

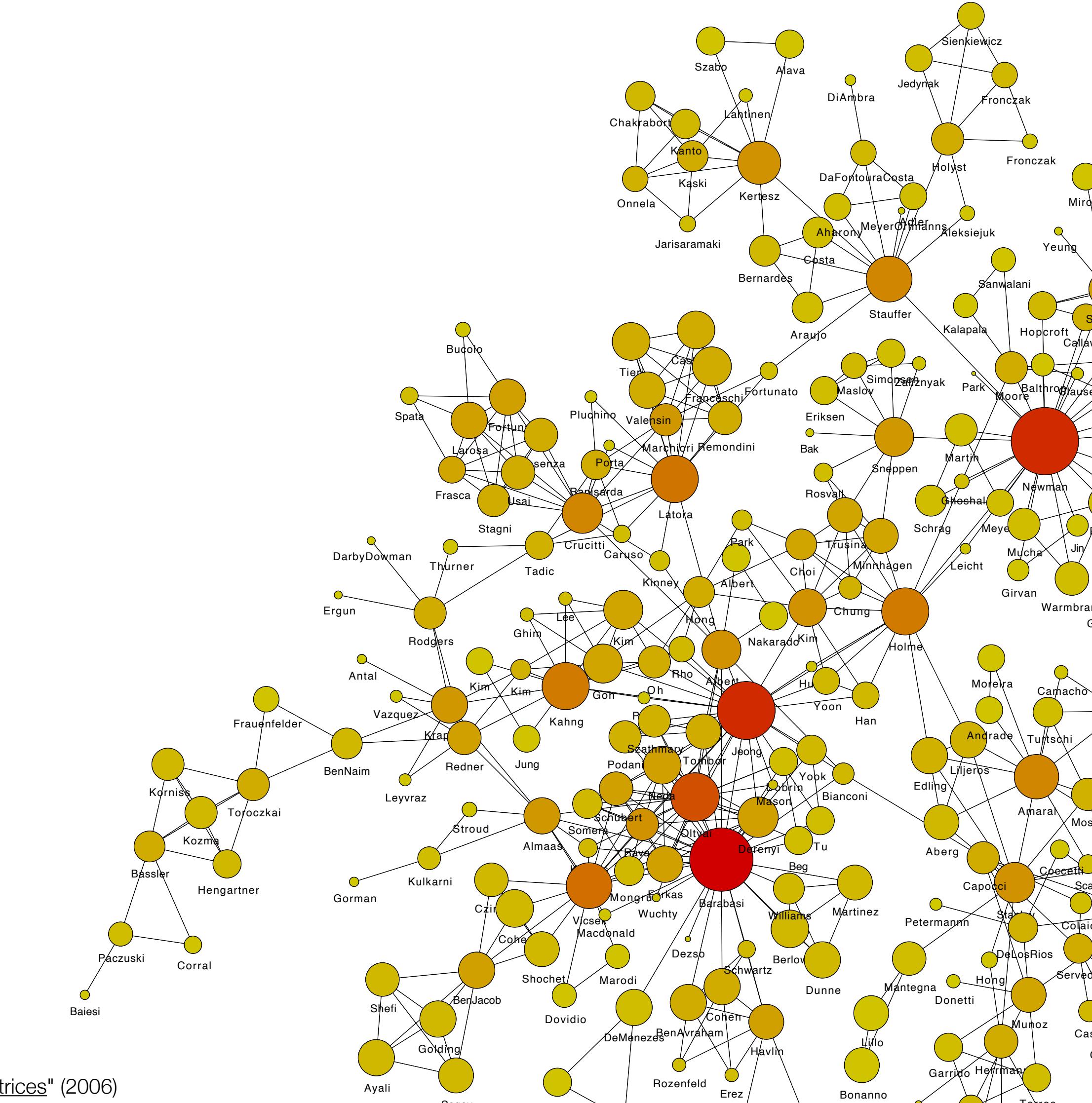
Networks untangle gender differences in productivity and prominence among scientists

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Computer Science Dept. & BioFrontiers Institute
University of Colorado, Boulder
External Faculty, Santa Fe Institute



network effects in scientific labor

► networks mediate most scientific activities

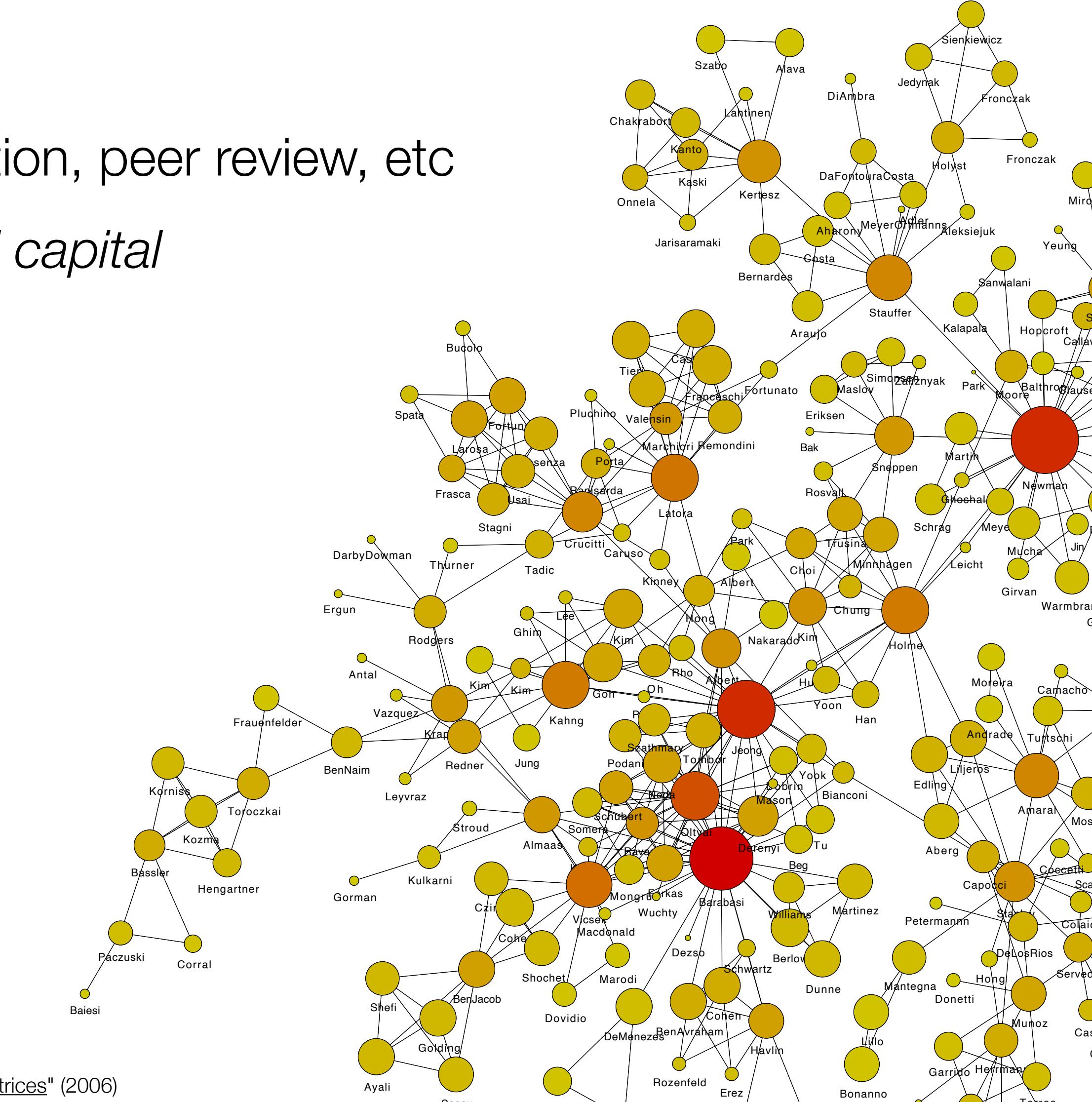


network effects in scientific labor

▶ networks mediate most scientific activities:

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

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



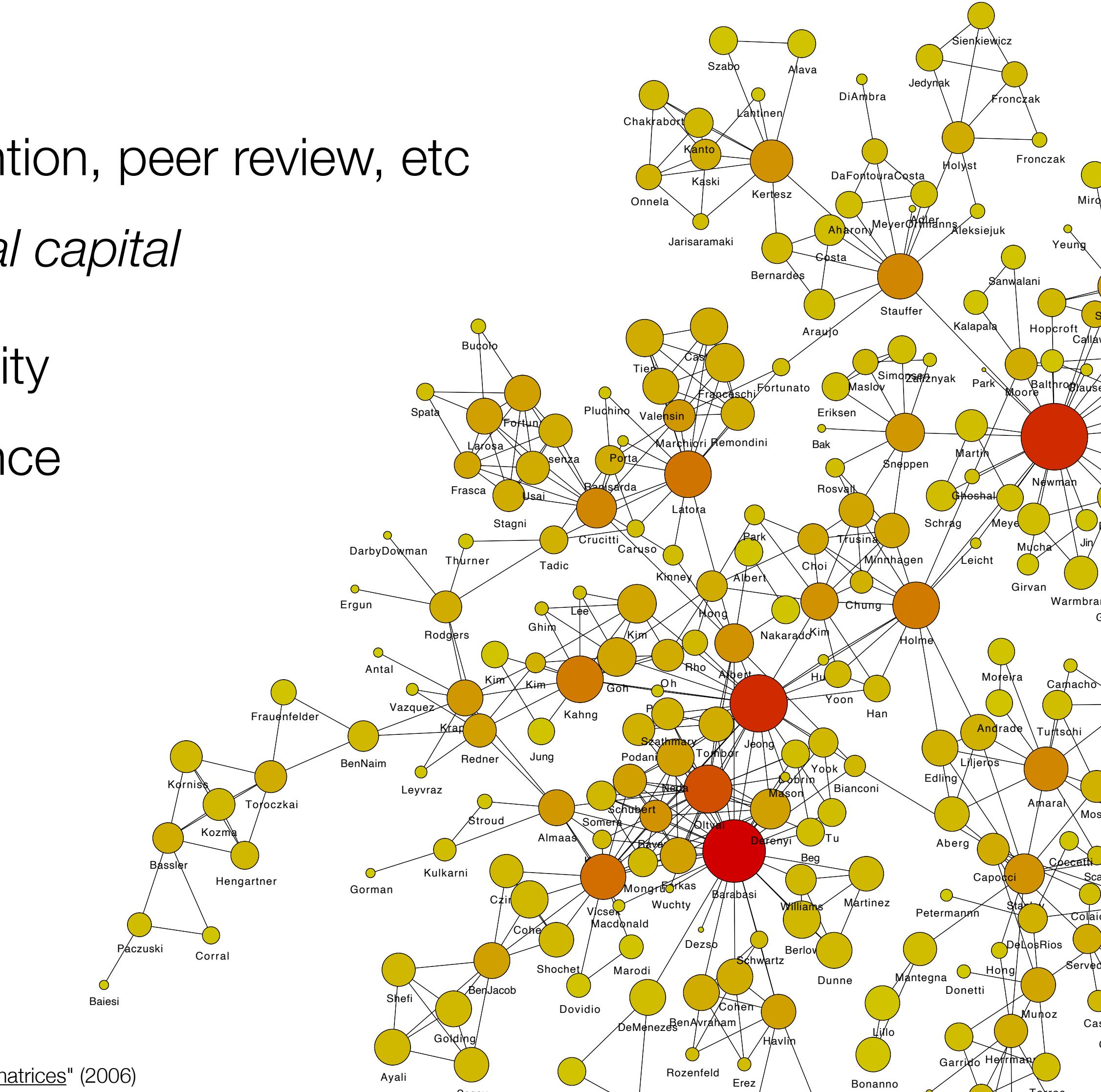
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- a prominent collaborator → increases your prominence



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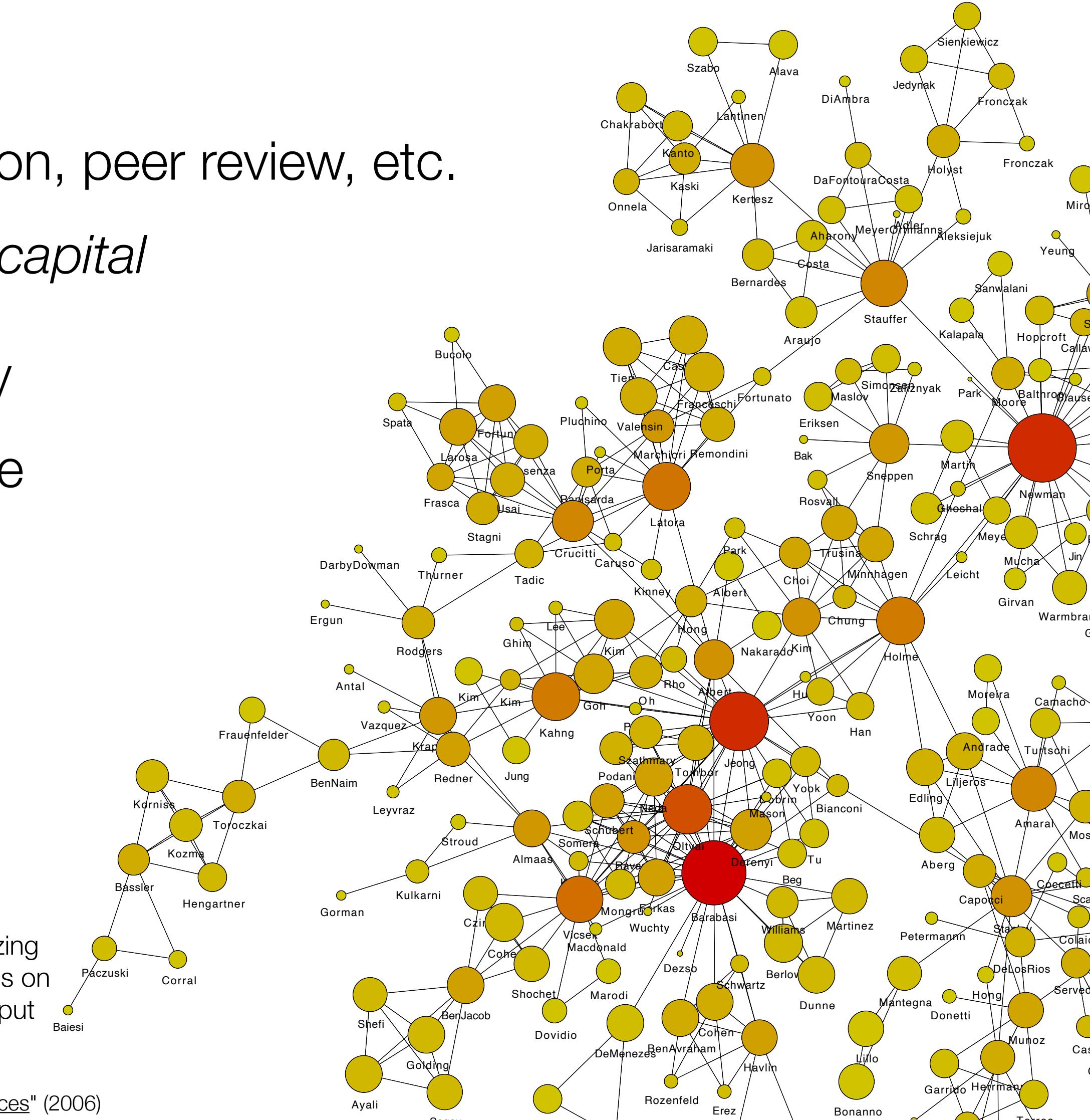
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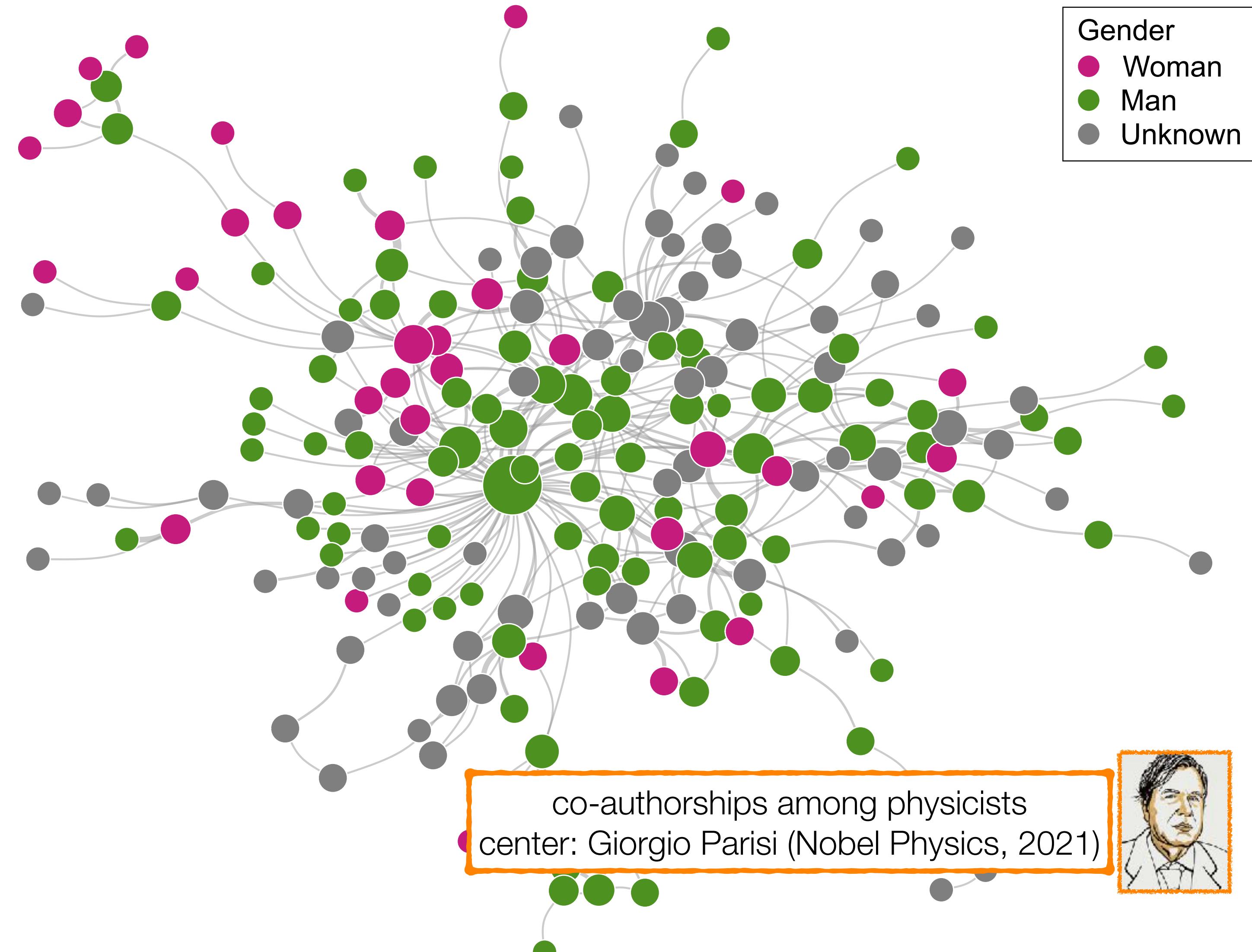


how much does who you work with impact
your productivity and prominence?

this requires marginalizing
out the network's effects on
a node's scholarly output

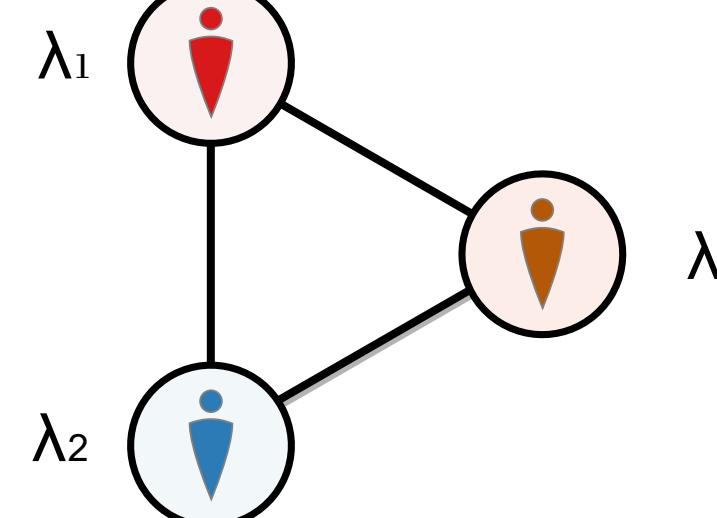


untangling the network's effects

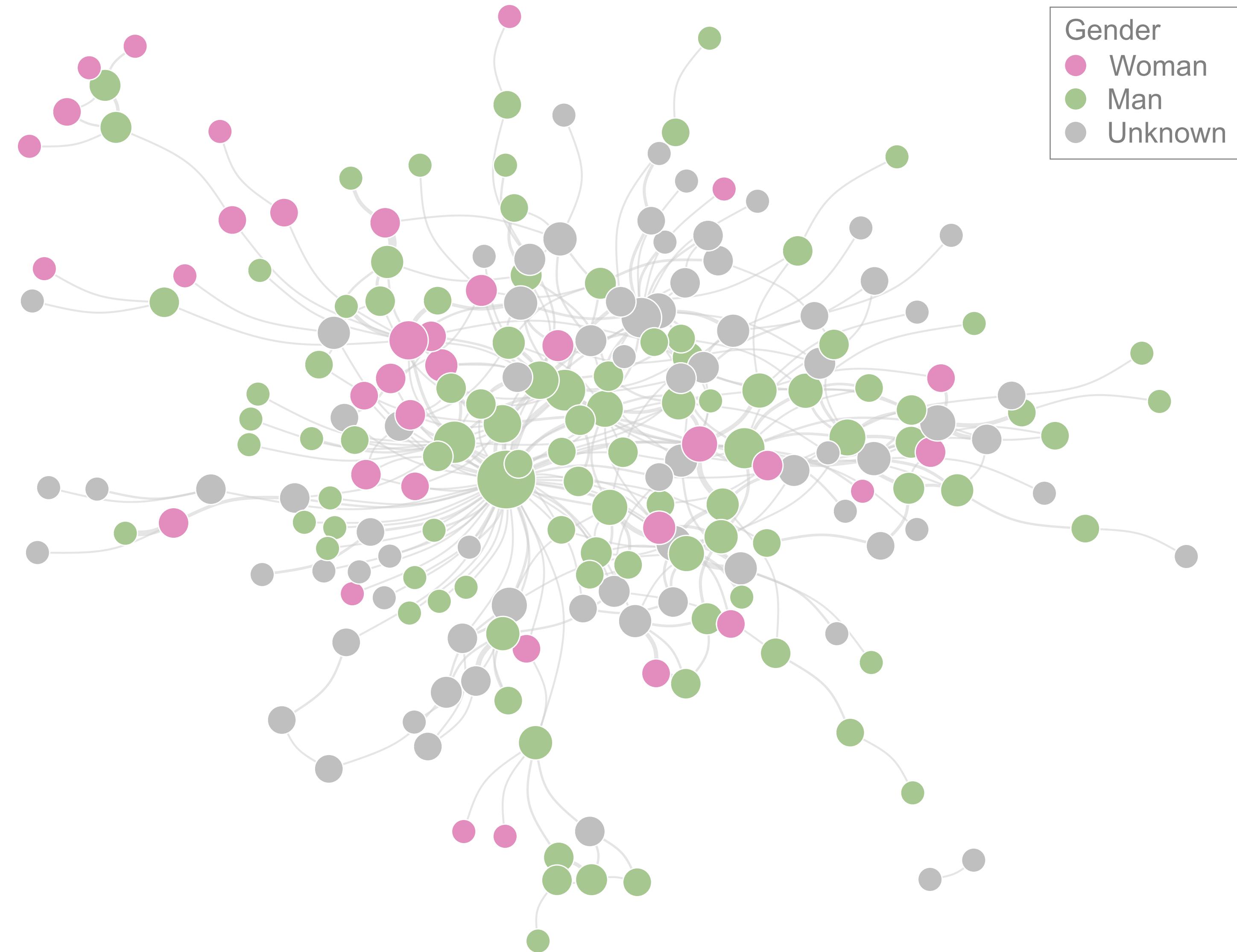


untangling the network's effects

Coauthorship network

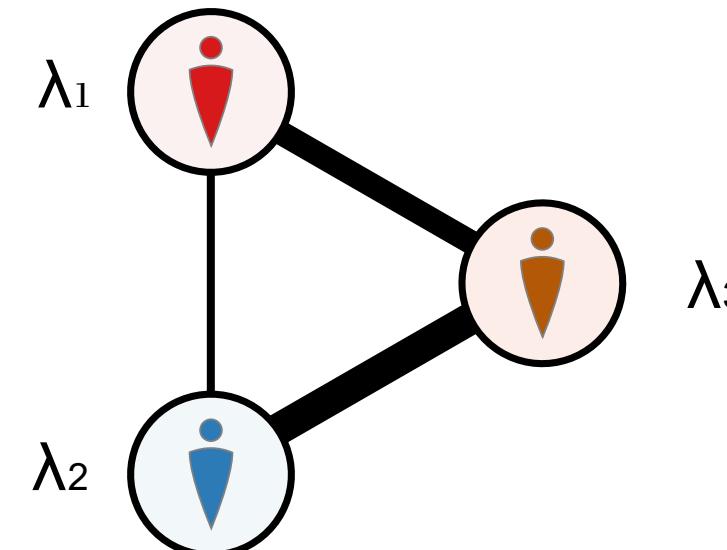


how to estimate
individual productivity,
net of coauthors' own
individual productivity?
for example...



