Table A1
Individual and Network Information on Faculty Members Per and Between Time Point.

| | 1994 | 1995 | 1996 | 1997 | 1998 | 1999 | 2000 | 2001 | 2002 | 2003 | 2004 | 2005[a] |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Individual information** | | | | | | | | | | | | |
| Faculty members | 1,396 | 1,424 | 1,456 | 1,485 | 1,532 | 1,592 | 1,638 | 1,667 | 1,698 | 1,710 | 1,741 | 1,774 |
| Joining | 110 | 101 | 96 | 105 | 133 | 142 | 117 | 124 | 98 | 110 | 118 | |
| Leaving | 82 | 69 | 67 | 58 | 73 | 96 | 88 | 93 | 86 | 79 | 85 | |
| Staying | 1,314 | 1,355 | 1,389 | 1,427 | 1,459 | 1,496 | 1,550 | 1,574 | 1,612 | 1,631 | 1,656 | |
| Average age | 64 | 63 | 61 | 60 | 59 | 58 | 56 | 55 | 54 | 54 | 53 | 52 |
| Gender (1 = Male) | 83% | 82% | 82% | 82% | 81% | 80% | 80% | 78% | 78% | 77% | 77% | 77% |
| Minority (1 = non-White) | 13% | 14% | 14% | 14% | 15% | 15% | 16% | 16% | 17% | 17% | 17% | 18% |
| Tenured | 64% | 62% | 61% | 61% | 61% | 59% | 58% | 56% | 55% | 55% | 54% | 54% |
| Untenured | 40% | 40% | 38% | 37% | 34% | 34% | 34% | 36% | 36% | 34% | 35% | 35% |
| Clinical | 16% | 18% | 20% | 21% | 22% | 24% | 25% | 26% | 27% | 28% | 29% | 29% |
| Stemfield (1 = Yes) | 65% | 65% | 65% | 66% | 66% | 66% | 67% | 67% | 68% | 68% | 68% | 68% |
| **Collaboration network** | | | | | | | | | | | | |
| Density | .002 | .003 | .002 | .003 | .002 | .002 | .002 | .003 | .003 | .003 | .003 | .002 |
| Ties | 3,582 | 3,598 | 3,307 | 3,852 | 4,296 | 4,340 | 4,556 | 4,652 | 5,501 | 5,948 | 5,555 | 4,860 |
| Degree (overall) | 4.22 | 4.24 | 3.89 | 4.53 | 4.47 | 4.51 | 4.74 | 4.84 | 5.44 | 5.88 | 5.49 | 4.80 |
| Non-stem | 0.46 | 0.55 | 0.56 | 0.43 | 0.60 | 0.62 | 0.87 | 0.94 | 0.53 | 0.93 | 0.94 | 0.60 |
| Stemfield | 6.27 | 6.27 | 5.72 | 6.78 | 6.44 | 6.50 | 6.71 | 6.83 | 7.86 | 8.32 | 7.74 | 6.88 |
| Transitivity (triads) | 26% | 31% | 22% | 20% | 21% | 26% | 24% | 25% | 23% | 21% | 20% | 19% |
| *Dyadic relations* | | | | | | | | | | | | |
| Same opportunity | 76% | 75% | 87% | 87% | 84% | 76% | 78% | 79% | 77% | 77% | 78% | 78% |
| Similar age | 16% | 15% | 15% | 16% | 16% | 16% | 15% | 15% | 16% | 17% | 16% | 16% |
| Same gender | 76% | 75% | 76% | 76% | 74% | 71% | 70% | 70% | 71% | 69% | 68% | 69% |
| Same race | 83% | 80% | 82% | 82% | 82% | 81% | 78% | 76% | 77% | 78% | 77% | 72% |
