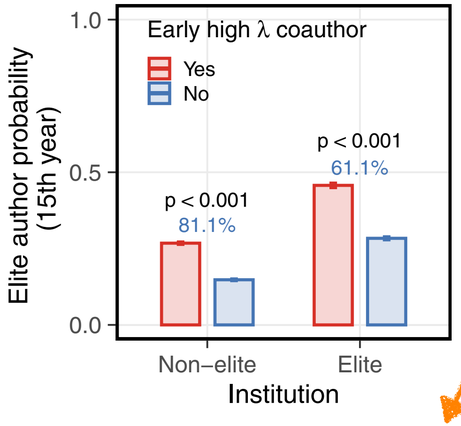

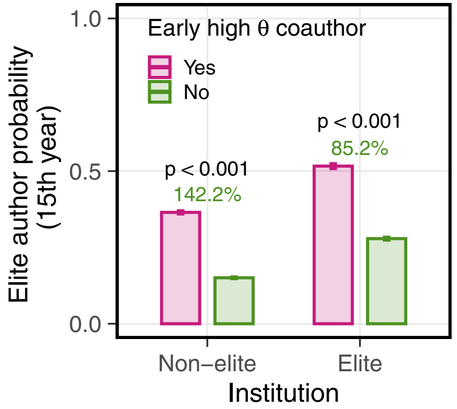

high-λ or early high-θ early collaborator substantially increases likelihood of high prominence in mid-career

- 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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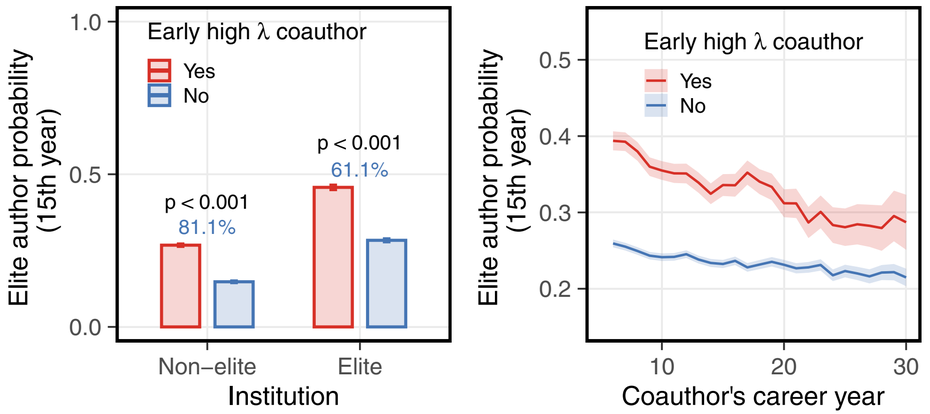

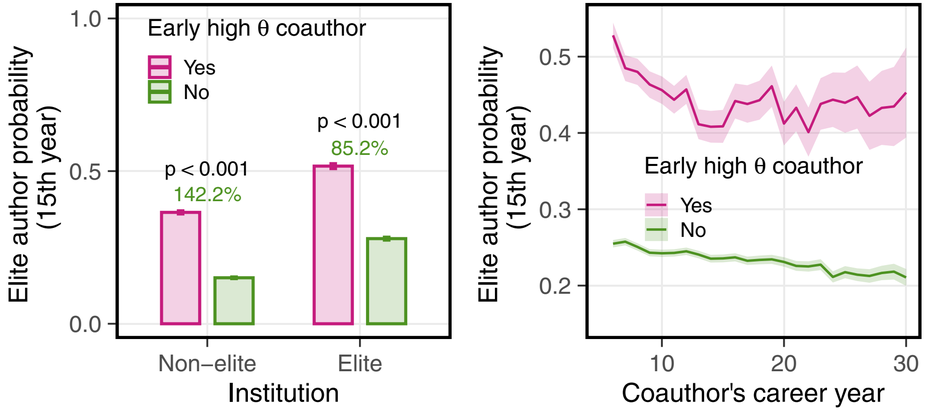

the 'benefits' are substantial regardless of coauthors career age

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

elite institutions = top 10 by *z*-score of high impact papers
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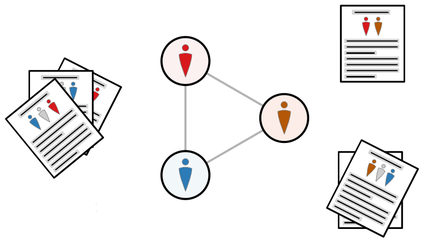
how important is who you work with?

networks act like unequally distributed social capital in science

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



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)

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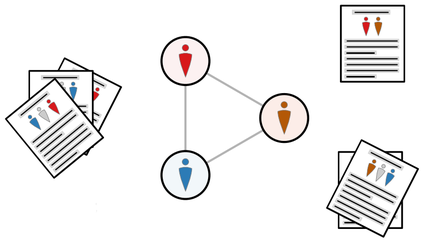

differences in collaboration networks can explain

- 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

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

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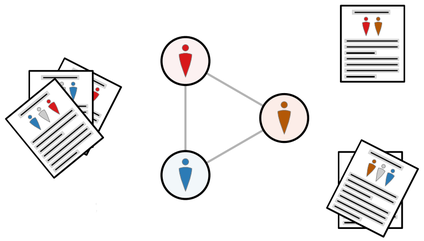

differences in collaboration networks can explain

- 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?

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how much of a meritocracy?

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

- prestige pervades and structures the scientific ecosystem

prestige in the sense of Burris (2004), as a form of social capital

how much of a meritocracy?

"*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

} 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)

prestige in the sense of Burris (2004), as a form of social capital

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 Wapman[1]✉, Sam Zhang[2], 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 Wapman[2], Daniel B. Larremore[2,3], Aaron Clauset[2,3,4]*

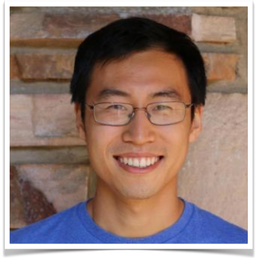
Science Advances 8, eabq7056 (2022)

Untangling the network effects of productivity and prominence among scientists

Weihua Li[1,2,3,4]✉, Sam Zhang[5], Zhiming Zheng[1,2,3,4], Skyler J. Cranmer[6] & Aaron Clauset[7,8,9]

Nature Communications 13, 4907 (2022)

Dr. Samuel F Way
(now: Spotify)



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Dr. Allison Morgan
(now: Code for America)

Prof. Skyler Cranmer
(Ohio State)

Prof. Daniel Larremore
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