untangling the network's effects

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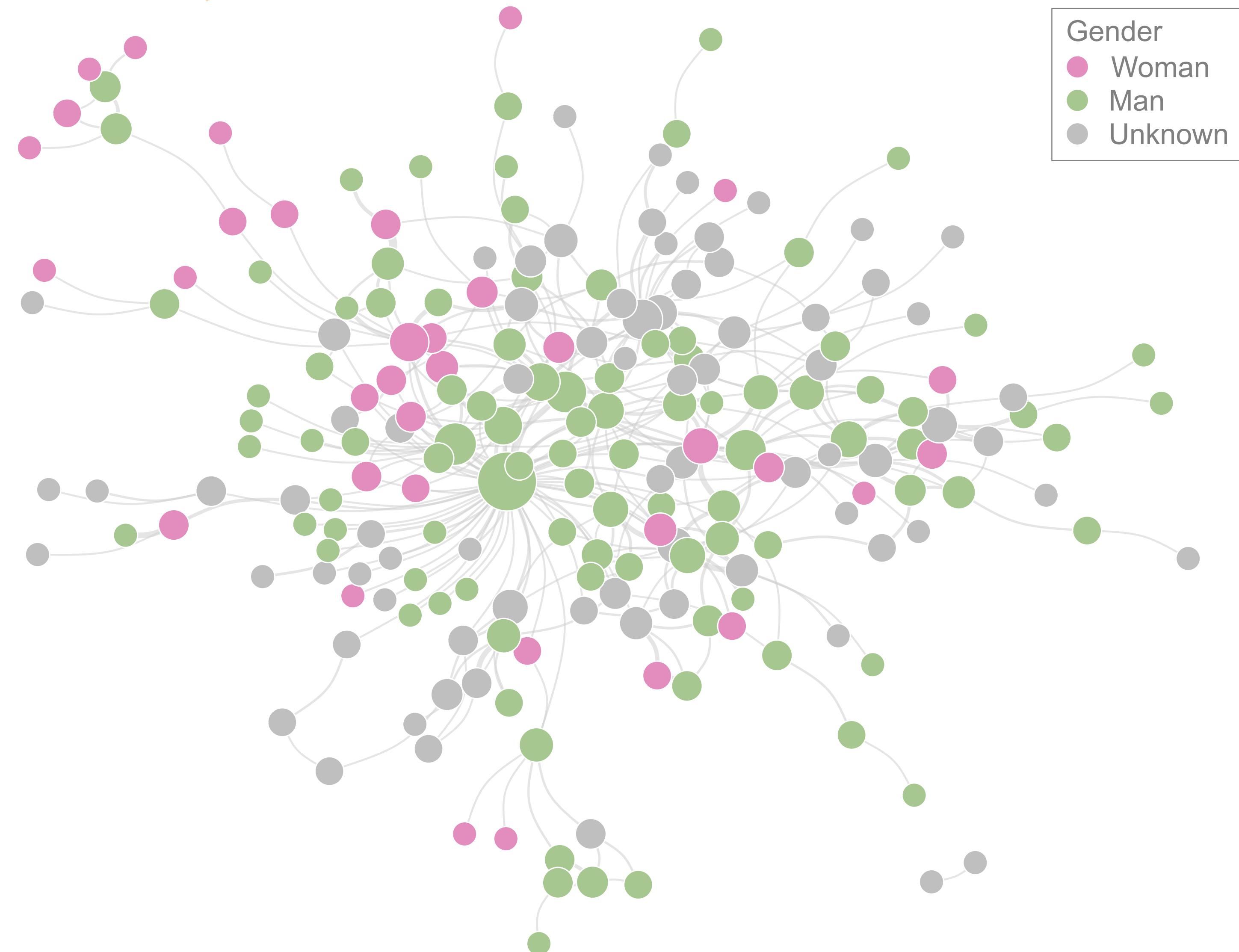


Pairwise productivity

Author pair	Papers	Time
i j	1	2
i k	3	2
j k	4	3

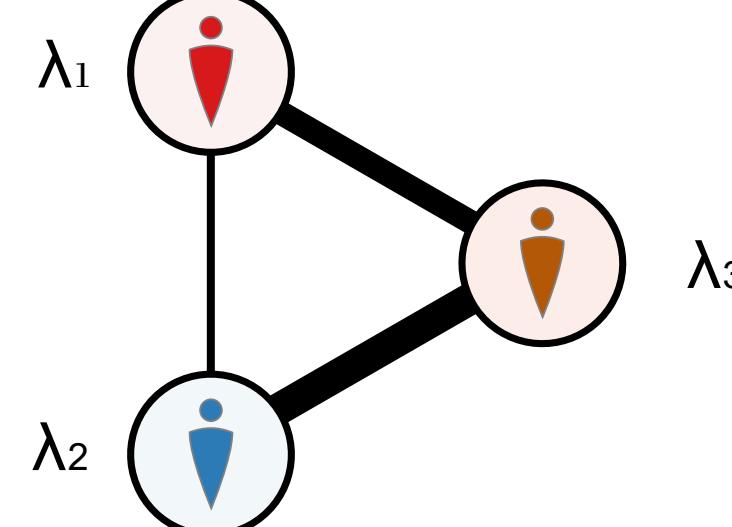
(i, j) N_{ij} t_{ij}

who is the most
individually productive?



untangling the network's effects

Coauthorship network



Pairwise productivity

Author pair	Papers	Time
$i \cdot j$	1	2
$i \cdot k$	3	2
$j \cdot k$	4	3
(i, j)	N_{ij}	t_{ij}

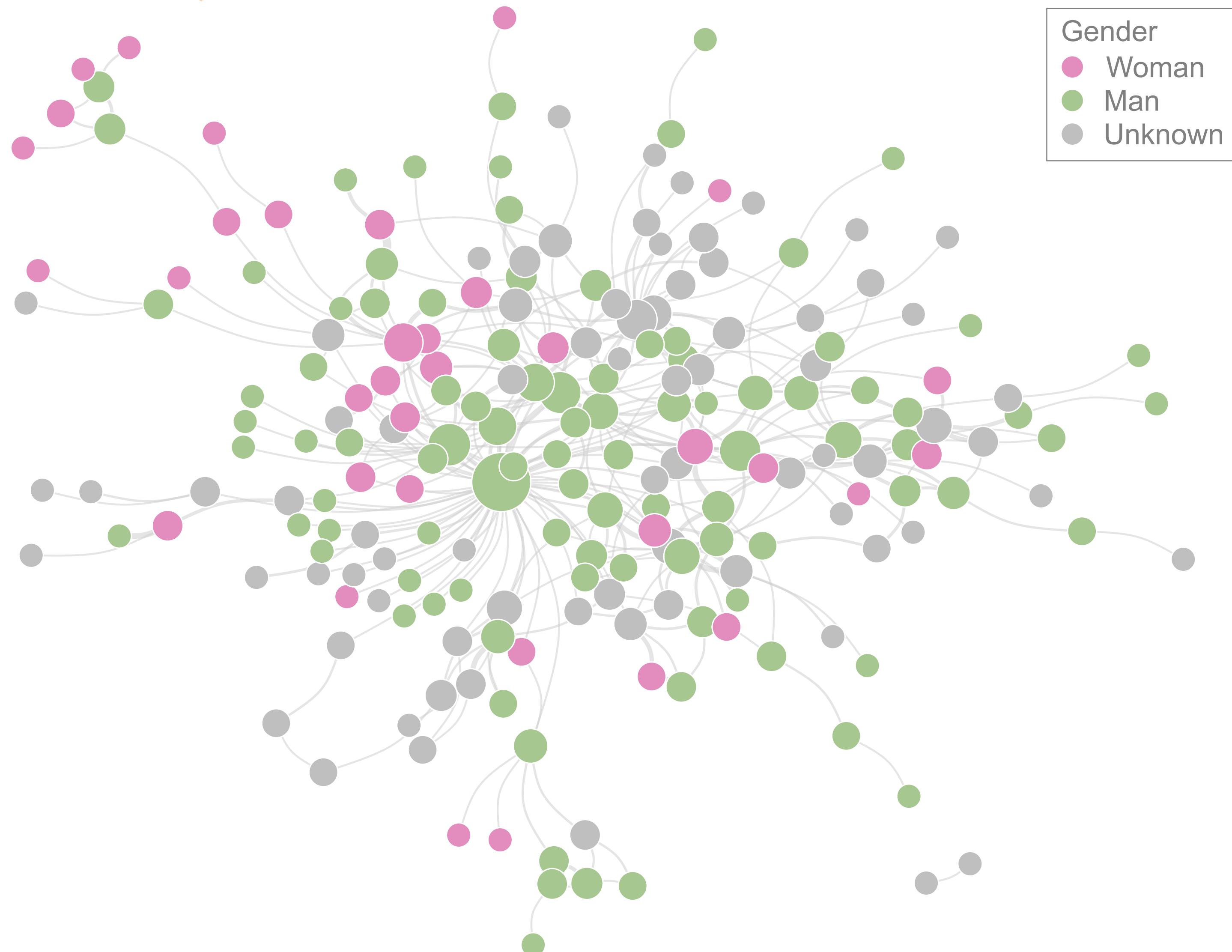
probabilistic model of *pairwise* productivity

number (i, j) -coauthored papers

$$\Pr(N_{ij}, t_{ij} | \lambda_i, \lambda_j)$$

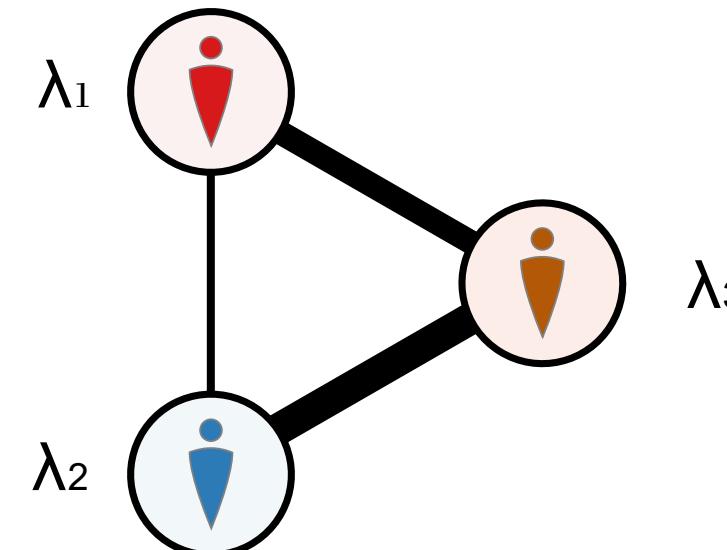
given time period

individual productivities



untangling the network's effects

Coauthorship network



Pairwise productivity

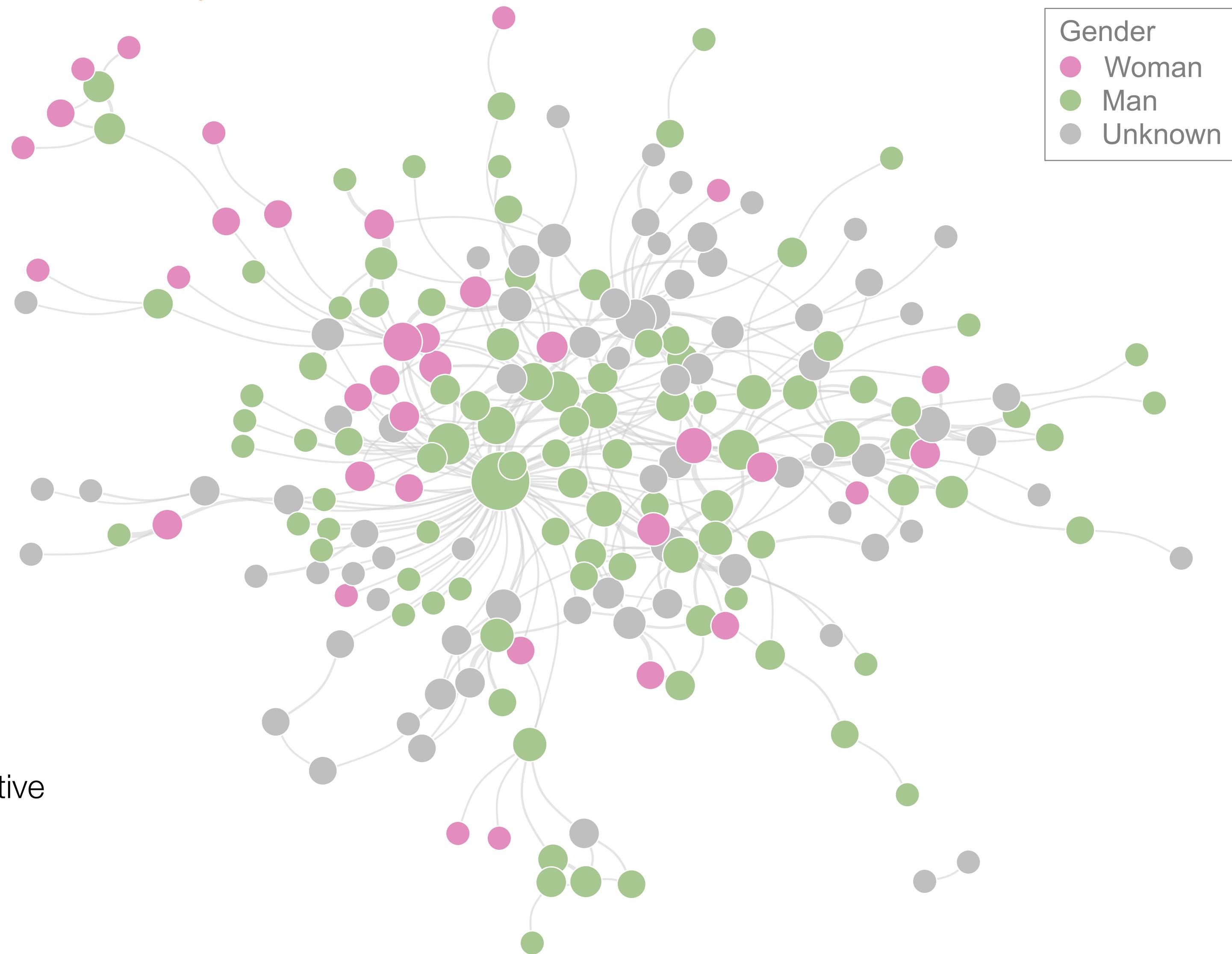
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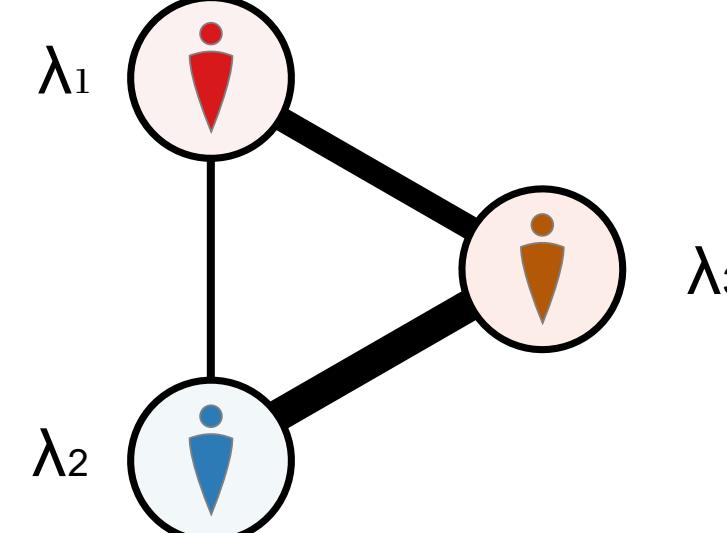
$$\Pr(N_{ij}, t_{ij} | \lambda_i, \lambda_j) = \text{Poisson}([\lambda_i + \lambda_j]t_{ij})$$

productivity is additive



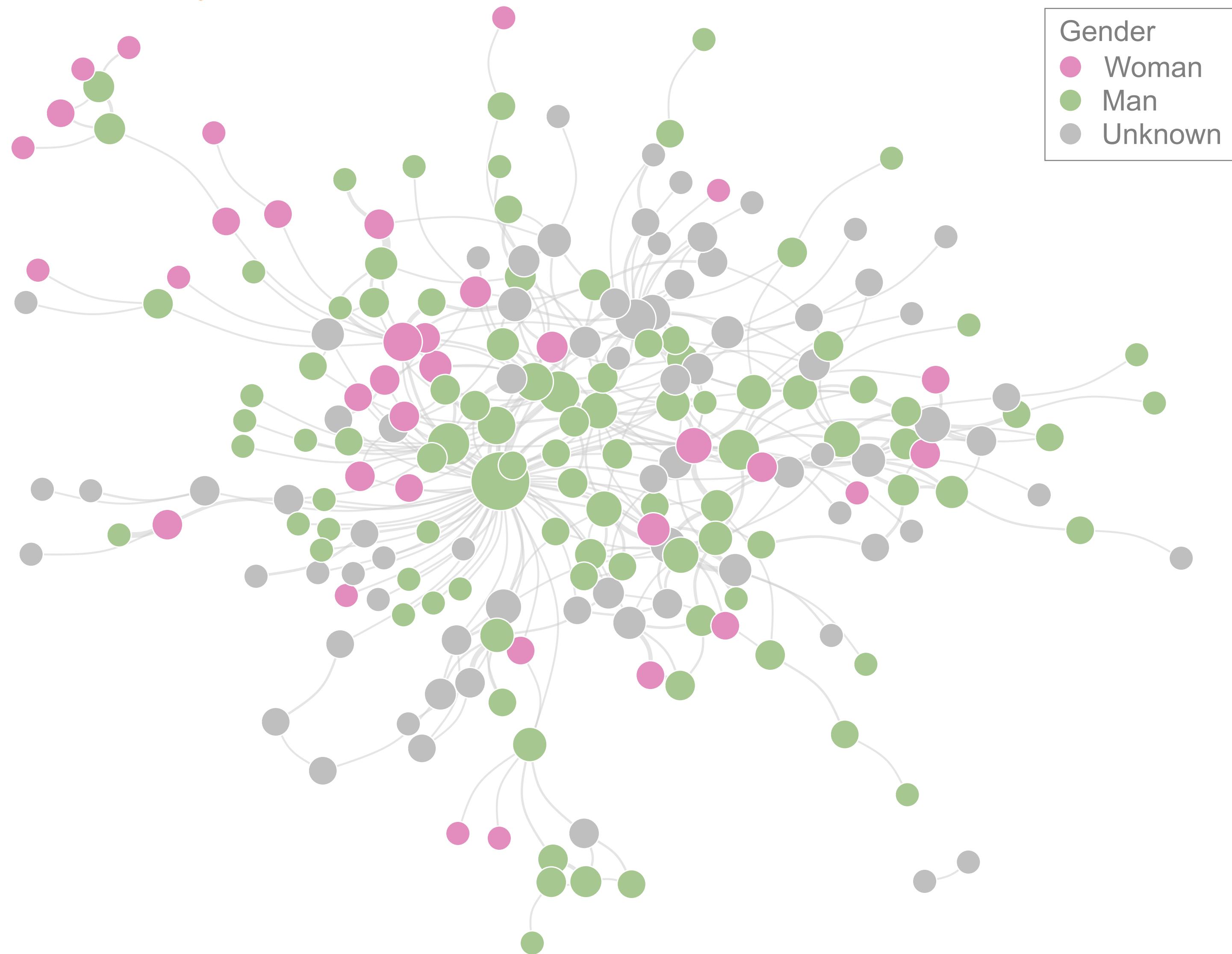
untangling the network's effects

Coauthorship network



Individual researcher metrics

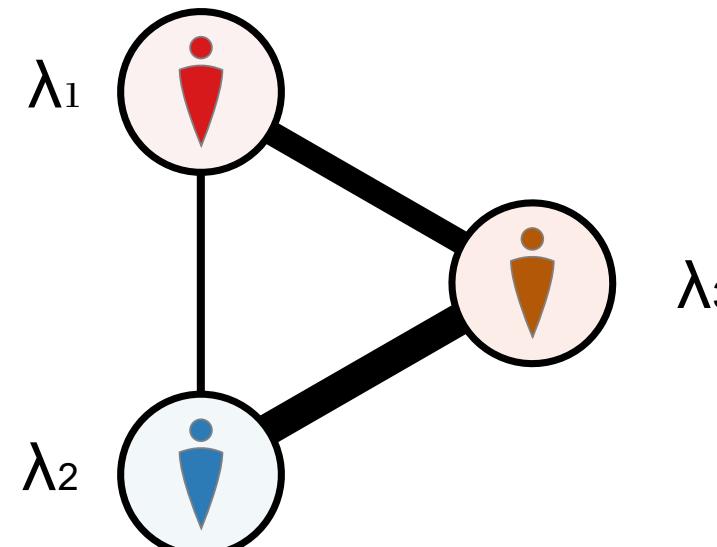
Author	Papers	Estimate
i	4	
j	5	
k	7	



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untangling the network's effects