| Same rank | 51% | 48% | 48% | 48% | 52% | 54% | 55% | 58% | 60% | 60% | 54% | 54% |
| *Tie changes* | | | | | | | | | | | | |
| Tie formation (0 → 1) | 1,136 | 1,229 | 1,335 | 1,570 | 1,618 | 1,723 | 1,384 | 2,002 | 1,729 | 1,244 | 1,430 | |
| Tie termination (1 → 0) | 1,120 | 1,520 | 790 | 1,126 | 1,574 | 1,507 | 1,288 | 1,153 | 1,282 | 1,637 | 2,125 | |
| Tie maintenance (1 → 1) | 2,462 | 2,078 | 2,517 | 2,726 | 2,722 | 2,833 | 3,268 | 3,499 | 4,219 | 4,311 | 3,430 | |
| Jaccard index (tie stability) | 52% | 43% | 54% | 50% | 46% | 47% | 55% | 53% | 58% | 60% | 49% | |
| **Shared language network** | | | | | | | | | | | | |
| Density | .004 | .005 | .005 | .006 | .005 | .006 | .006 | .006 | .006 | .007 | .008 | .008 |
| Ties | 6,250 | 6,612 | 7,300 | 8,031 | 9,473 | 10,686 | 11,444 | 11,774 | 12,927 | 14,460 | 15,492 | 16,644 |
| Degree (overall) | 7.36 | 7.80 | 8.59 | 9.45 | 9.85 | 11.12 | 11.90 | 12.25 | 12.78 | 14.30 | 15.32 | 16.45 |
| Non-stem | 0.70 | 0.74 | 0.82 | 1.08 | 1.20 | 1.33 | 1.40 | 1.45 | 1.46 | 1.54 | 1.64 | 1.46 |
| Stemfield | 11.0 | 11.66 | 12.85 | 14.04 | 14.26 | 16.10 | 17.25 | 17.74 | 18.36 | 20.59 | 22.06 | 23.85 |
| Transitivity (triads) | 20% | 20% | 21% | 20% | 20% | 20% | 20% | 18% | 18% | 18% | 18% | 19% |
| *Dyadic relations* | | | | | | | | | | | | |
| Same opportunity | 84% | 84% | 86% | 87% | 88% | 88% | 88% | 87% | 86% | 85% | 85% | 87% |
| Similar age | 15% | 16% | 16% | 15% | 16% | 16% | 15% | 16% | 16% | 15% | 15% | 15% |
| Same gender | 77% | 76% | 75% | 74% | 71% | 71% | 71% | 71% | 70% | 69% | 68% | 66% |
| Same race | 82% | 81% | 81% | 81% | 79% | 78% | 77% | 75% | 74% | 72% | 72% | 69% |
| Same rank | 50% | 46% | 45% | 44% | 46% | 47% | 48% | 49% | 48% | 50% | 49% | 51% |
| *Tie changes* | | | | | | | | | | | | |
| Tie formation (0 → 1) | 2,320 | 2,706 | 2,986 | 3,760 | 4,142 | 3,931 | 4,226 | 4,888 | 5,225 | 5,503 | 5,773 | |
| Tie termination (1 → 0) | 1,958 | 2,018 | 2,255 | 2,318 | 2,929 | 3,173 | 3,896 | 3,735 | 3,692 | 4,471 | 4,621 | |
| Tie maintenance (1 → 1) | 4,292 | 4,594 | 5,045 | 5,713 | 6,544 | 7,513 | 7,548 | 8,039 | 9,235 | 9,989 | 10,871 | |
| Jaccard index (tie stability) | 50% | 49% | 49% | 49% | 48% | 51% | 48% | 48% | 51% | 50% | 51% | |

*Notes.* [a]The collaboration networks and shared language networks are based on articles published in the current and the following two years (and additional indicators for the collaboration network, see Methods section for details). The 2005 networks thus make use of information gathered up to 2007.

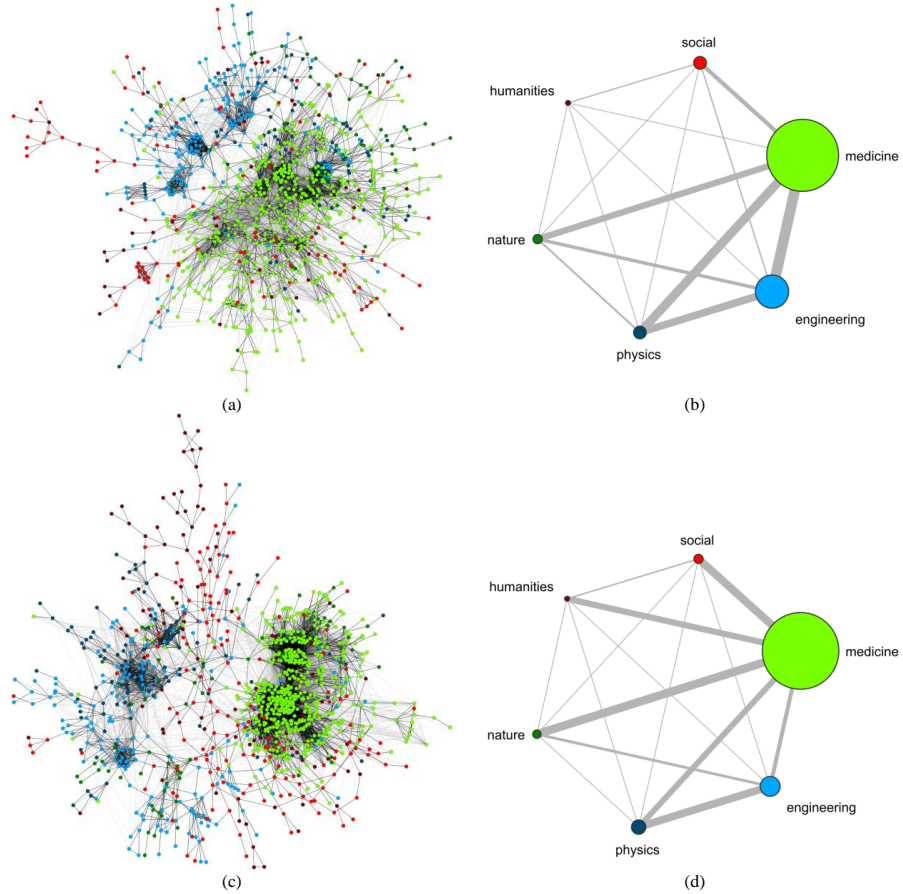**Appendix B: Network visualizations for the period 1994-1997 and 2002-2005**
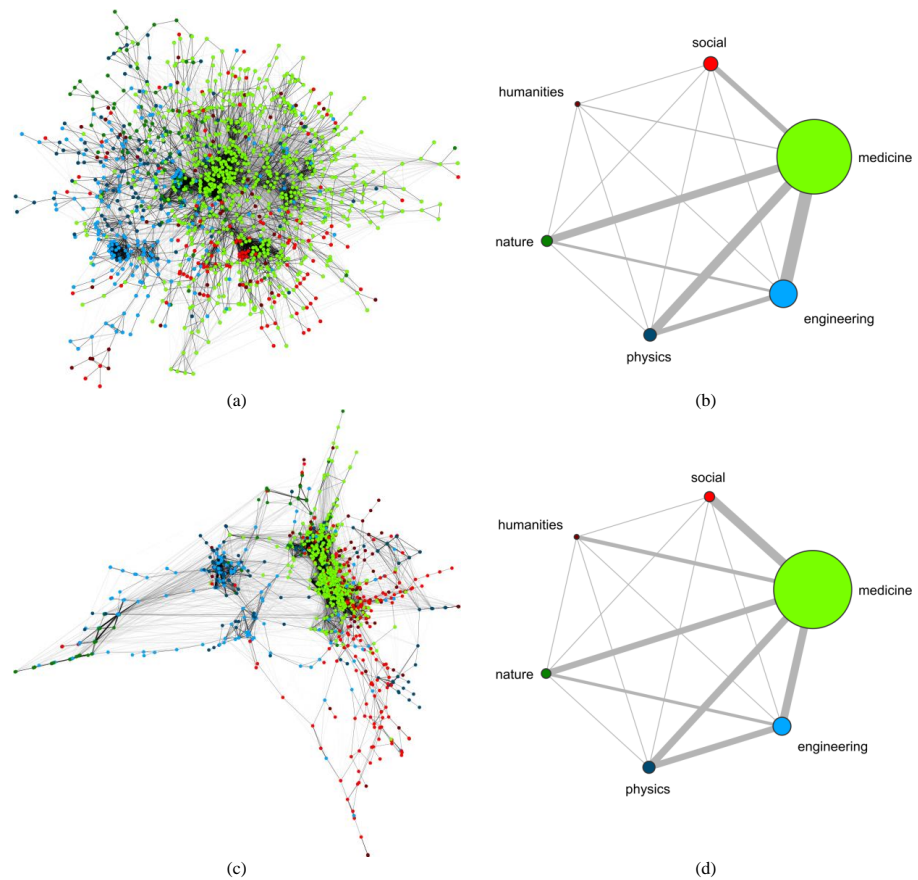