Coauthorship network



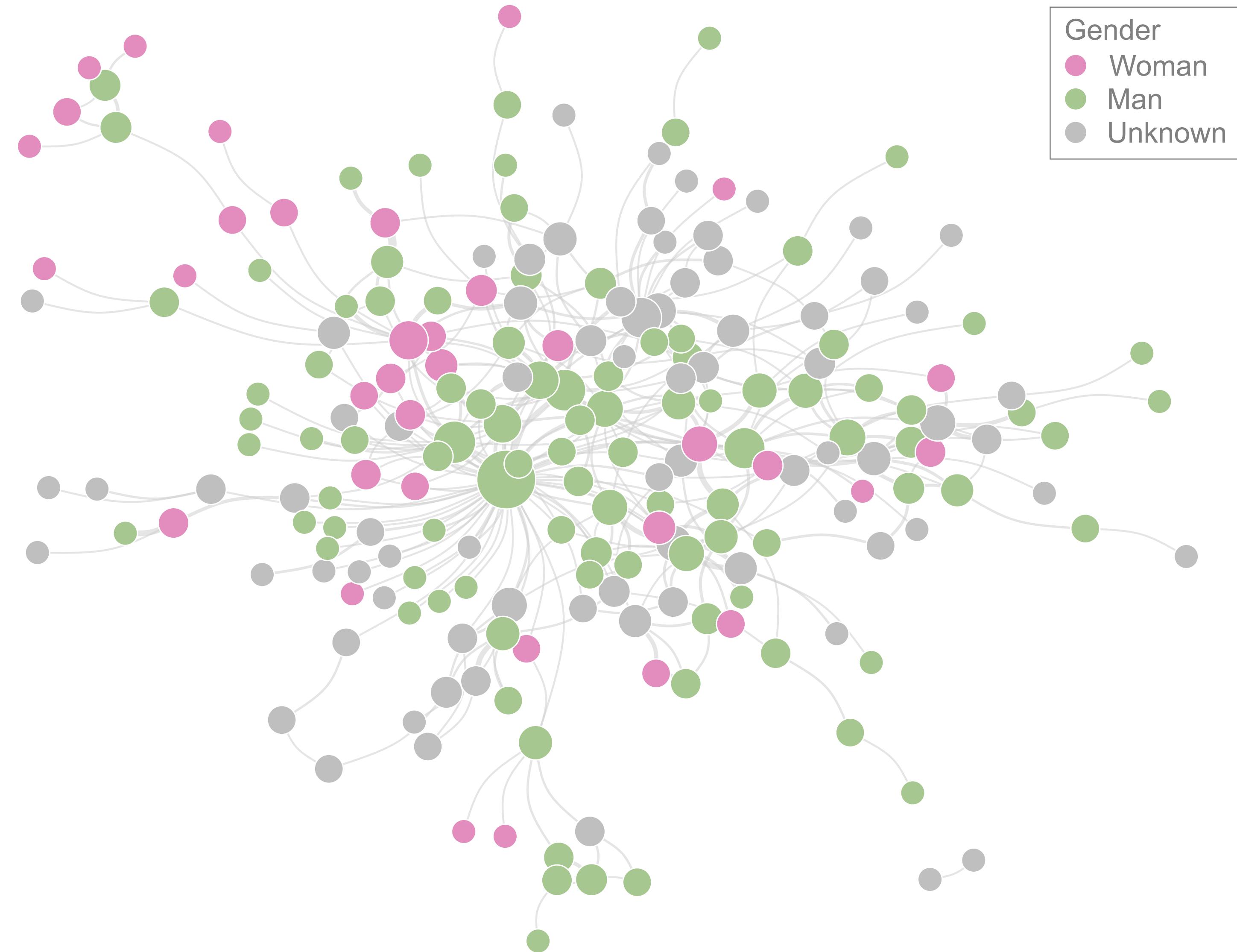
Individual researcher metrics

Author	Papers	Estimate
i	4	$\lambda_1 = 0.33$
j	5	$\lambda_2 = 0.17$
k	7	$\lambda_3 = 1.17$

N_i

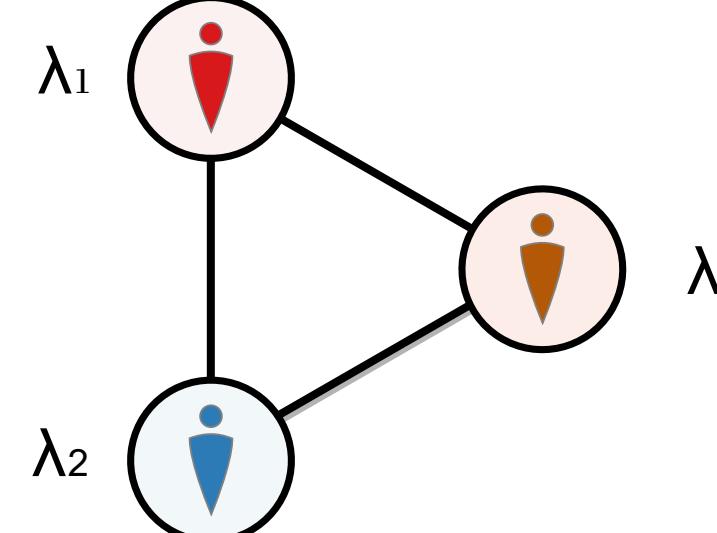
who is the most
individually productive?

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

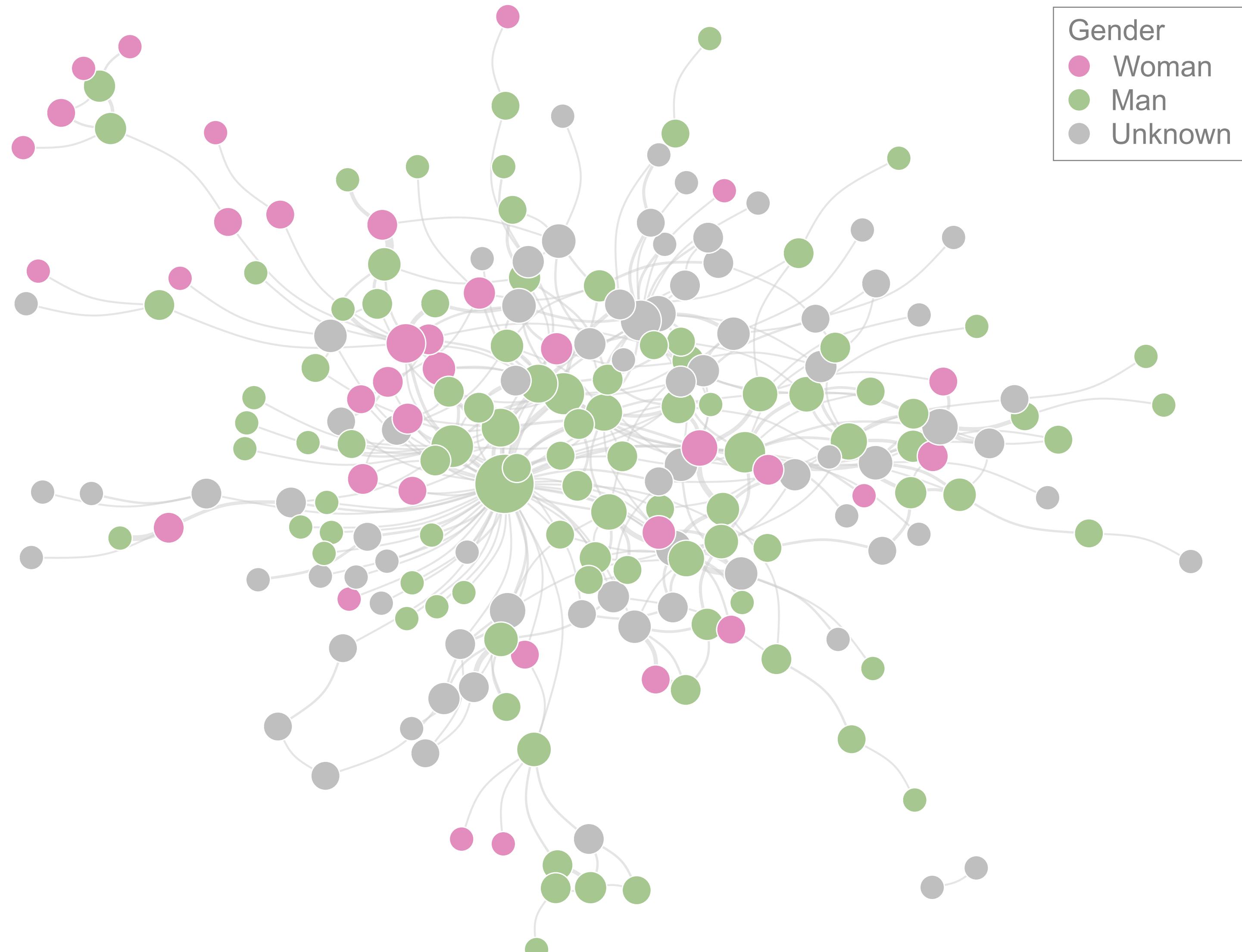


untangling the network's effects

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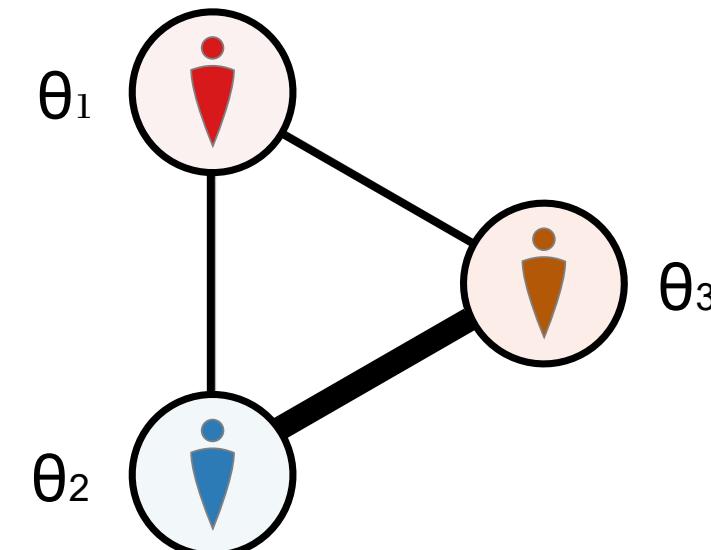


how to estimate
individual prominence,
defined as number of
"high impact" papers?
for example...



untangling the network's effects

Coauthorship network

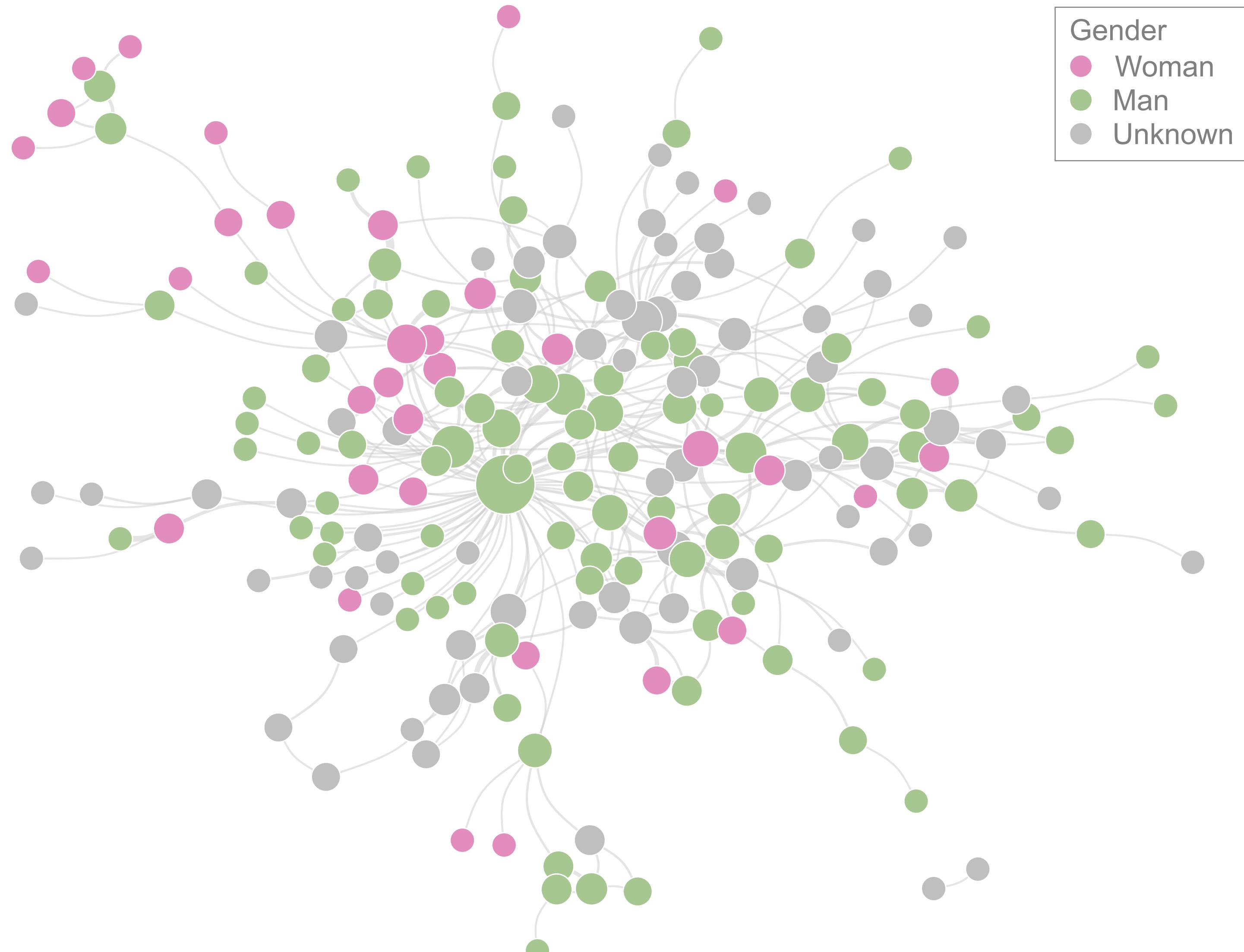


Pairwise impact

Author pair	Papers	Hit papers
• ⚡	1	1
• ⚡	3	1
⚡ ⚡	4	3

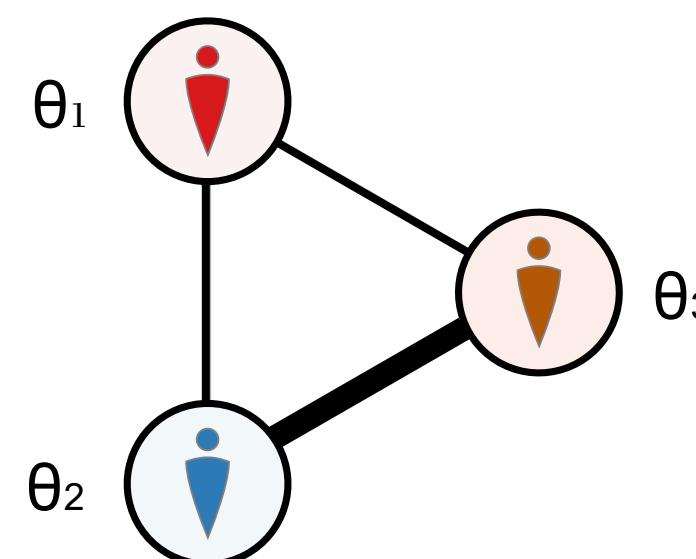
(i, j) N_{ij} m_{ij}

who is the most
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untangling the network's effects

Coauthorship network



Pairwise impact

Author pair	Papers	Hit papers
●, ●	1	1
●, ○	3	1
○, ○	4	3
(i, j)	N_{ij}	m_{ij}

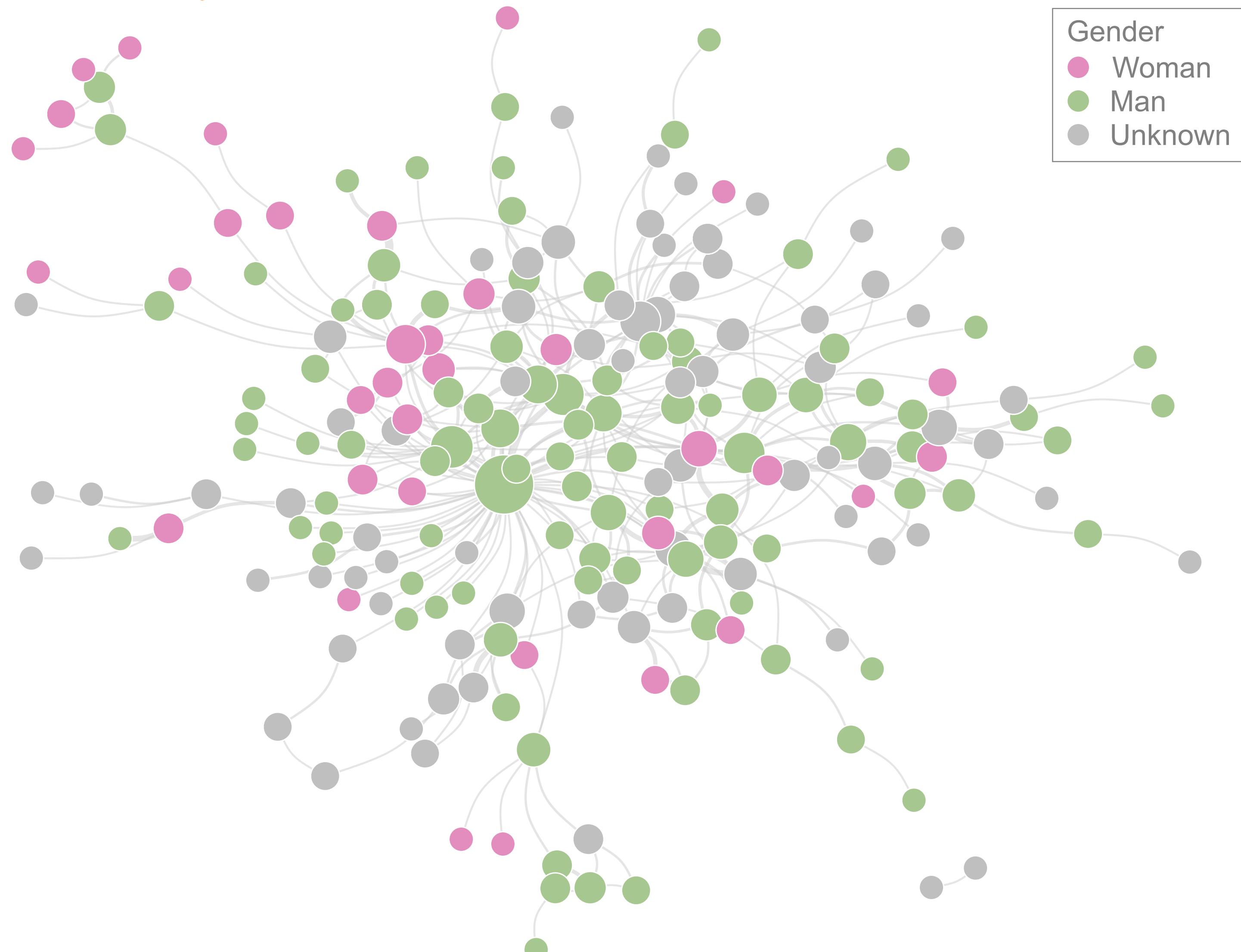
probabilistic model of *pairwise* prominence

number (i, j) -coauthored papers

$$\Pr(N_{ij}, m_{ij} | \theta_i, \theta_j) =$$

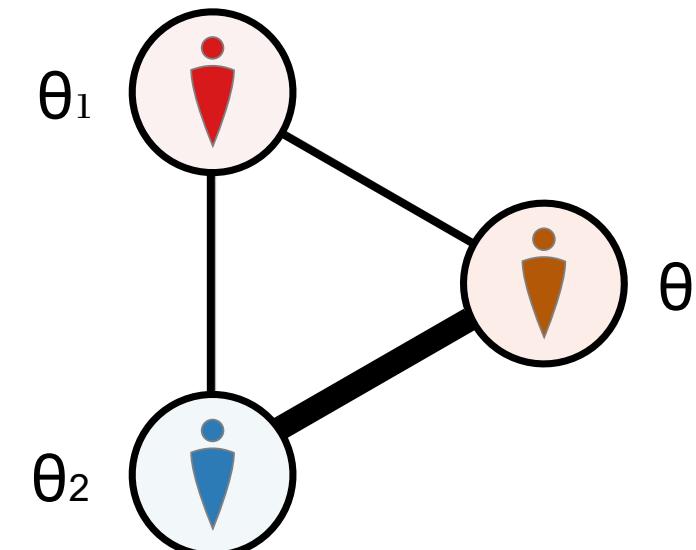
individual prominences

number of "high impact" papers



untangling the network's effects

Coauthorship network



Pairwise impact

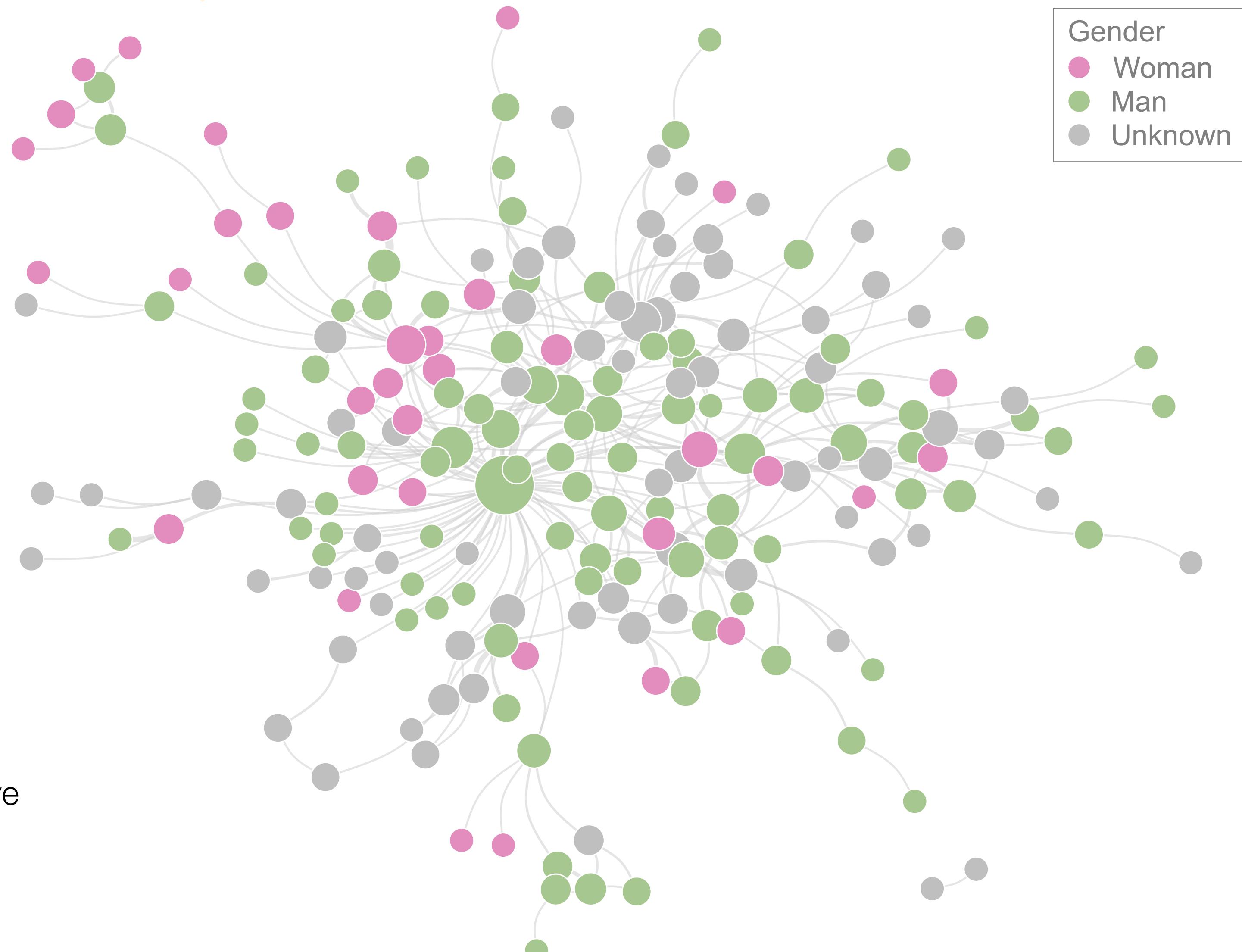
Author pair	Papers	Hit papers
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•, ●	3	1
▲, ●	4	3