(a)

(b)

(c)

(d)

**Figure A1.** Illustration of collaboration and shared language networks in the period 1994-1997.

*Notes.* (a) shows network consisting of collaboration ties ($n$=6,796) in the period 1994-1997 among all faculty ($n$=1,051) who belong to the core network (referring to faculty with at least one tie connection to the large structure; $n$=648 excluded); (b) shows a simplified version of complete network in (a). (c) shows network consisting of shared language ties ($n$=13,766) in the period 1994-1997 among all faculty ($n$=1,160) who belong to the core network (referring to faculty with at least one tie connection to the large structure; $n$=539 excluded); (d) shows a simplified version of complete network in (c). Larger nodes in (b) and (d) have more within-discipline tie connections and thicker lines have more between-discipline tie connections.

**Figure A2.** Illustration of collaboration and shared language networks in the period 2002-2005.

*Notes.* (a) shows network consisting of collaboration ties (*n*=9,433) in the period 2002-2005 among all faculty (*n*=1,325) who belong to the core network (referring to faculty with at least one tie connection to the large structure; *n*=698 excluded); (b) shows a simplified version of complete network in (a). (c) shows network consisting of shared language ties (*n*=28,292) in the period 2002-2005 among all faculty (*n*=1,534) who belong to the core network (referring to faculty with at least one tie connection to the large structure; *n*=489 excluded); (d) shows a simplified version of complete network in (c). Larger nodes in (b) and (d) have more within-discipline tie connections and thicker lines have more between-discipline tie connections.

## Appendix C: Goodness of fit plots and visual representation of SAOM effects
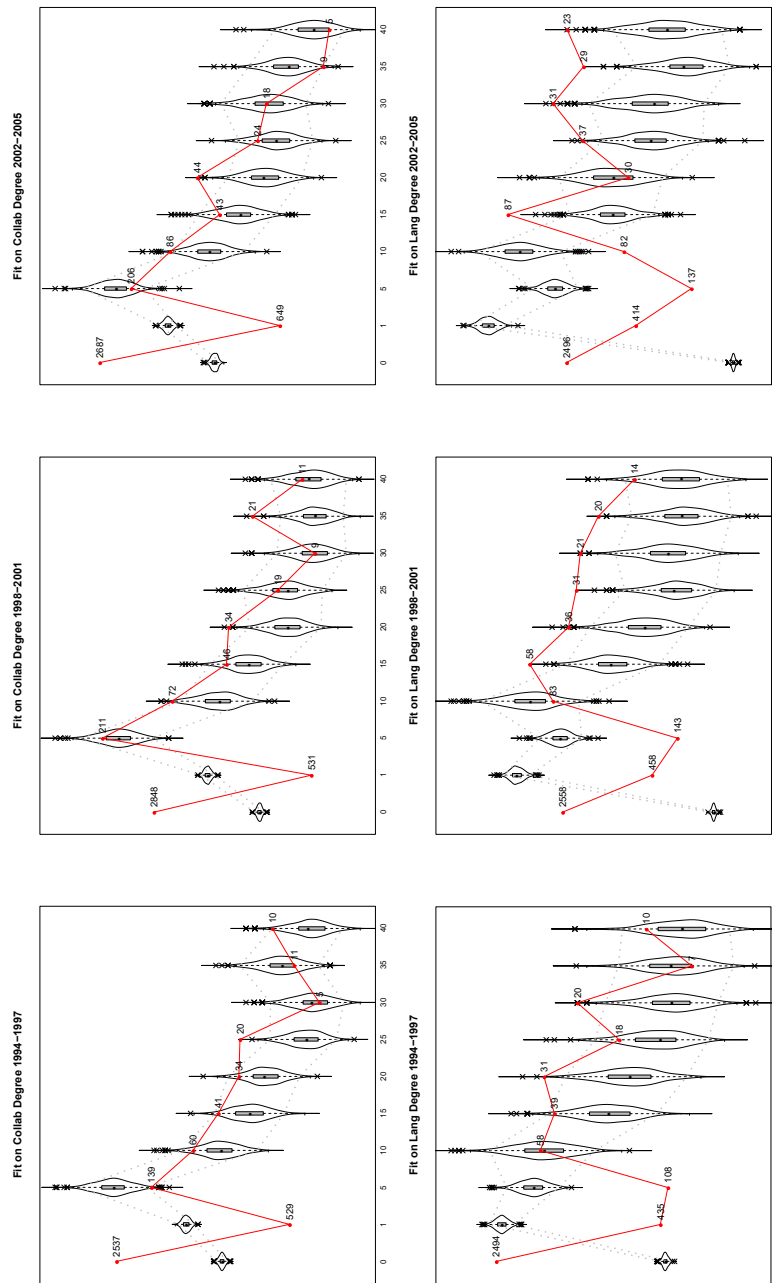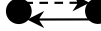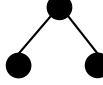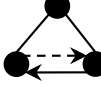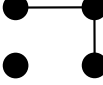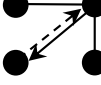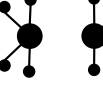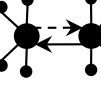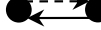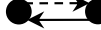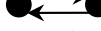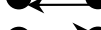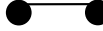


**Figure A3.** Goodness of fit test with auxiliary statistics for the models in Table 2. The differences between the cumulative degree distribution in the observed networks (summed across the four waves of data for each period — solid line) and the simulated values in the model (summed across 4,000 random networks — violin plots) were assessed with the Mahalonobis distance test (Ripley et al. 2020). Panel 1-3 show the cumulative degree distribution for the collaboration network in the three periods (referring to 1994-1997, 1998-2001, and 2002-2005); Panels 4-6 show the degree distribution for the shared language network in the three periods.

**Table A2**

Visual representation of SAOM effects

| Effect Parameters | | Hypothetical change | | |
|---|---|---|---|---|
| | | t*x* | → | t*x* + *m* |
| *Rate Parameter* | | | | |
| 1 | Network rate t1→t2 | NA | | NA |
| 2 | Network rate t2→t3 | NA | | NA |
| 3 | Network rate t3→t4 | NA | | NA |
| *Structure Effects* | | | | |
| 4 | Degree (density) | | → | |
| 5 | Transitive triads (clustering) | | → | |
| 6 | Degree of alter (centralization)[a] | | → | |
| 7 | Degree assortativity (stratification) | | → | |
| *Individual Effects*[b] | | | | |
| 8 | Age (older) | | → | |
| 9 | Male (ref. = female) | | → | |
| 10 | Minority group (ref. = White) | | → | |
| 11 | STEM (ref. = non-STEM) | | → | |
| 12 | Untenured (ref. = tenured) | | → | |
| 13 | Clinical faculty (ref. = tenured) | | → | |
| *Dyadic Effects* | | | | |
| 14 | Same affiliations (opportunity) | | → | |
| 15 | Similar age | | → | |
| 16 | Same gender | | → | |
| 17 | Same race | | → | |
| 18 | Same rank | | → | |
| *Cross-Network Effects* | | | | |
| 19 | Existing tie X → New tie Y | | → | |

*Note.* NA = Not applicable.

# Appendix D: Between-Panel Comparison of Parameter Estimates

**Table A3**

Comparison of Parameter Estimates Between Collaboration Networks and Shared Language Networks in the Three Periods.