(i, j) N_{ij} m_{ij}

probabilistic model of *pairwise* prominence

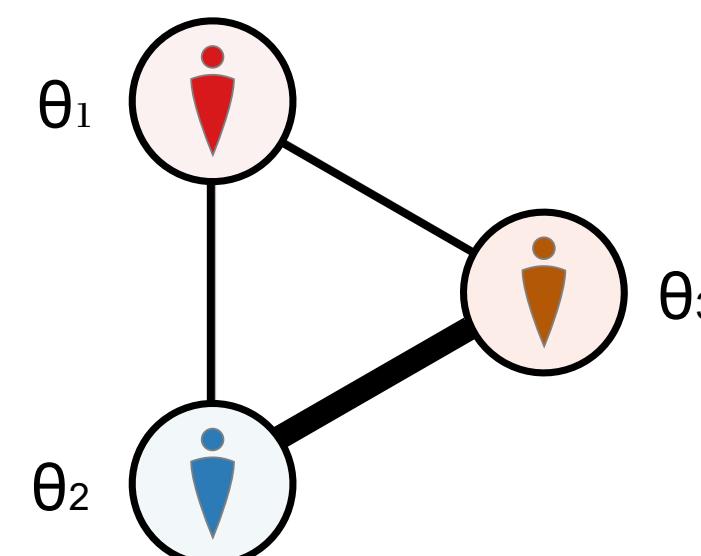
$$\Pr(N_{ij}, m_{ij} | \theta_i, \theta_j) = \text{Binomial}(N_{ij}, [\theta_i + \theta_j])$$

↑
prominence is additive



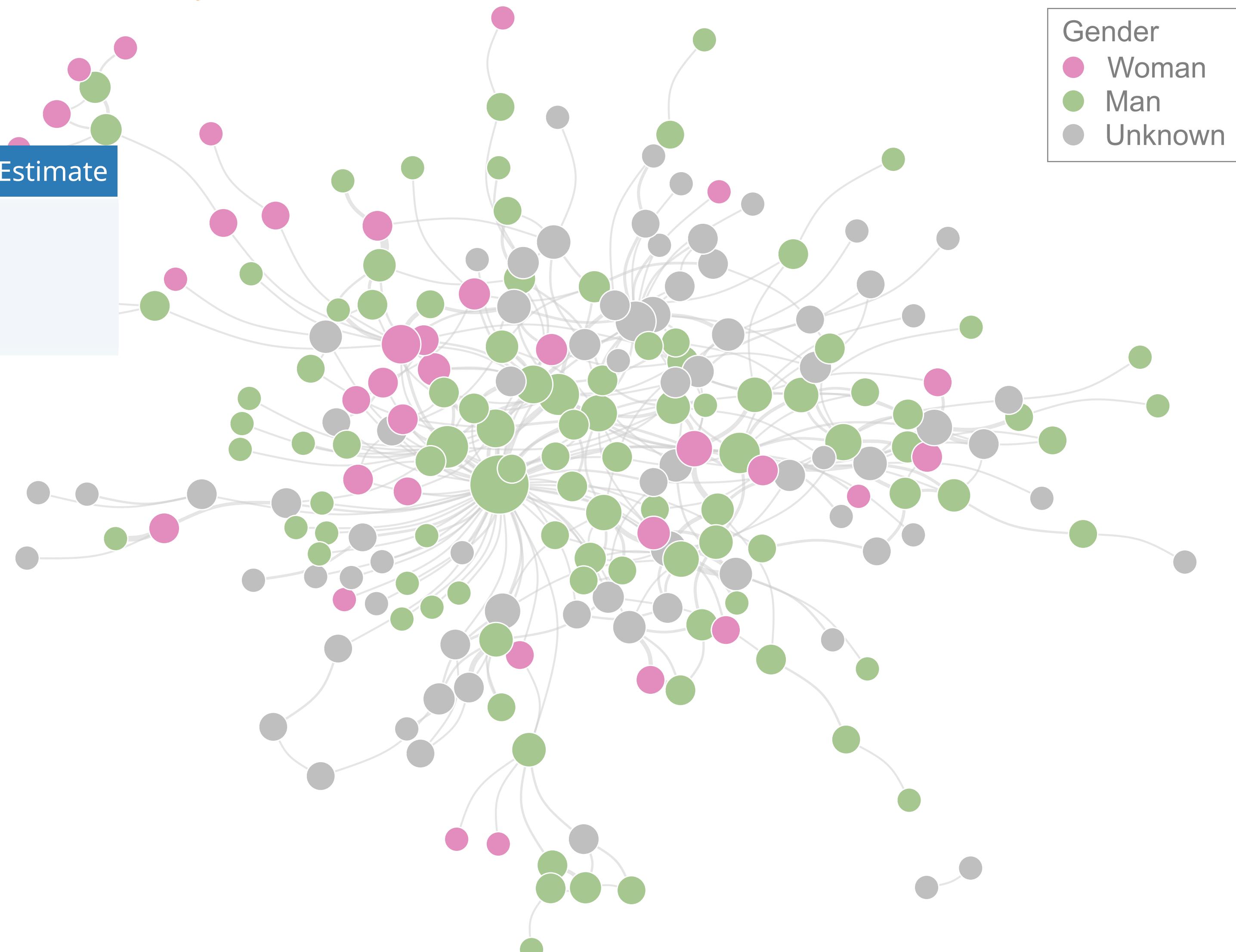
untangling the network's effects

Coauthorship network



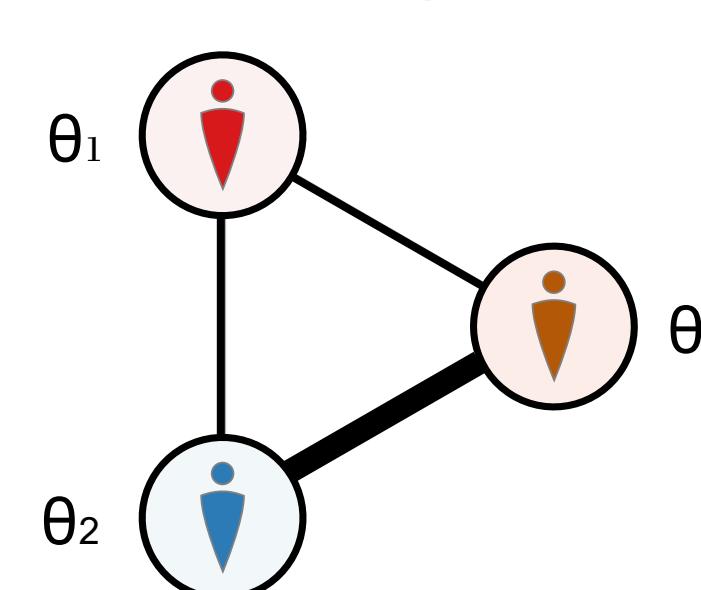
Author	Papers	Hit papers	Estimate	Estimate
i	N_i	m_i		
●	4	2	$\lambda_1 = 0.33$	
●	5	4	$\lambda_2 = 0.17$	
●	7	4	$\lambda_3 = 1.17$	

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

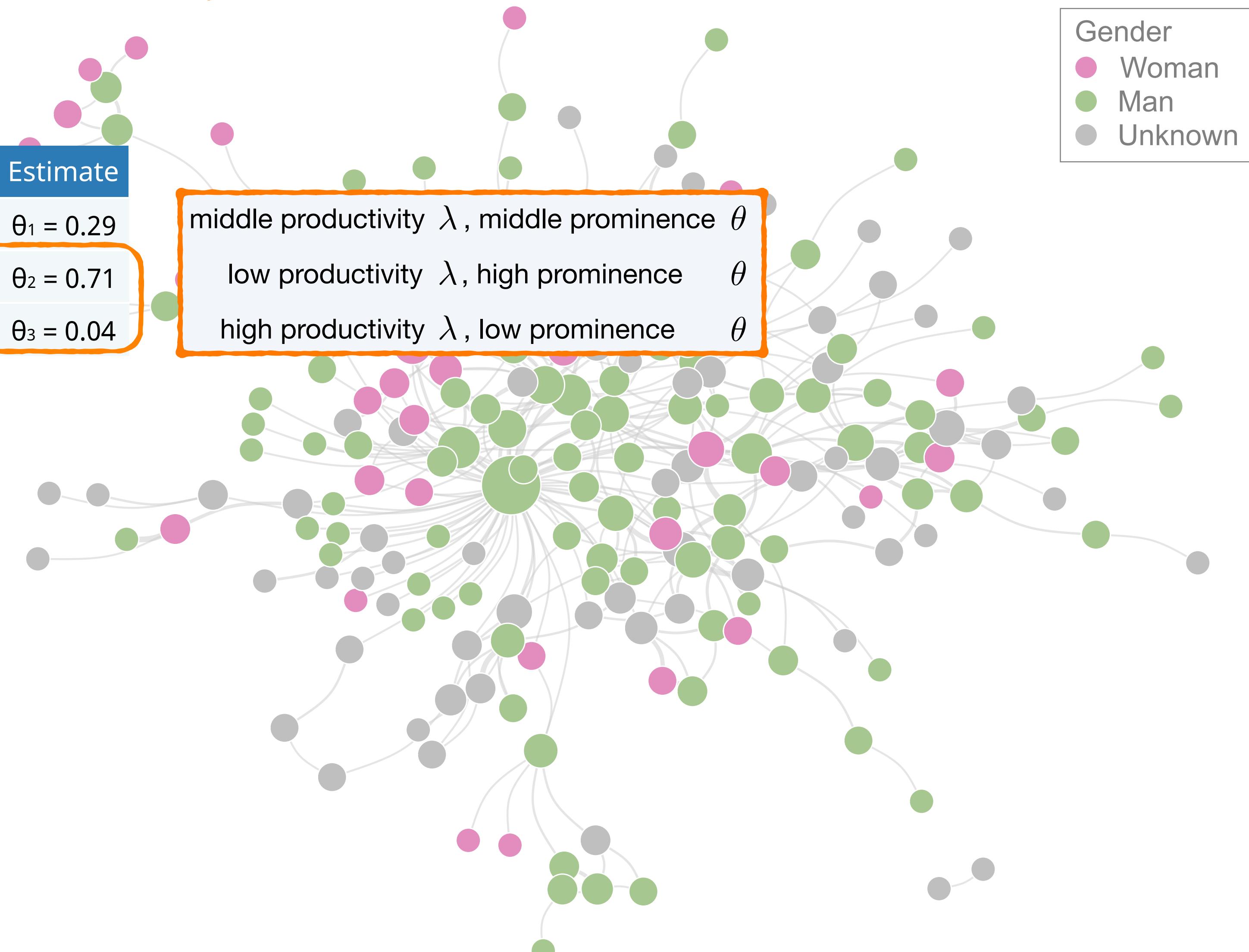


untangling the network's effects

Coauthorship network



Author	Papers	Hit papers	Estimate	Estimate
i	N_i	m_i		
red icon	4	2	$\lambda_1 = 0.33$	$\theta_1 = 0.29$
blue icon	5	4	$\lambda_2 = 0.17$	$\theta_2 = 0.71$
orange icon	7	4	$\lambda_3 = 1.17$	$\theta_3 = 0.04$

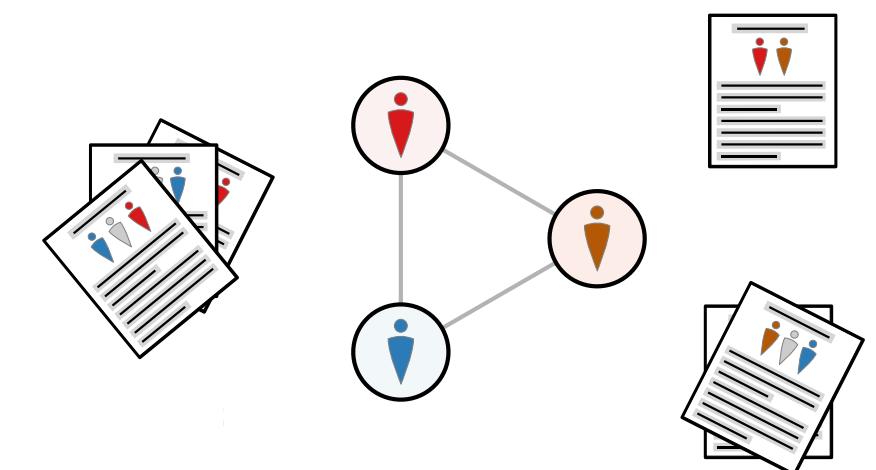


untangling the network's effects

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)
- 'high impact' paper = in upper 8% for given year-field

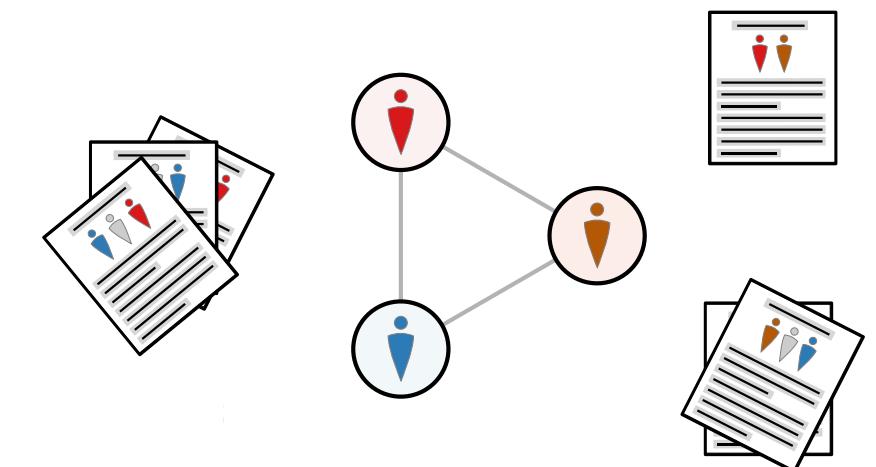


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Estimate individual (λ_i, θ_i) parameters for each scientist

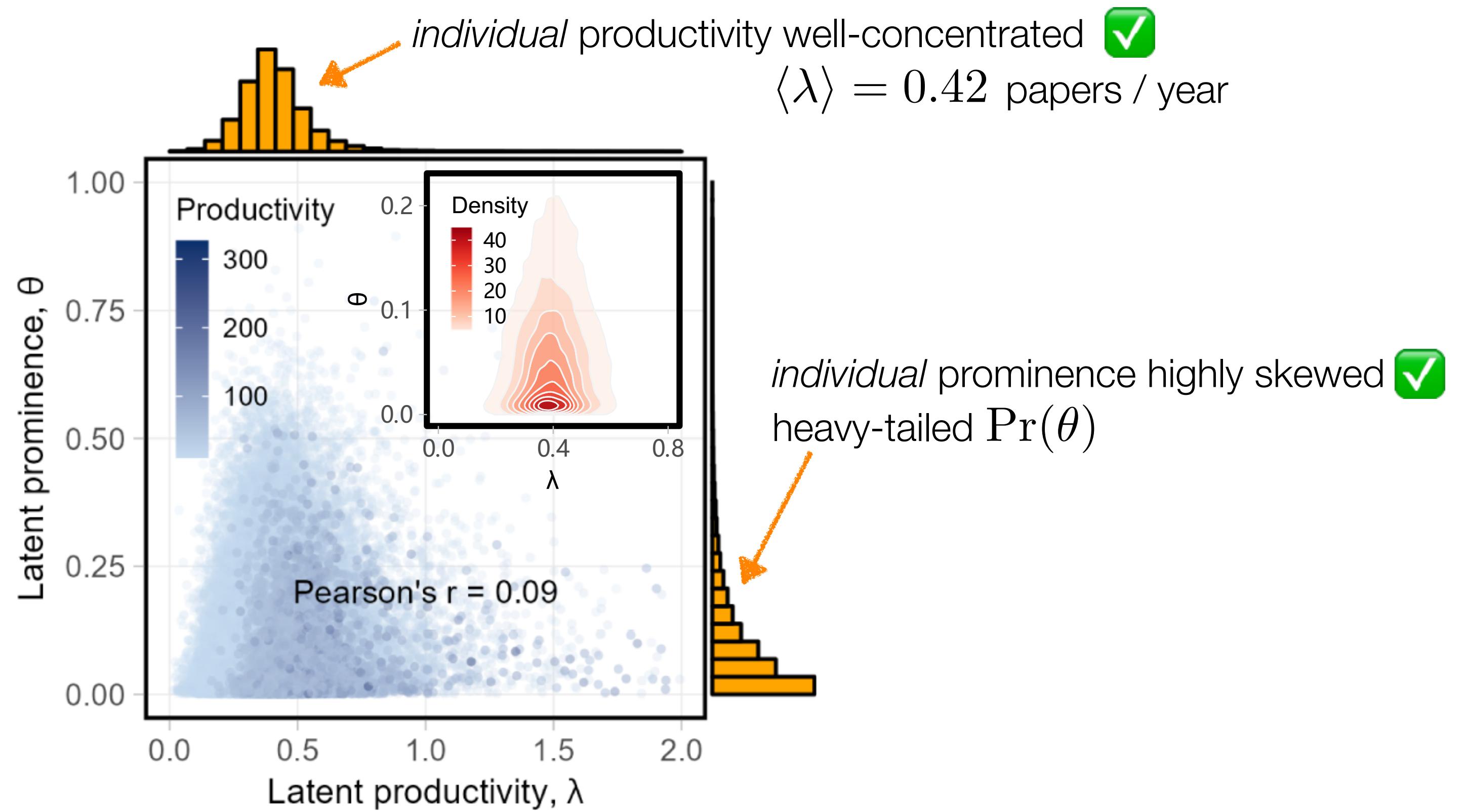
- estimate using network 1950– T , for variable T in [1975,2017]
- bootstrapped convex optimization, then record mean λ_i and θ_i
- investigate how (λ_i, θ_i) covary with gender, prestige, etc.

model checking

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

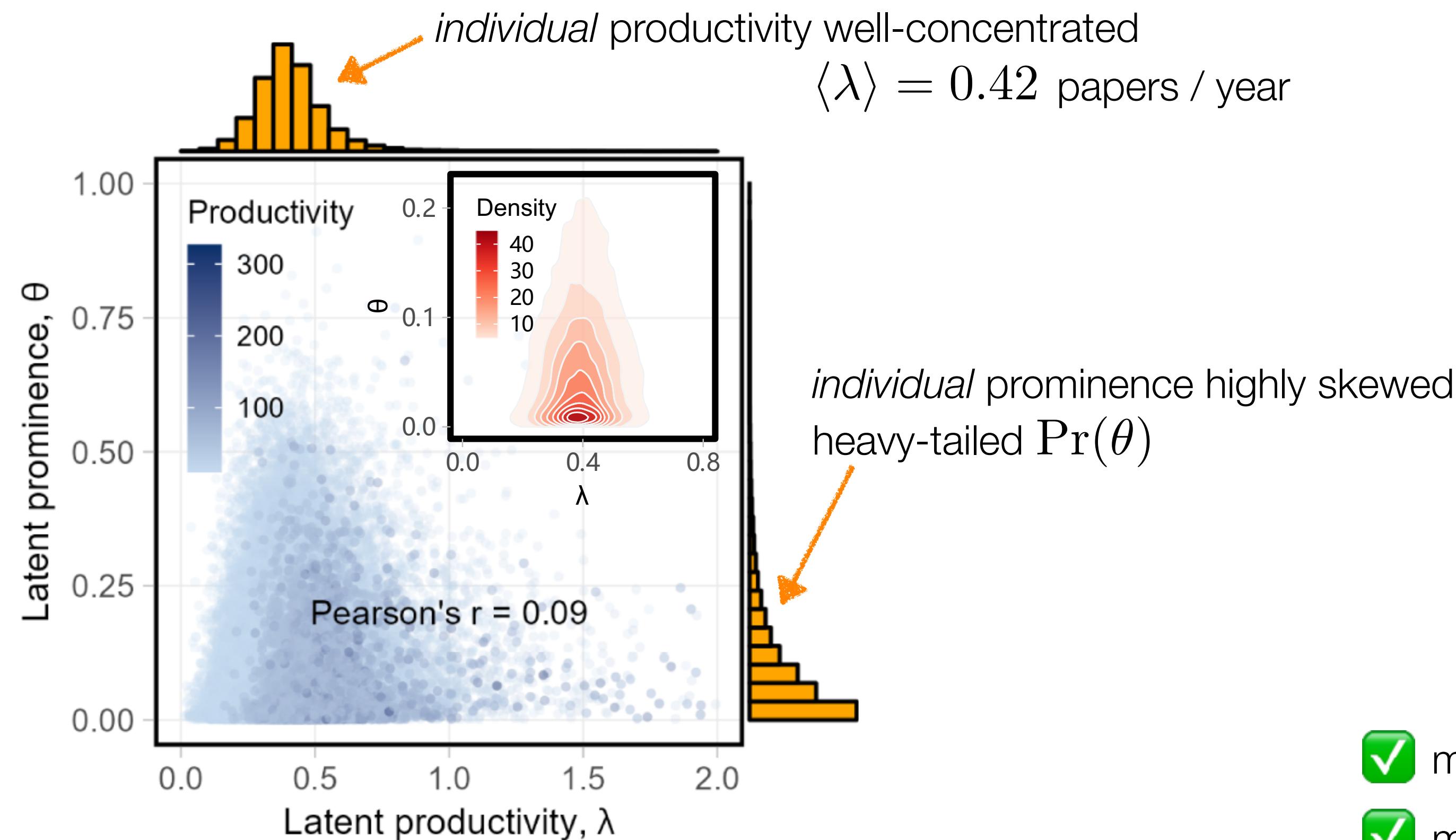
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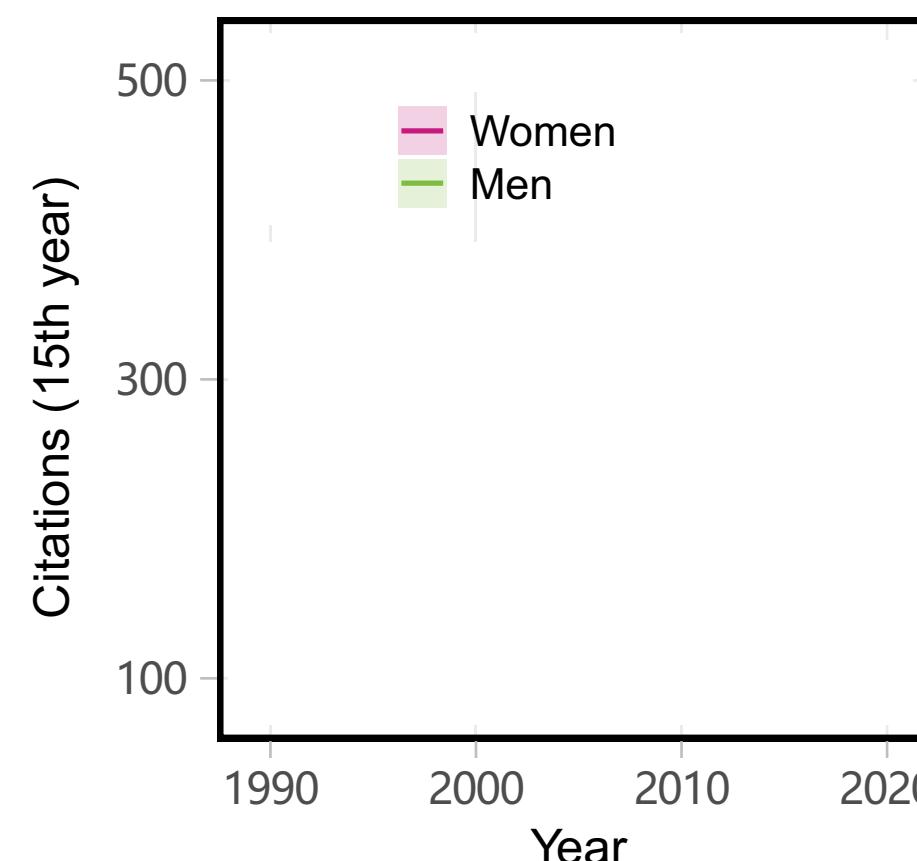
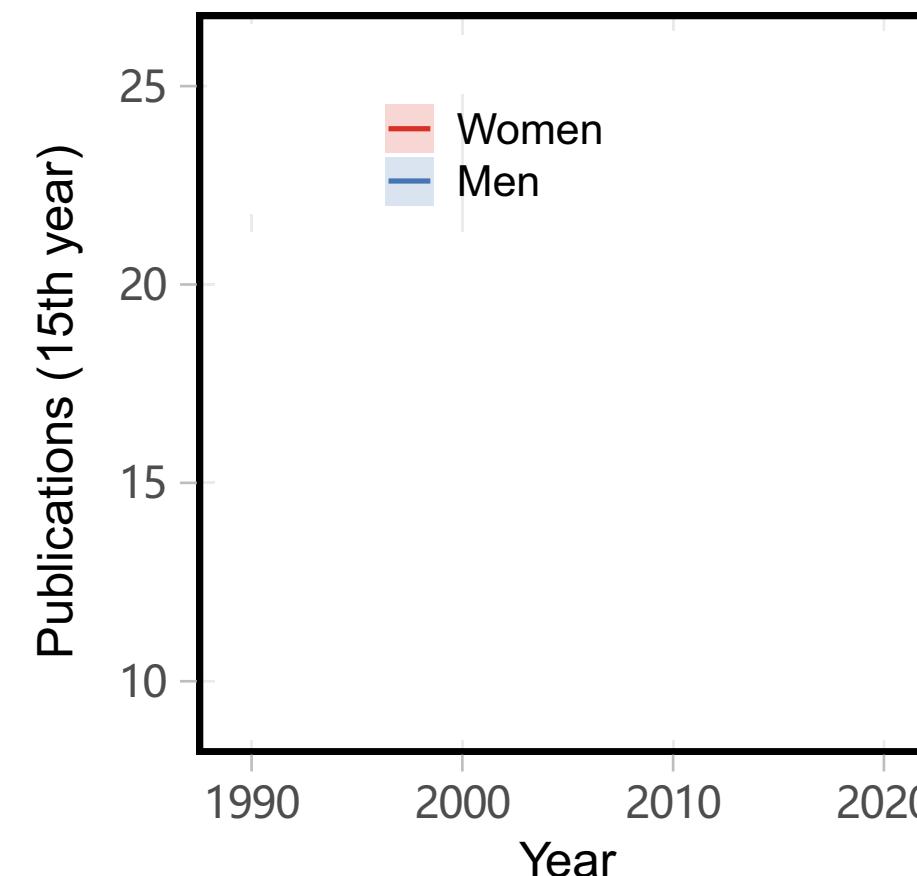
individual prominence highly skewed
heavy-tailed $\text{Pr}(\theta)$

	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

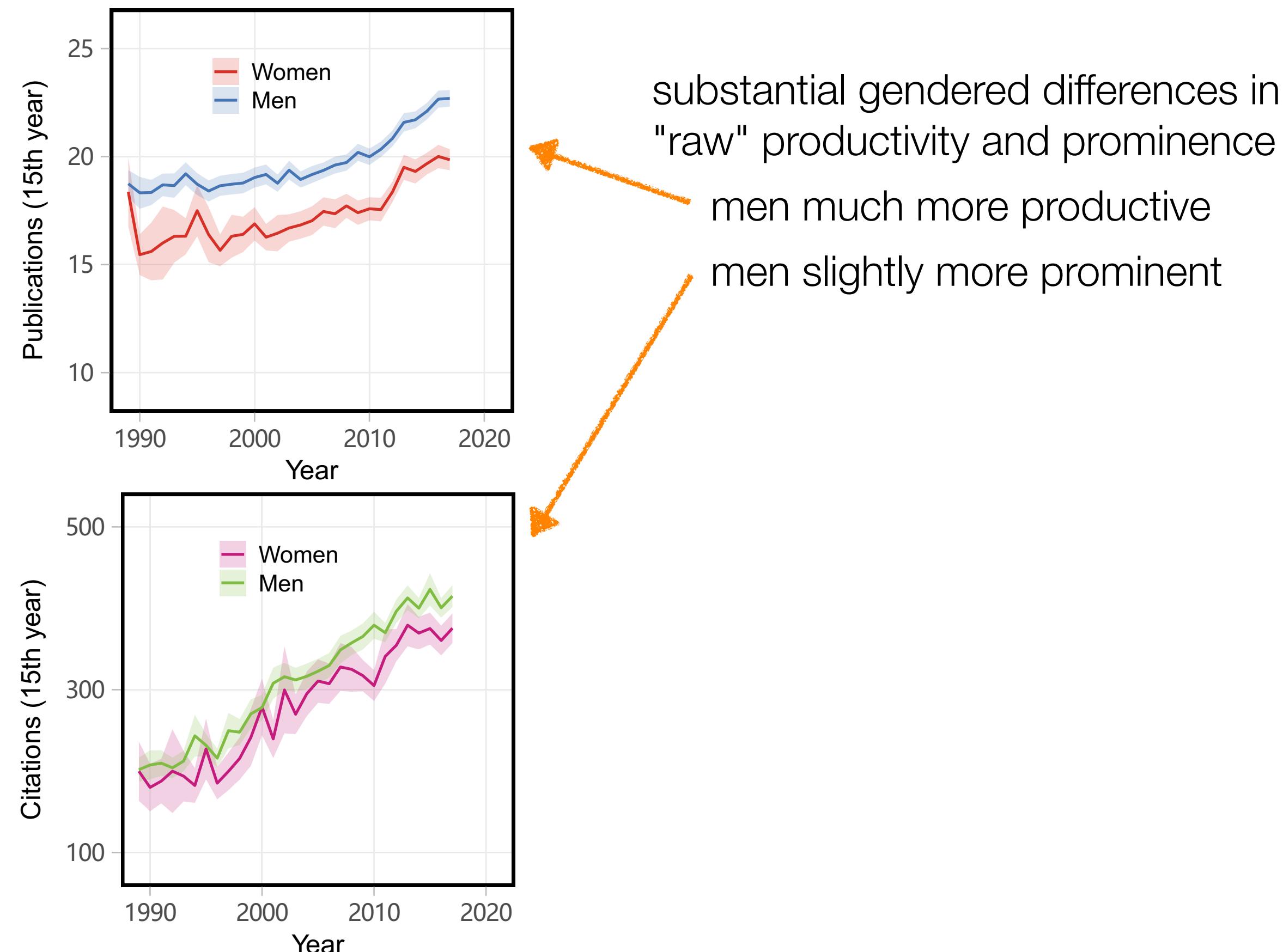
gender vs. productivity & prominence

- ▶ 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

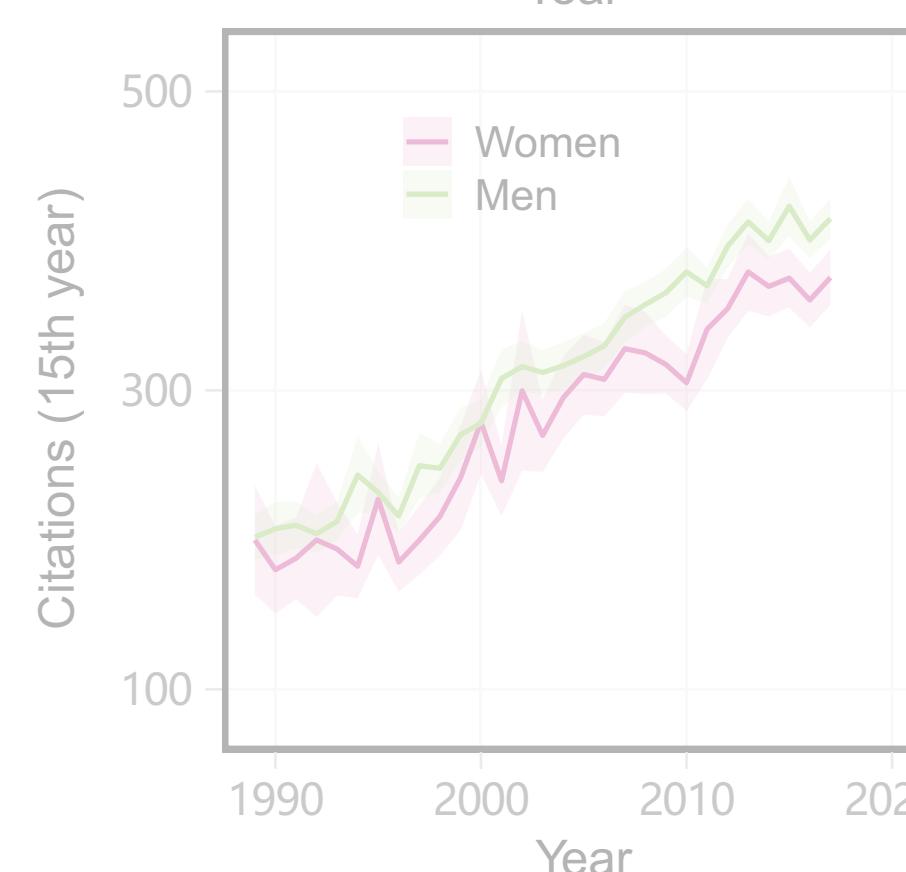
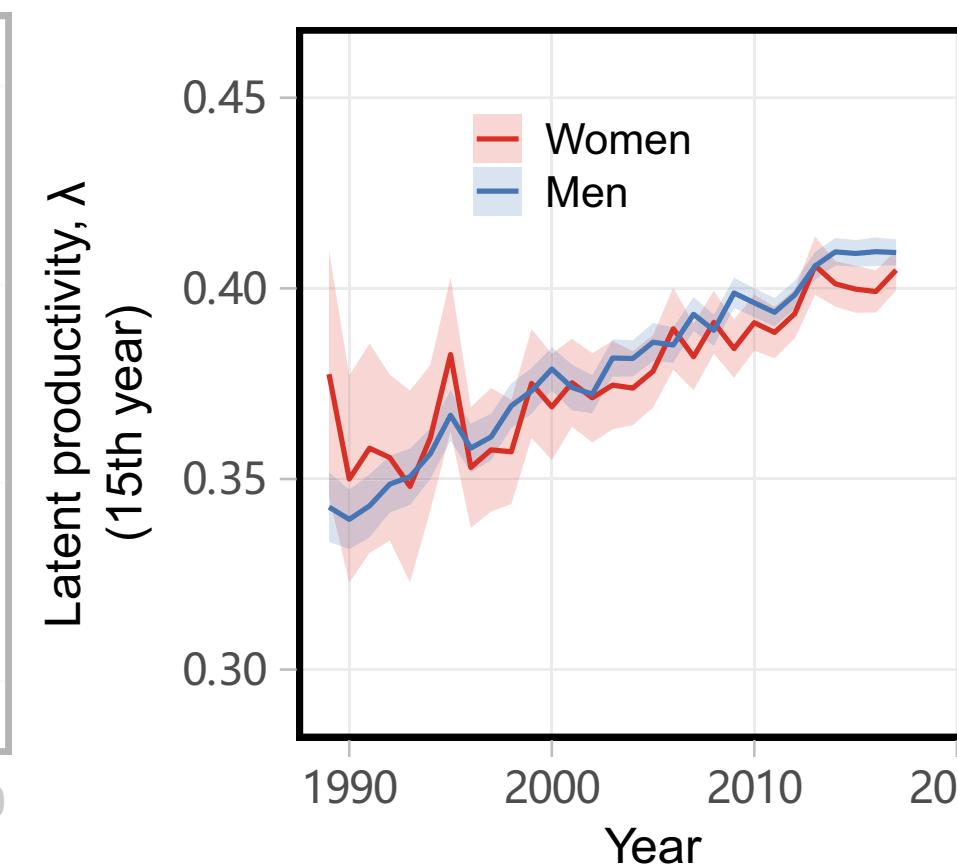
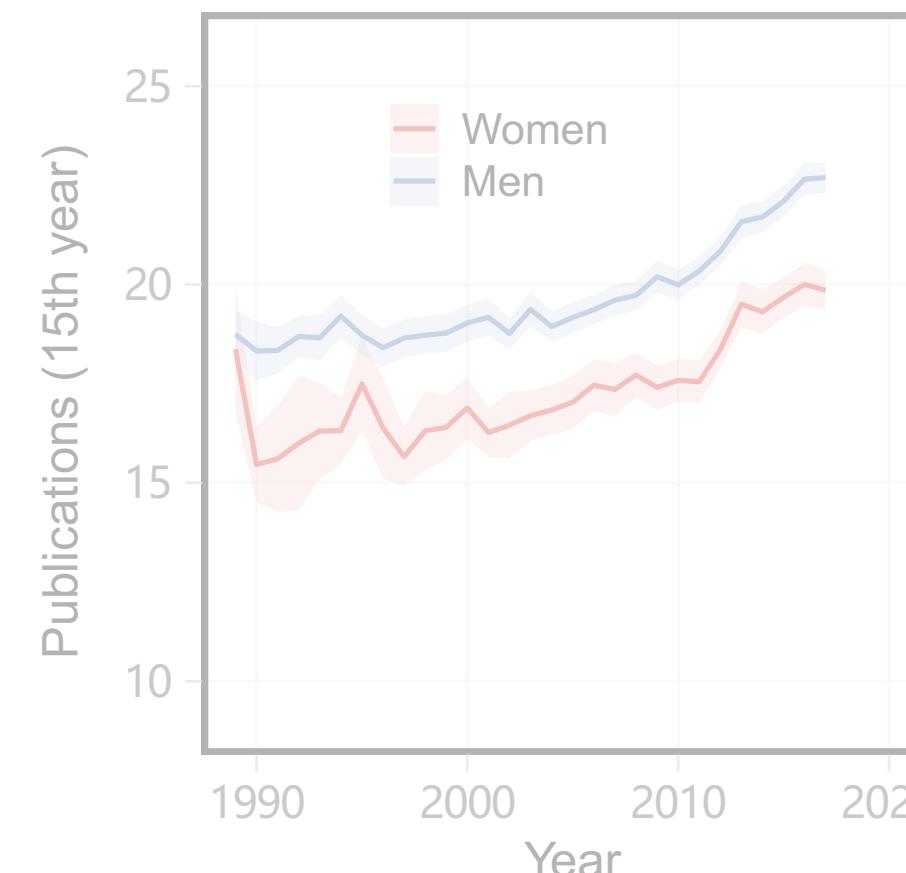
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shaded areas are 95% confidence intervals

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



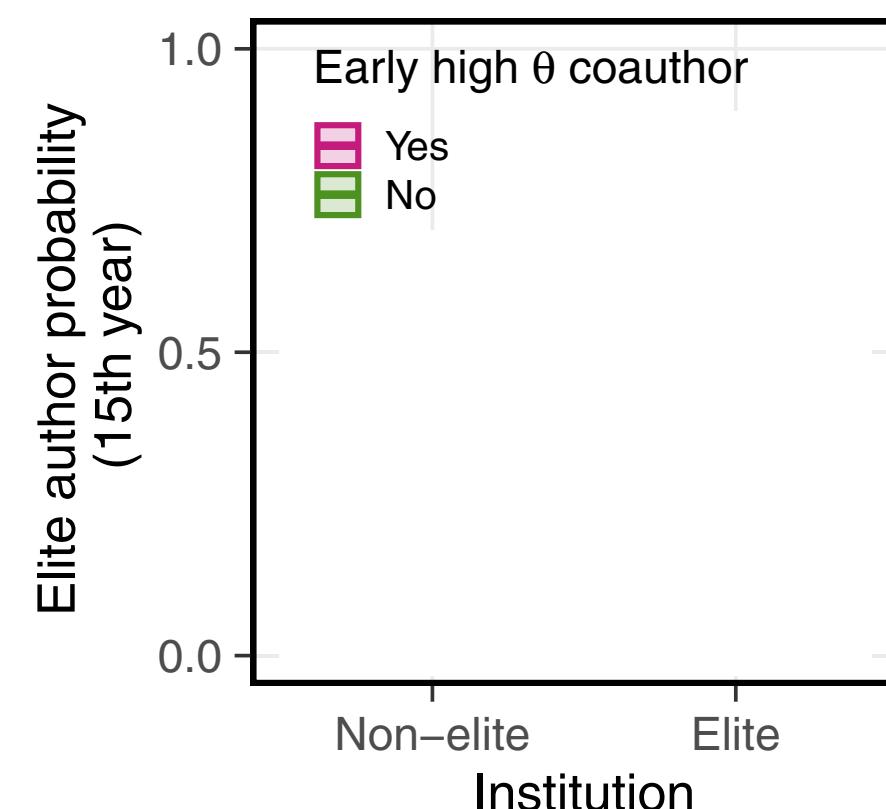
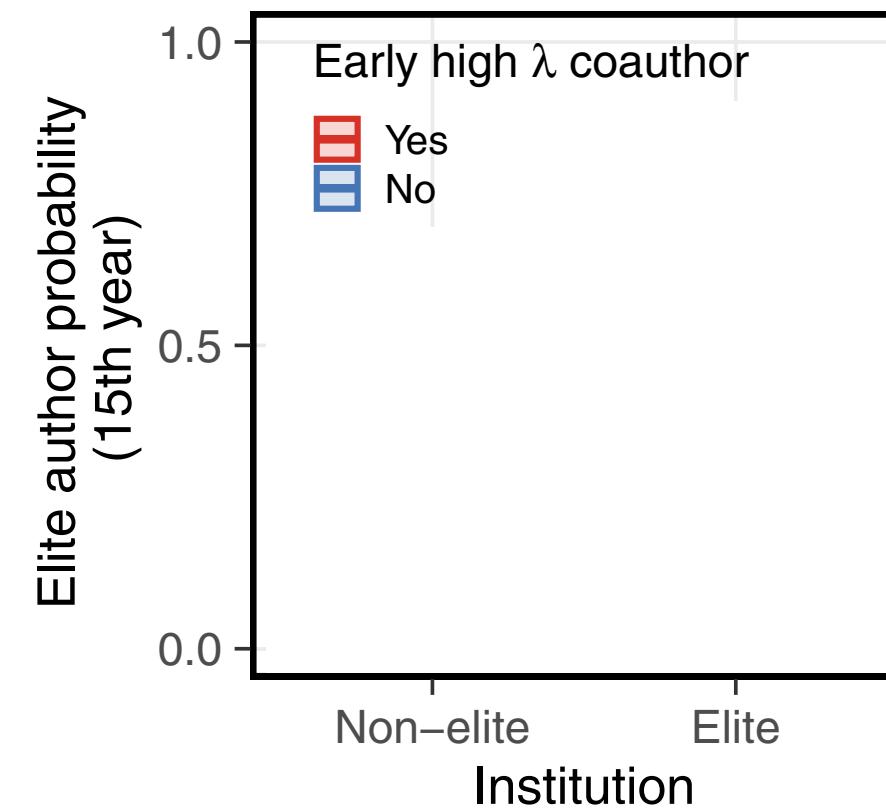
but: latent productivity and prominence
is *not* gendered

- ▶ 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

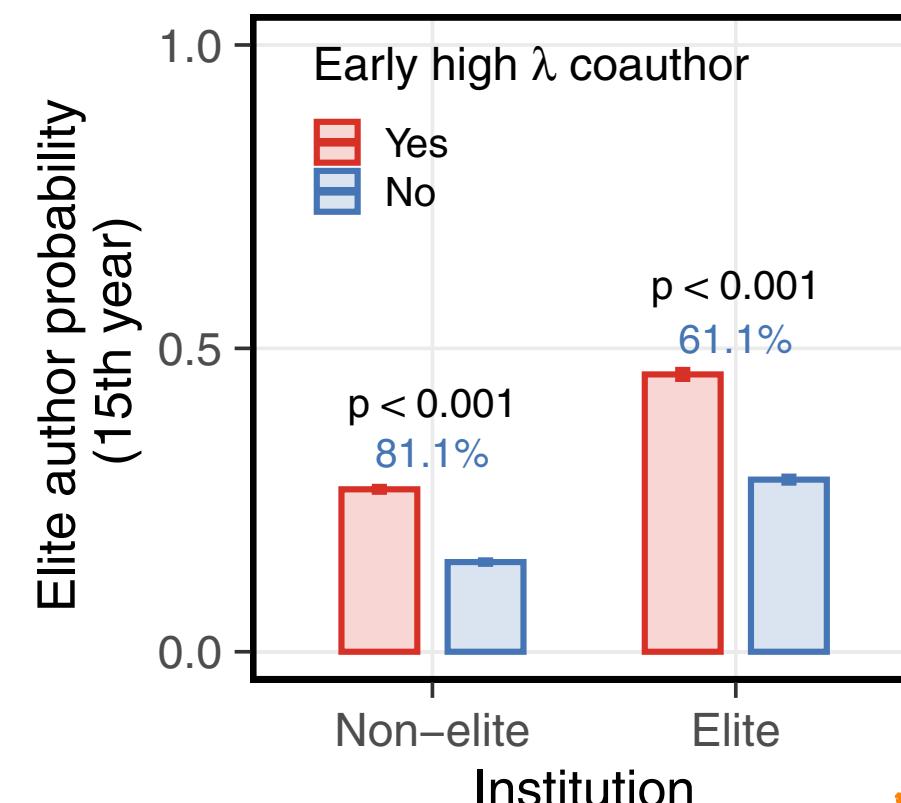


elite institutions = top 10 by z-score of high impact papers
early-career collaboration = within first 5 years of publishing history
"elite author" = upper 5% of citations among authors in a given field-year
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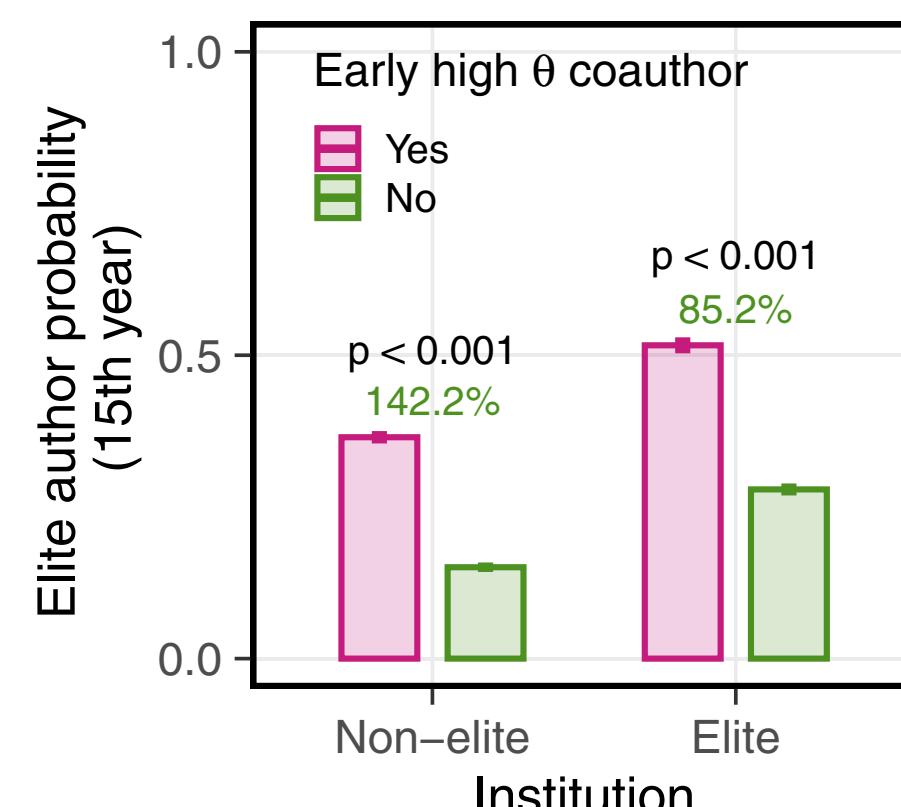
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early high- λ or early high- θ collaborator substantially increases likelihood of high prominence in mid-career

- ▶ much more common at elite institutions
- ▶ effect appears at non-elite institutions too



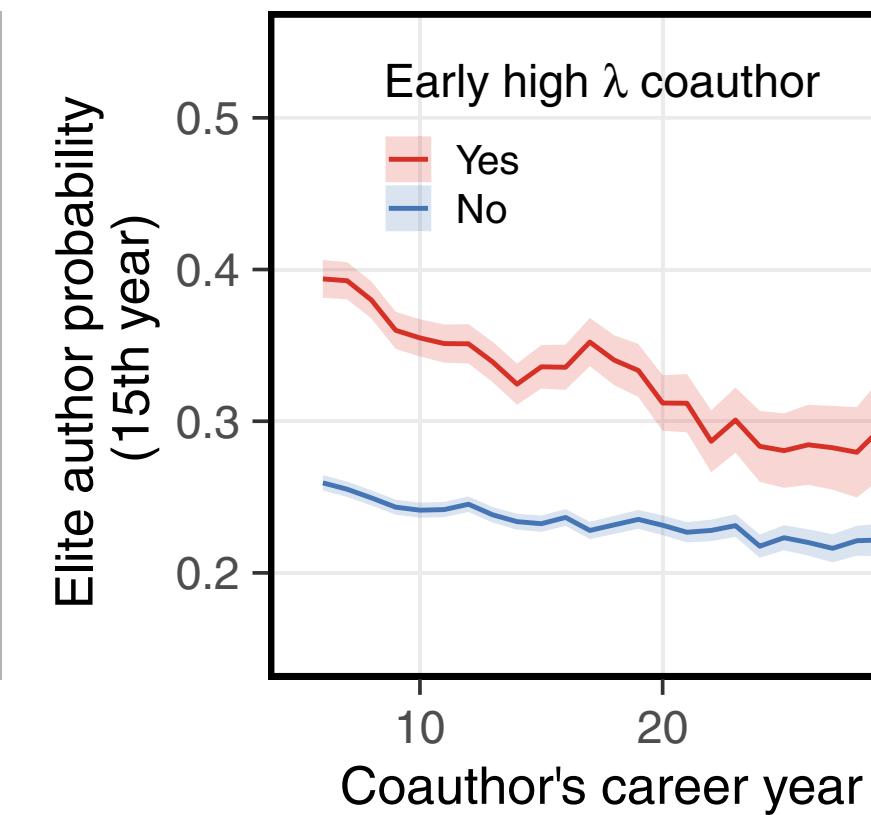
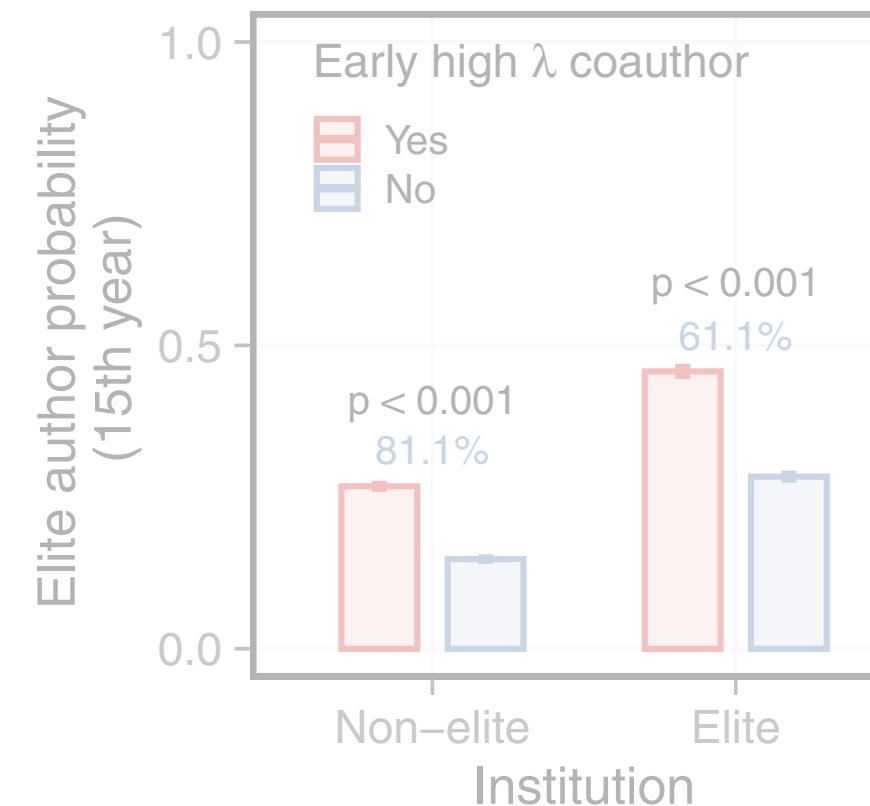
Pr. of high- λ early collab = 0.18 (elite) & 0.15 (non-elite)

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

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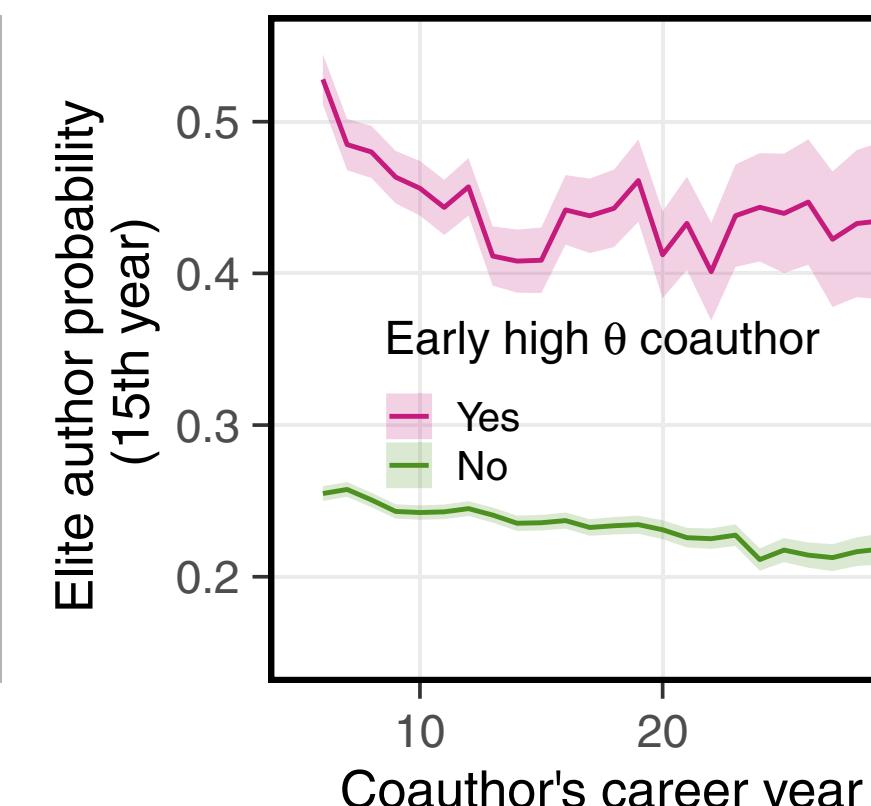
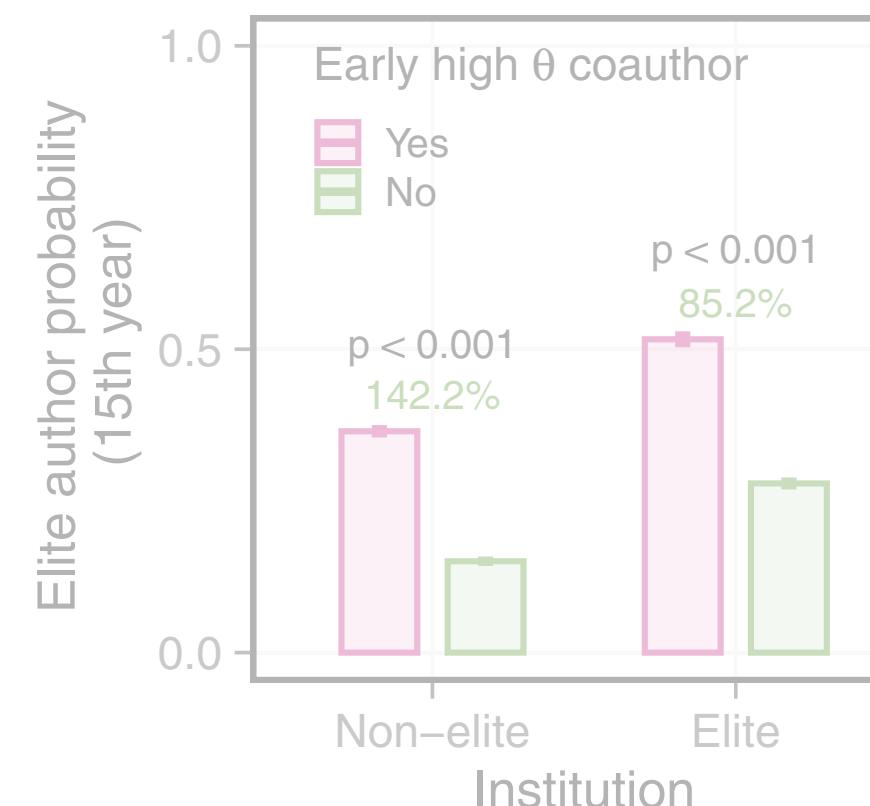
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the 'benefits' are substantial regardless of coauthors career age

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

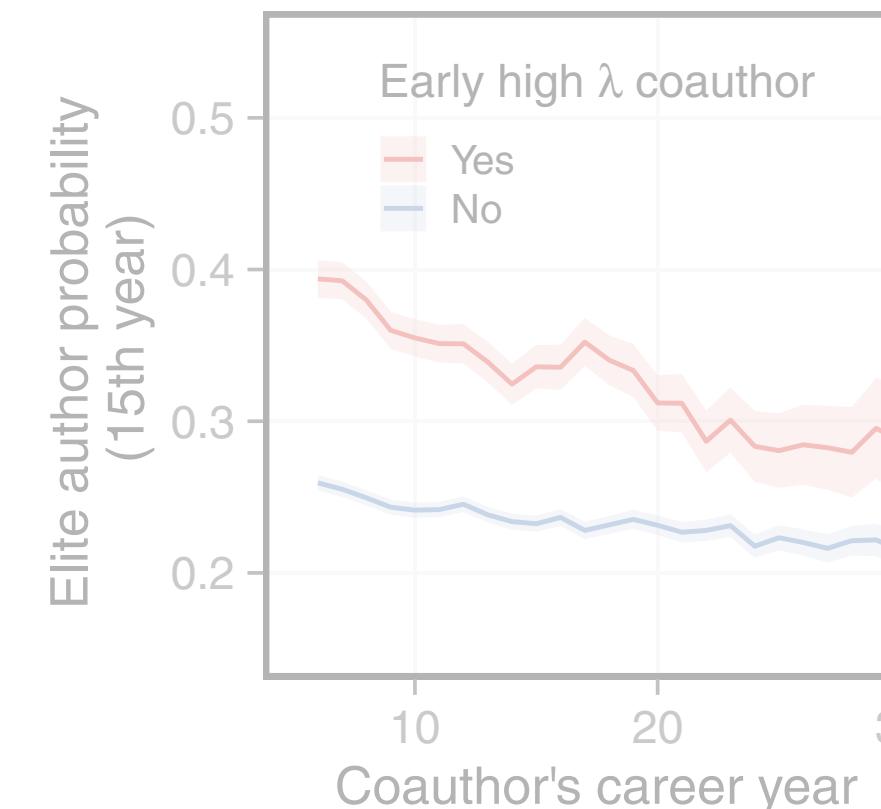
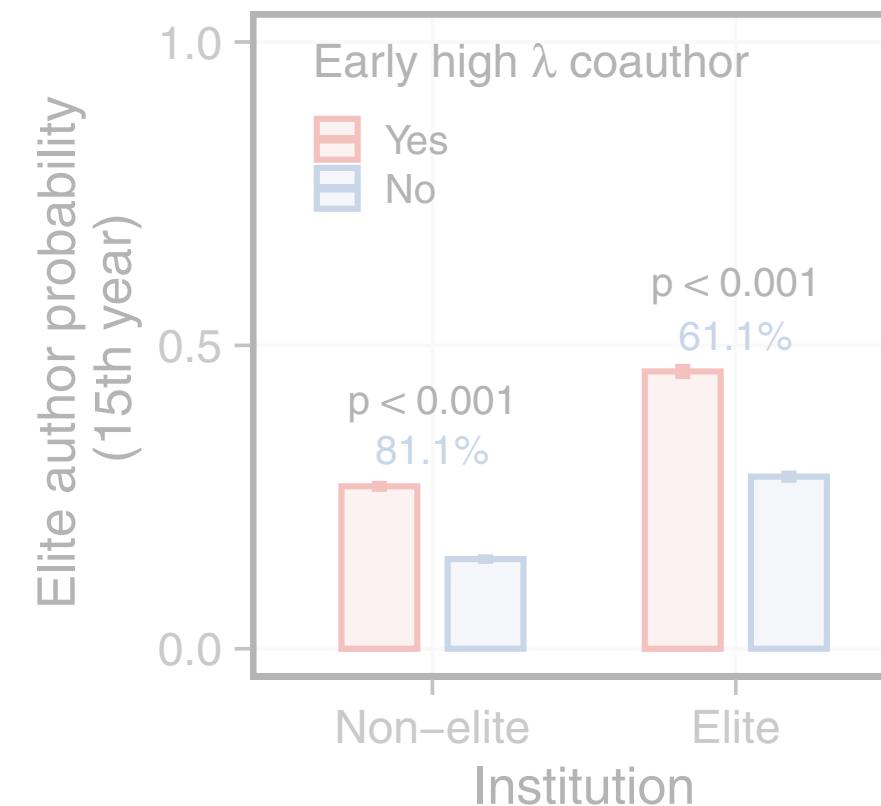


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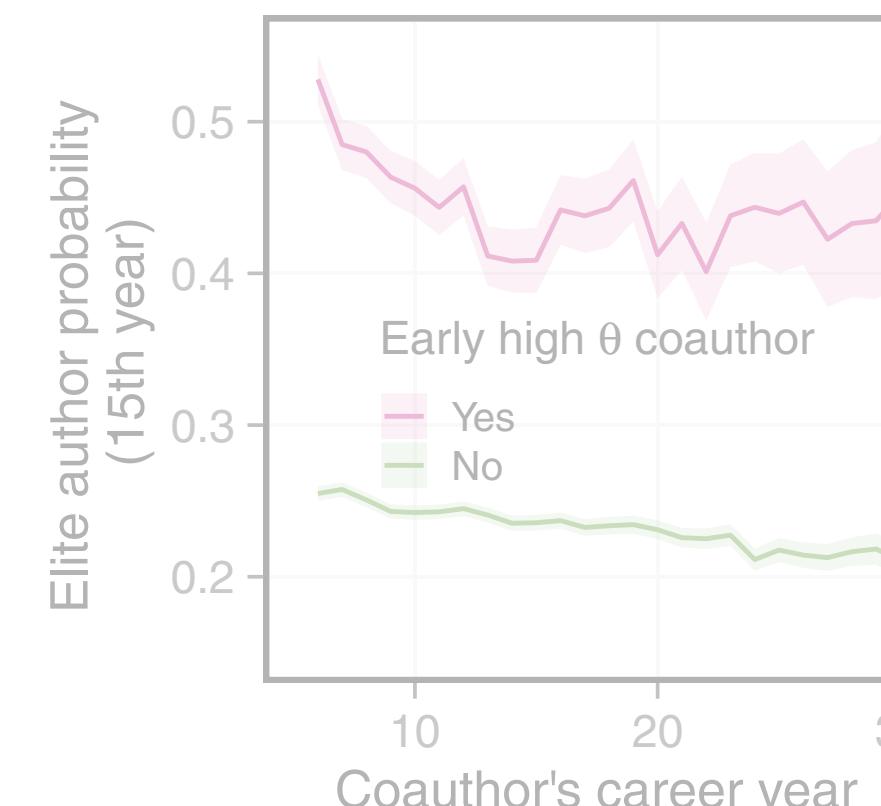
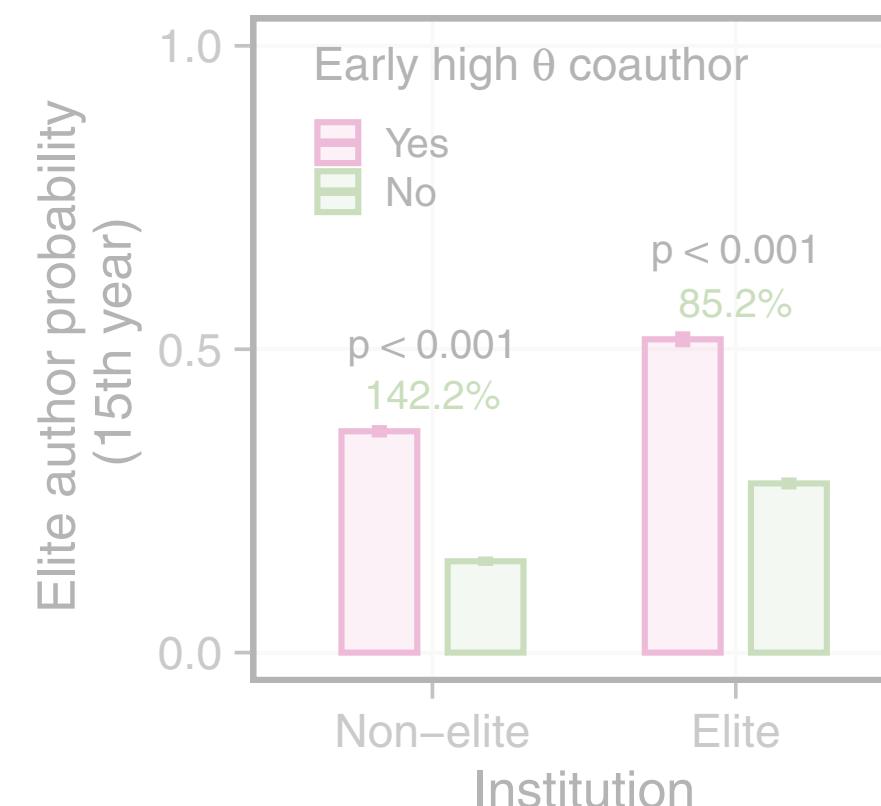
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let's dig deeper into world of elite physicists

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shaded areas are 95% confidence intervals

networks and elite physicists

► elite physicists play a special role in their field, as exemplars of accomplishment and the best ideas

does physics value elite men and women physicists equally?
how meritocratic is the field?

The undervaluing of elite women in physics

Weihua Li,^{1,2,3,4,5} Hongwei Zheng^{6 *} & Aaron Clauset^{7,8,9 *}

Preprint available upon request

networks and elite physicists

- ▶ use our network model to net out coauthor effects, 1950-2023
 - controlling for collaborators, most men and women in physics are nearly equally productive and nearly equally prominent

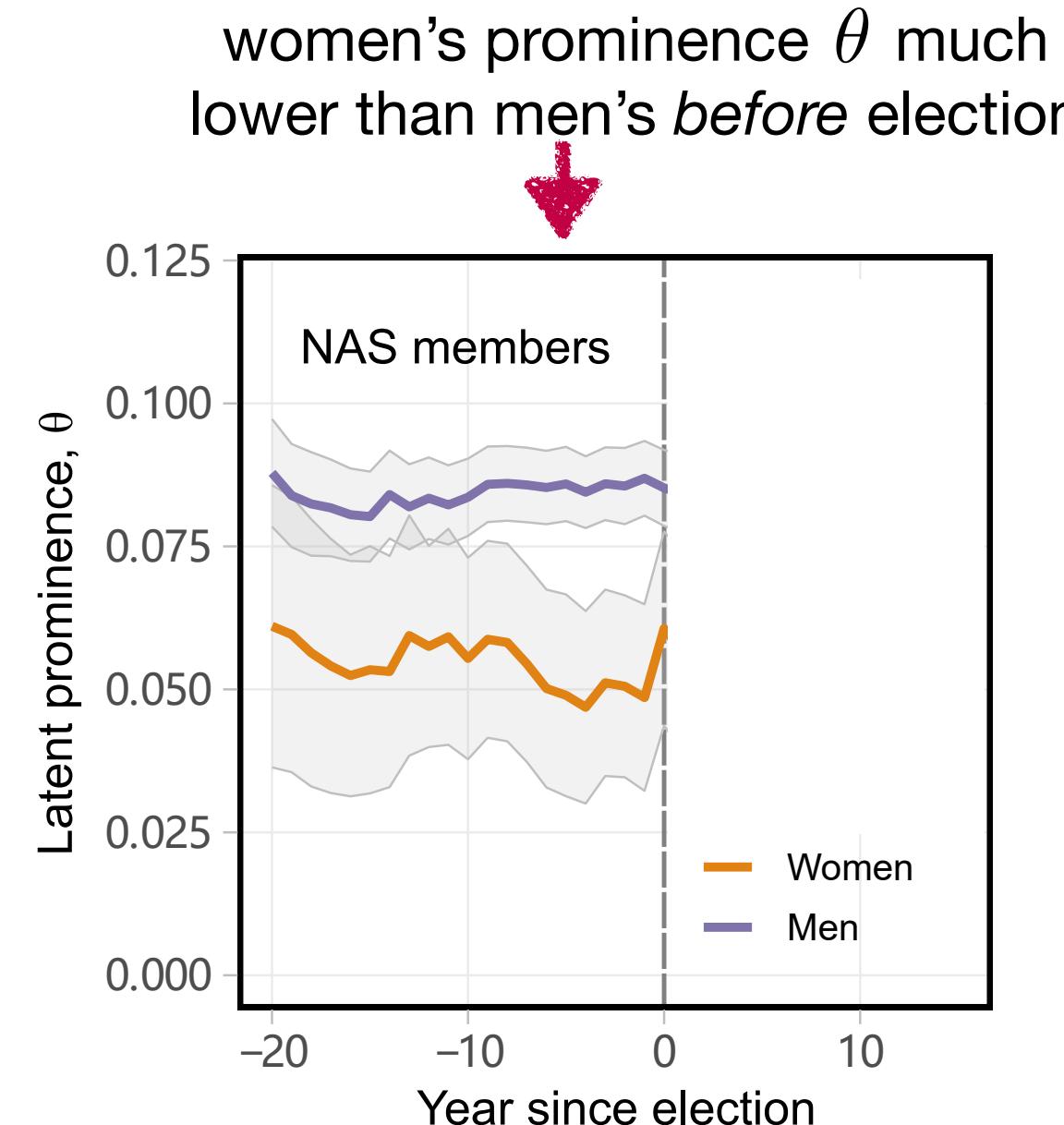
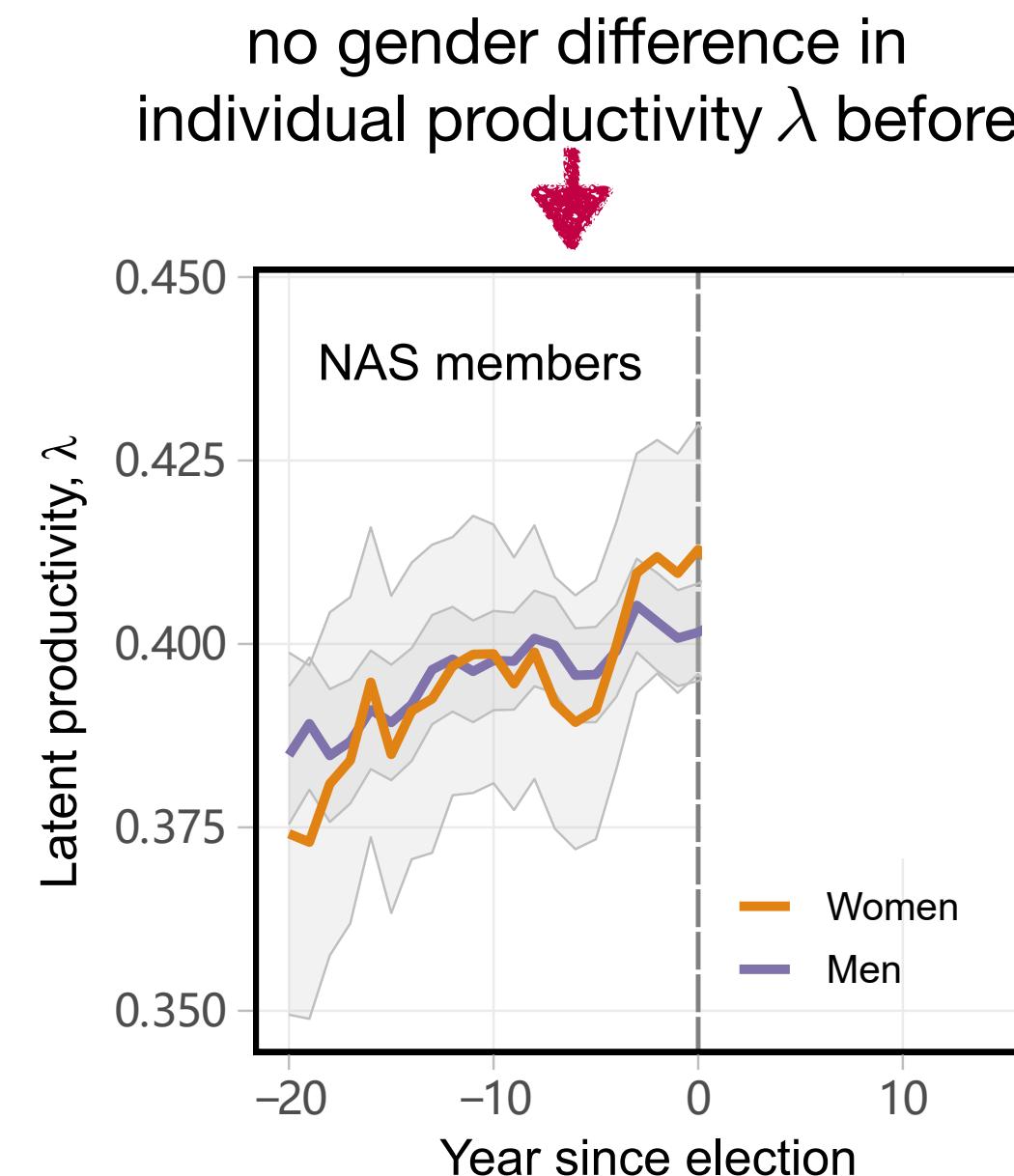
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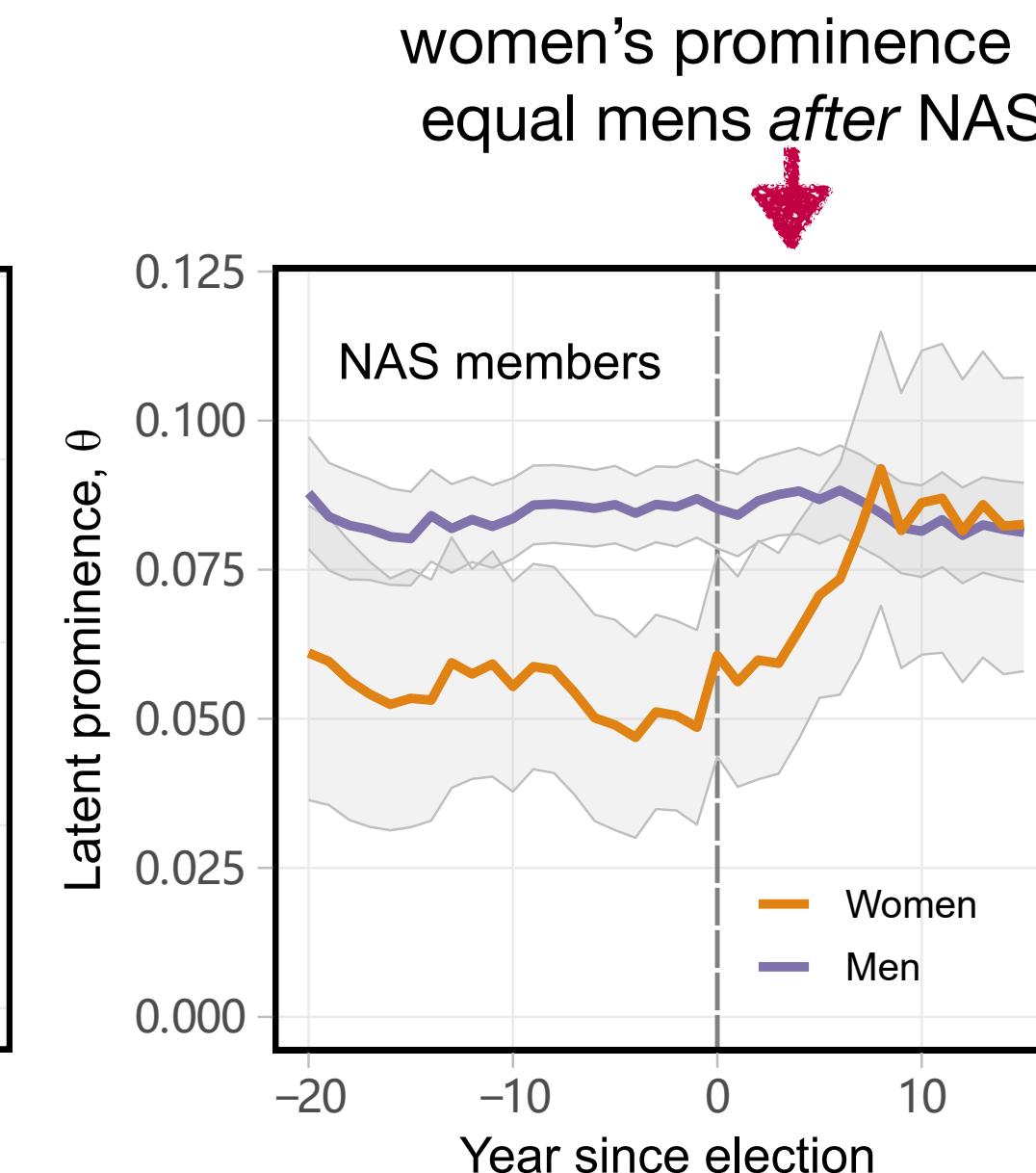
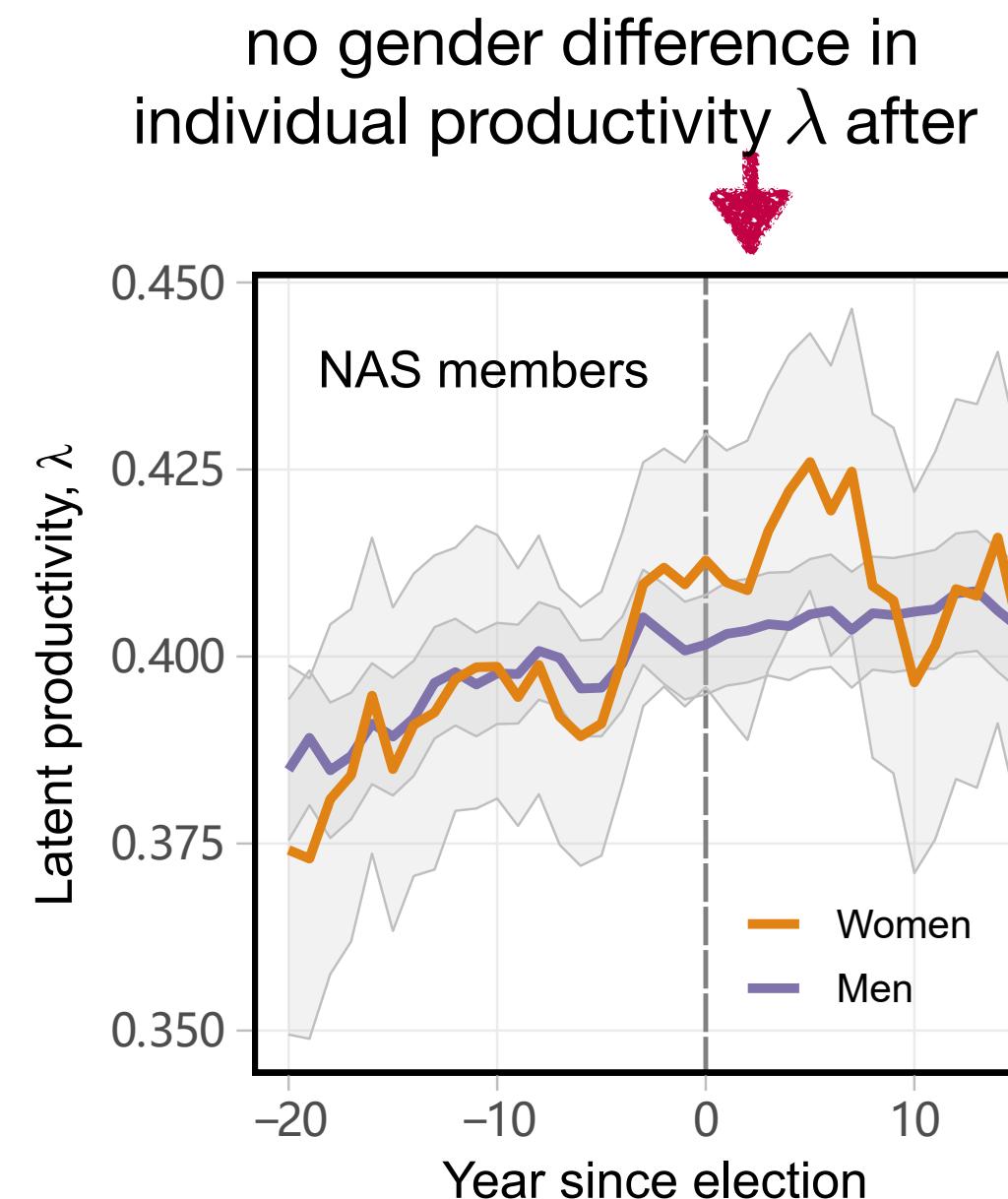
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 - controlling for collaborators, most men and women in physics are nearly equally productive and nearly equally prominent
 - but elite women are elected to US National Academy when they are much less prominent (and ~4 later than men)

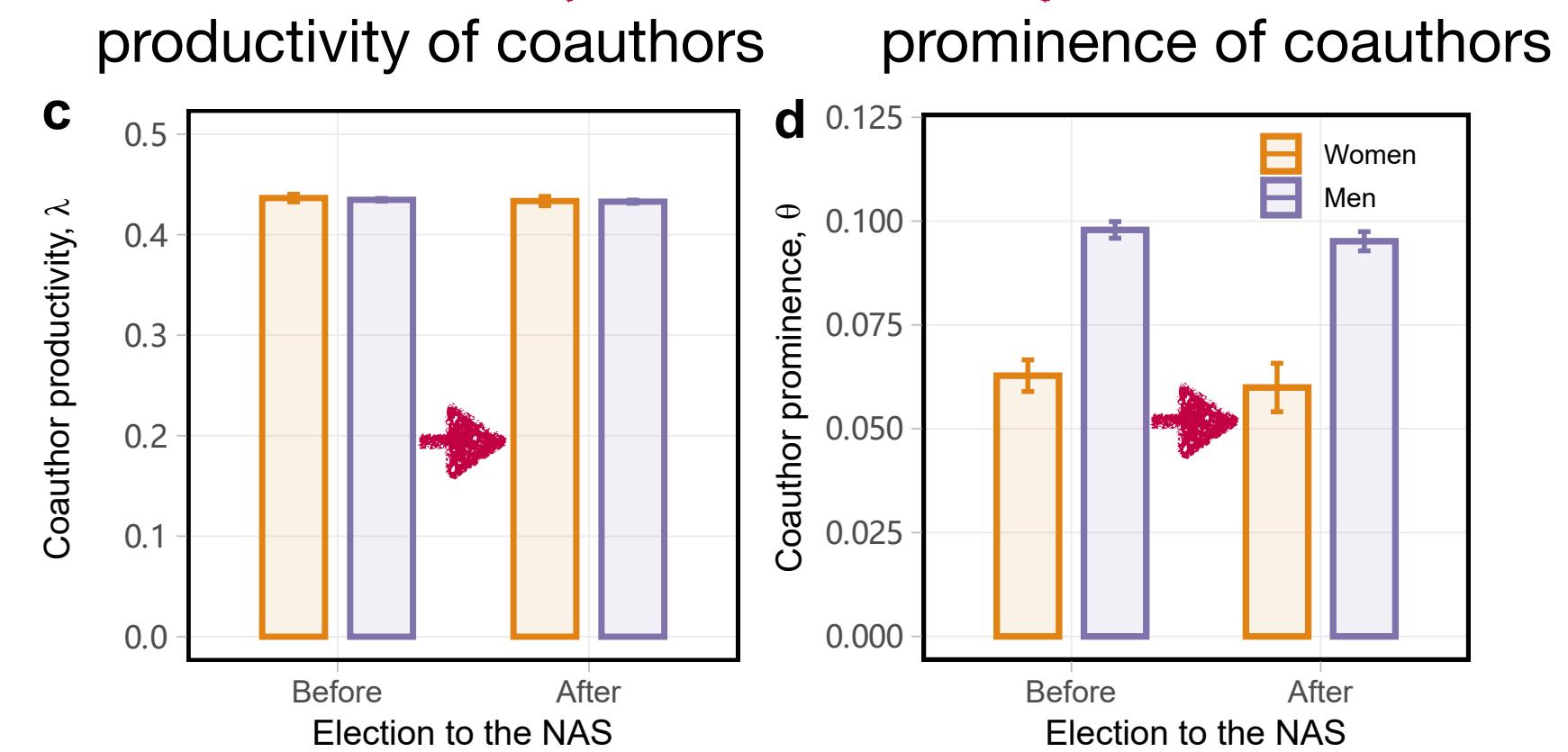


The undervaluing of elite women in physics

Weihua Li,^{1,2,3,4,5} Hongwei Zheng^{6 *} & Aaron Clauset^{7,8,9 *}

Preprint available upon request

not a coauthor effect – networks don't change



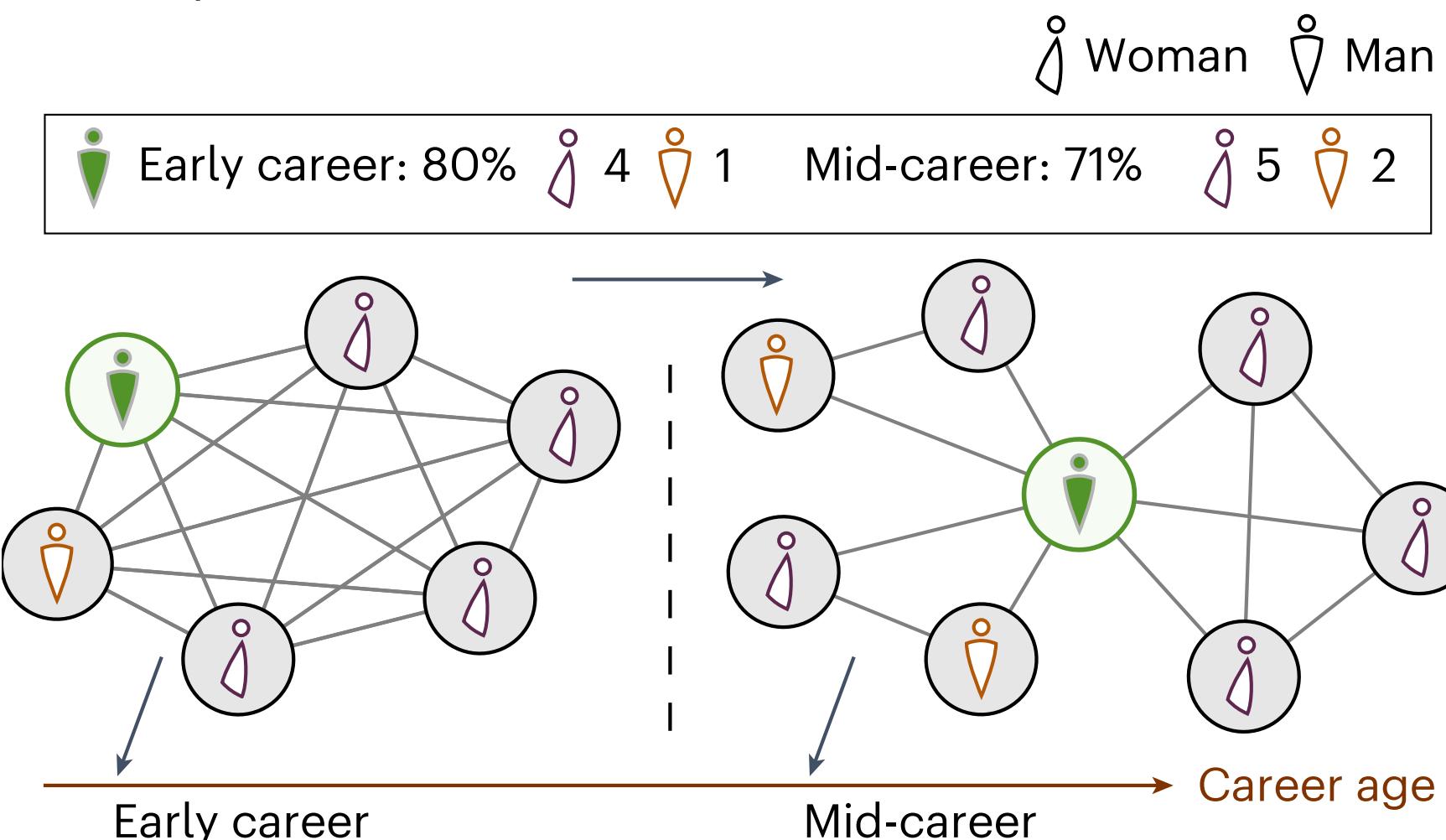
election seems to correct previous undervaluing of elite women in physics

early-career network diversity

▶ how does the *diversity* of early-career teams influence later-career collaboration networks?

homophily : women prefer women, men prefer men

what if preferences can be socialized?



man who trains with high density of women → man who advises high density of early-career women

Article

<https://doi.org/10.1038/s43588-025-0122-1>

Gender and racial diversity socialization in science

Received: 4 December 2024

Weihua Li ^{1,2,3,4,5,6}, Hongwei Zheng ⁷✉, Jennie E. Brand⁸ &

Accepted: 20 March 2025

Aaron Clauset ^{9,10,11}✉

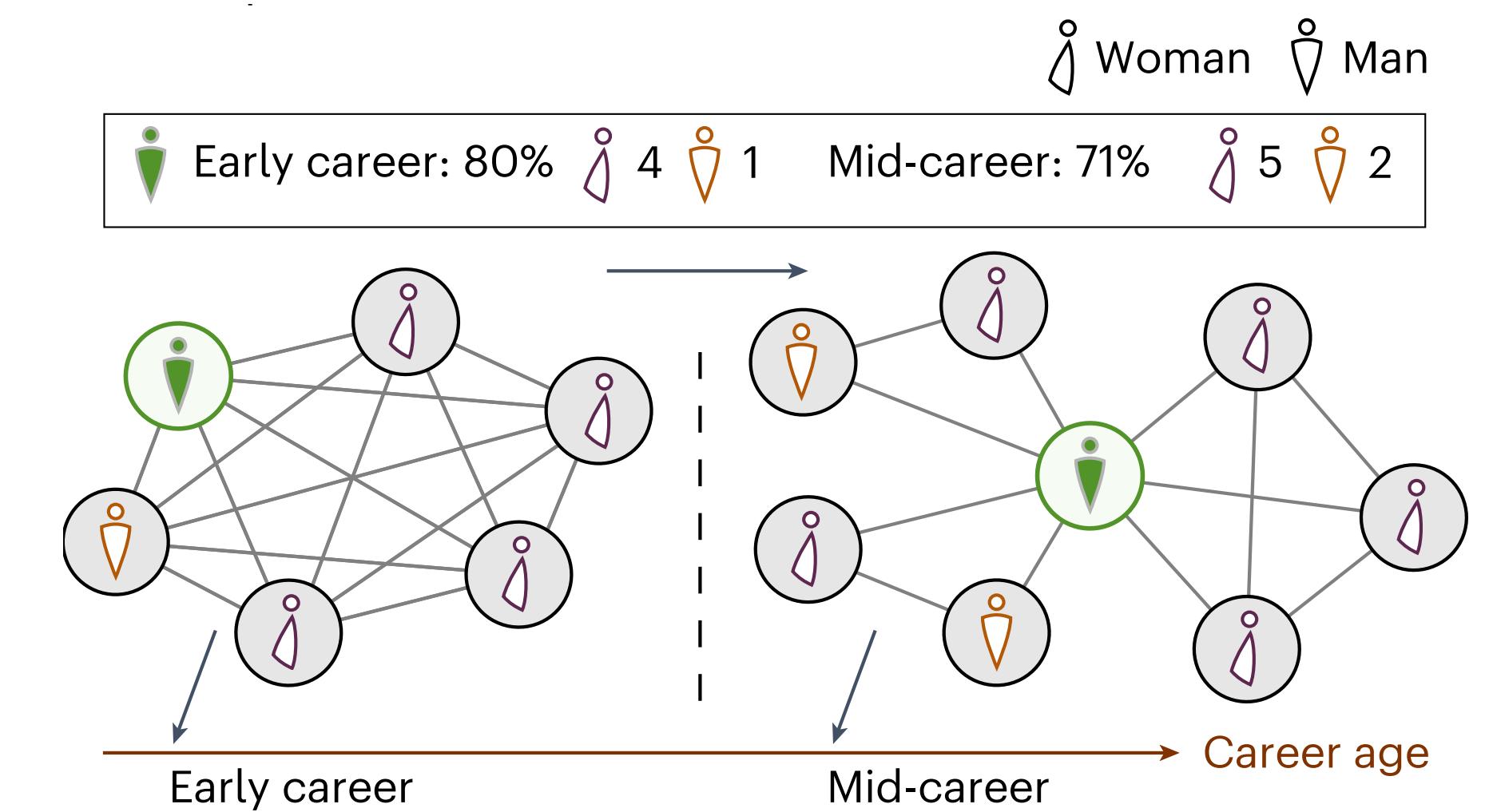
Nature Computational Science (2025)

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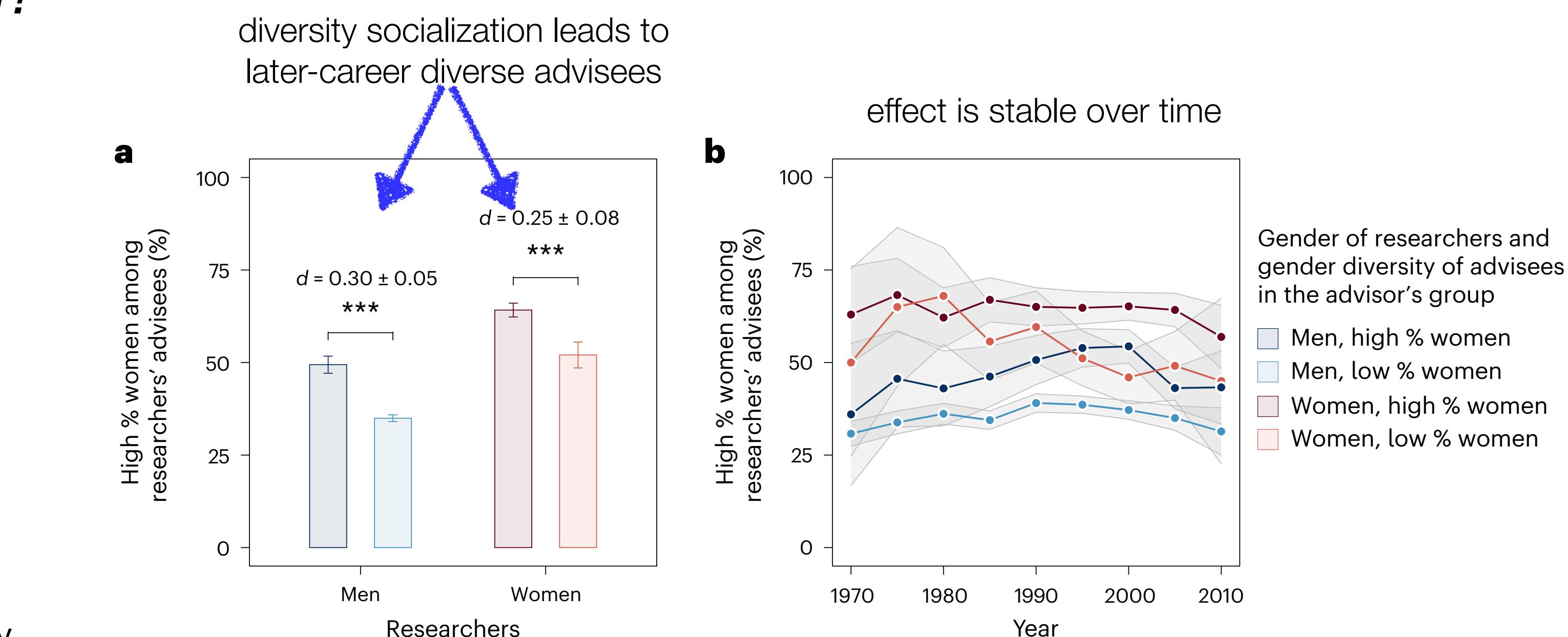
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homophily is not destiny – diversity is a learnable preference

Article

<https://doi.org/10.1038/s43588-025-0122-2>

Gender and racial diversity socialization in science

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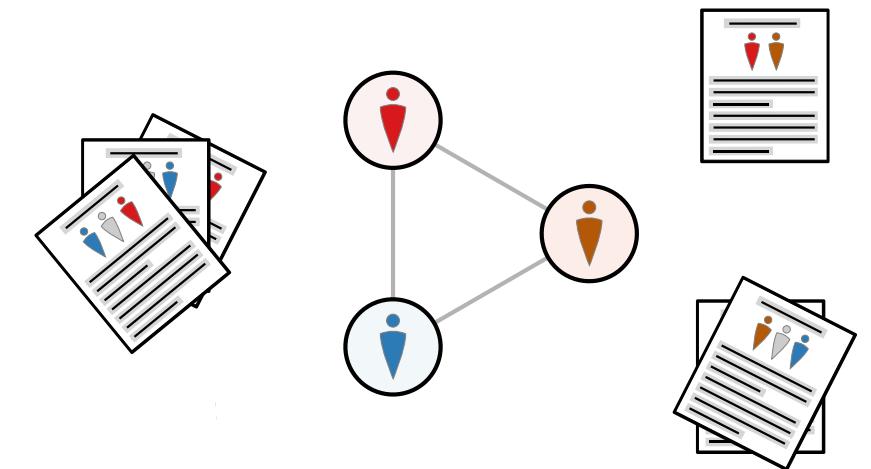
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Nature Computational Science (2025)

how important is who you work with?

networks act like unequally distributed social capital in science

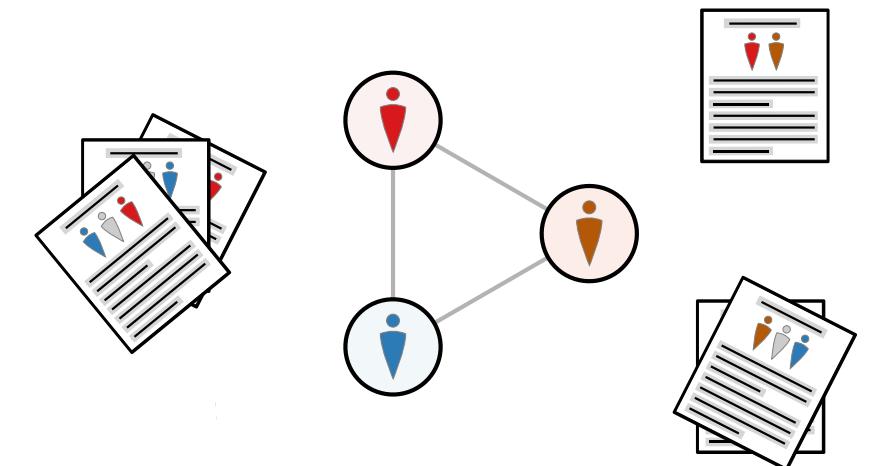
- *they mediate our scientific attention, evaluation, and collaboration*



how important is who you work with?

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- they mediate our scientific attention, evaluation, and collaboration



differences in collaboration networks can explain

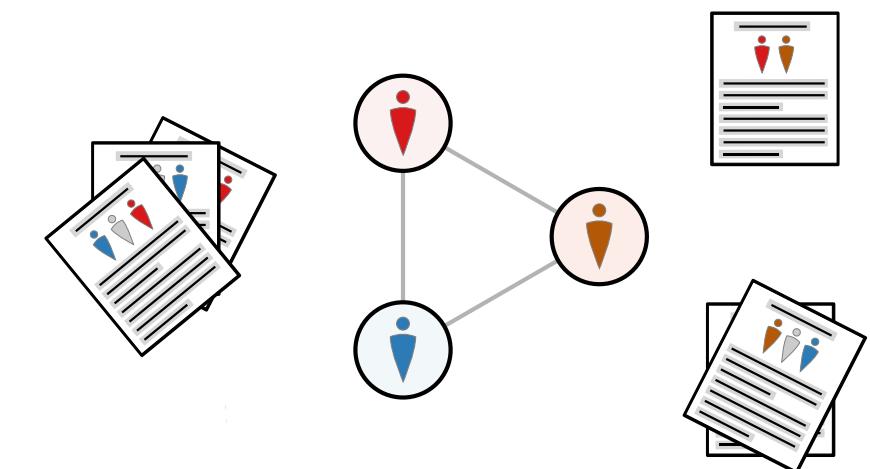
- gendered differences in productivity & prominence →
 - no difference in *individual* productivity & prominence (λ_i, θ_i)
 - but men do publish more and are more prominent, implying the difference is due to their networks
 - hence, should not compare *unadjusted* measures of productivity & prominence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

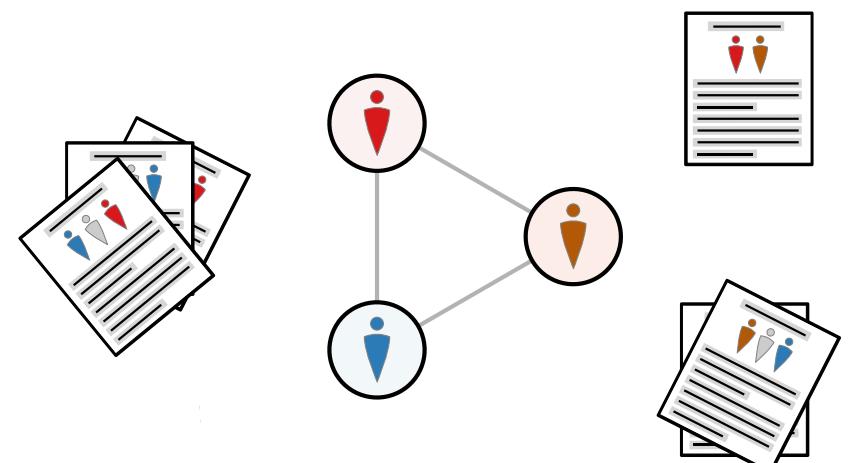
- ➔ • elite senior coauthors bequeath some of their networks to junior coauthors — inter-generational transfers
- this effect is independent of institutional prestige
- but junior scholars have greater access to elite coauthors at elite institutions



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? ➔

Edge interventions can mitigate demographic and prestige disparities in the Computer Science coauthorship network

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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

Preprint, [arxiv:2506.04435](https://arxiv.org/abs/2506.04435) (2025)

the scientific ecosystem

no scientist is an island → productivity is driven by environmental & network effects



the scientific ecosystem

no scientist is an island → productivity is driven by environmental & network effects

- where you train *doesn't* seem to matter (conditioned on getting a faculty job)

- where you work *does* matter : prestige → available labor → more scientific output



- prestige shapes your working environment – like a slope underneath the whole ecosystem
- no results on the *value* of different scientific outputs, only their total volume
- many unobserved confounds: quality of job talk, fundability of ideas, quality of writing, etc.

the scientific ecosystem

no scientist is an island → productivity is driven by environmental & network effects

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productivity & prominence are network effects → who you work with shapes your output

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productivity & prominence are network effects → who you work with shapes your output

- net of their coauthors, men & women *equal* in their *individual* productivity & prominence
- early-career researchers can *inherit* collaboration networks → like generational wealth transfer

- prestige shapes who you *can* work with (environment)
- no results about scientific *value*, only the volume and the attention outputs receive
- comparing individual researchers is unfair without accounting for different coauthor network effects

the scientific ecosystem

no scientist is an island → productivity is driven by environmental & network effects

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ecosystem metaphor is rich → what other environmental or network effects?

- how should we intervene in an ecosystem?
- what might accelerate scientific discovery?

- The undervaluing of elite women in physics
- Gender and racial diversity socialization in science
- Epistemic inequality in the diffusion of scientific ideas

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

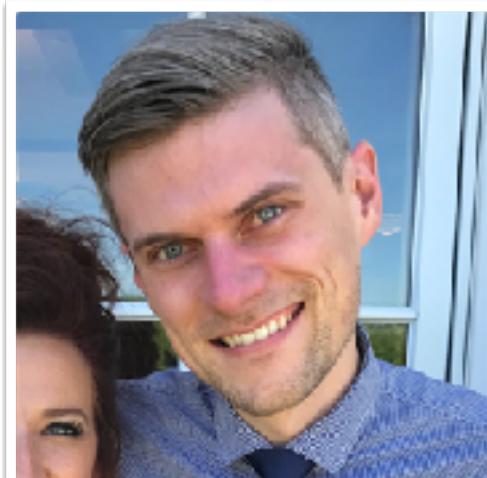
Sam Zhang^{1*}, K. Hunter Wapman², Daniel B. Larremore^{2,3}, Aaron Clauset^{2,3,4*}

Science Advances 8, eabq7056 (2022)

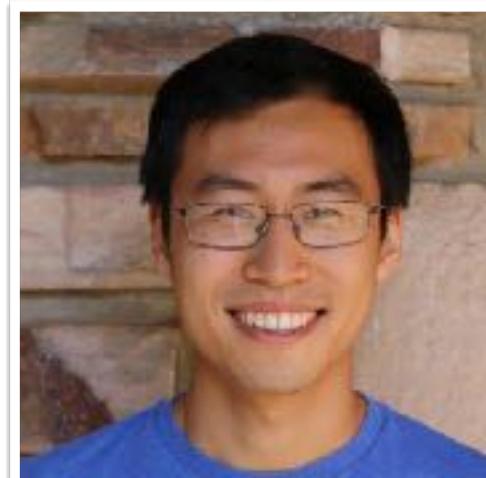
Untangling the network effects of productivity and prominence among scientists

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)



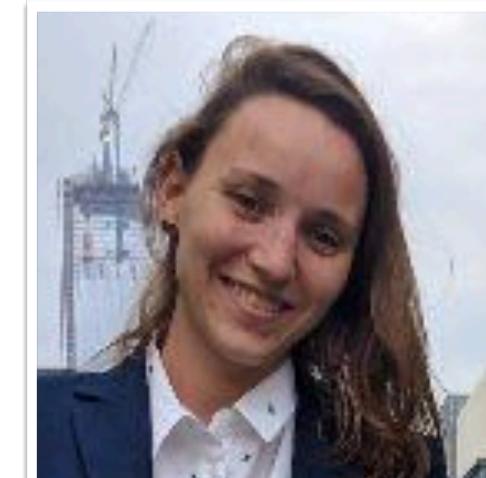
Dr. K. Hunter Wapman
(Colorado)



Prof. Weihua Li
(Beihang)



Prof. Zhiming Zhang
(Beihang)



Dr. Allison Morgan
(now: Code for America)



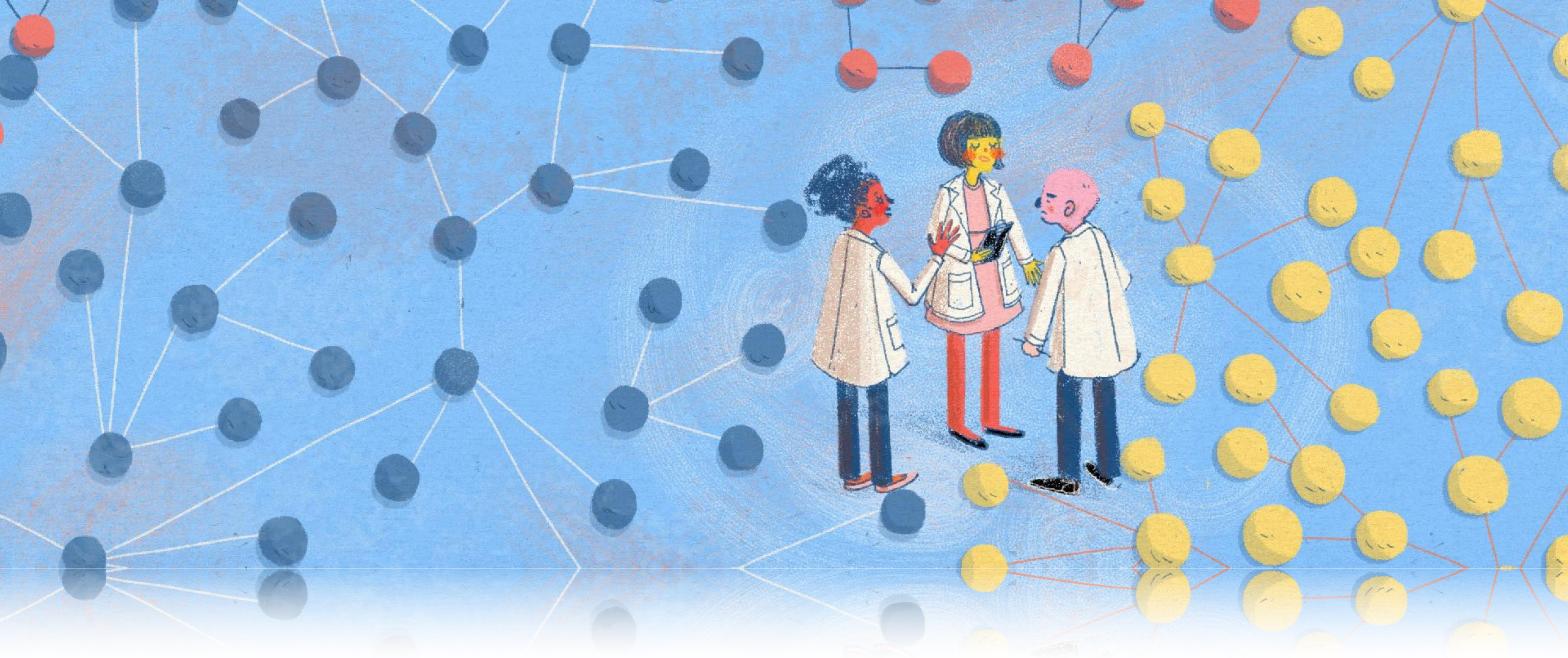
Prof. Skyler Cranmer
(Ohio State)



Prof. Daniel Larremore
(Colorado)

Funding:





fin



papers, code, data

<https://aaronclauset.github.io>