| Effect Parameters | Between-Network Comparison [a] | | | | | |
|---|---|---|---|---|---|---|
| | Period 1 (1994-1997) n=1,699 | | Period 2 (1998-2001) n=1,923 | | Period 3 (2002-2005) n=2,023 | |
| | Δ Est. | z | Δ Est. | z | Δ Est. | z |
| *Rate Parameter* | | | | | | |
| 1 Network rate t1→t2 | 4.85 | 13.39*** | 8.98 | 18.07*** | 12.63 | 35.51*** |
| 2 Network rate t2→t3 | 2.19 | 3.80*** | 5.85 | 12.37*** | 15.13 | 43.80*** |
| 3 Network rate t3→t4 | 8.75 | 23.58*** | 12.78 | 33.70*** | 11.75 | 31.54*** |
| *Structure Effects* | | | | | | |
| 4 Degree (density) | .57 | 7.68*** | .53 | 10.92*** | .92 | 20.33*** |
| 5 Transitive triads (clustering) | -.21 | -2.64*** | -.37 | -29.77*** | -.14 | -23.73*** |
| 6 Degree of alter (centralization) | .004 | 1.84+ | -.002 | -.93 | -.002 | -1.32 |
| 7 Degree assortativity (stratification) | .01 | .80 | .03 | 5.65*** | .002 | .66 |
| *Individual Effects* | | | | | | |
| 8 Age (older) | .002 | 1.39 | .001 | 6.26*** | .01 | 6.90*** |
| 9 Male (ref. = female) | -.14 | -3.41*** | -.01 | -.26 | -.08 | -3.22 |
| 10 Minority group (ref. = White) | .02 | .35 | .01 | .27 | .02 | .66 |
| 11 STEM (ref. = non-STEM) | -.02 | -.34 | -.30 | -6.79*** | -.05 | -1.09 |
| 12 Untenured (ref. = tenured) | .08 | 2.35* | .01 | .27 | -.06 | -1.84+ |
| 13 Clinical faculty (ref. = tenured) | -.14 | -4.52*** | -.35 | -15.59*** | -.27 | -13.58** |
| *Dyadic Effects* | | | | | | |
| 14 Same affiliations (Opportunity) | -.55 | -25.06*** | -.19 | -9.27** | -.36 | -19.19*** |
| 15 Similar age | -.30 | -3.02** | -.41 | -4.55*** | -.31 | -3.55*** |
| 16 Same gender | -.04 | -.93 | .003 | .10 | .01 | .47 |
| 17 Same race | .01 | .14 | .05 | 1.30 | -.02 | -.69 |
| 18 Same rank | .08 | 2.35* | -.07 | -2.61* | .23 | 9.35*** |
| *Cross-Network Effects* | | | | | | |
| 19 Existing tie X → New tie Y | .34 | 5.31*** | .47 | 8.42*** | .03 | .54 |

*Notes.* Positive Δ (difference) = Est. Shared Language > Est. Collaboration, Negative Δ = Est. Collaboration > Est. Shared Language. $*p \leq .05$, $**p \leq .01$, $***p \leq .001$ (two-tailed test). [a]The z-score test assumes equal variance across groups: $z = (Est._{.a} - Est._{.b}) / \text{sqrt}(s.e._{.a}^2 + s.e._{.b}^2)$, with $a$ = shared language, and $b$ = collaboration network. Under the null-hypothesis of equal parameters, the test has an approximately standard normal distribution (Ripley et al. 2020).

**Table A4**

Comparison of Parameter Estimates in the Collaboration Networks Between the Three Periods and of Parameter Estimates in the Shared Language Networks Between the Three Periods

| | Between Collaboration-Networks Comparison[a] | | | | Between Shared Language-Networks Comparison[a] | | | |
|---|---|---|---|---|---|---|---|---|
| | Period 1 (1994–1997) versus Period 2 (1998–2001) | | Period 2 (1998–2001) versus Period 3 (2002–2005) | | Period 1 (1994–1997) versus Period 2 (1998–2001) | | Period 2 (1998–2001) versus Period 3 (2002–2005) | |
| Effect Parameter | Δ Est. | z | Δ Est. | z | Δ Est. | z | Δ Est. | z |
| *Rate Parameter* | | | | | | | | |
| 1 Network rate t1→t2 | 2.73 | 7.67*** | -3.24 | -9.91*** | 6.85 | 13.66*** | .42 | .81 |
| 2 Network rate t2→t3 | -.66 | -1.06 | -4.83 | -12.65*** | 3.01 | 7.24*** | 4.45 | 10.02*** |
| 3 Network rate t3→t4 | .37 | 1.44 | 2.10 | 7.61*** | 4.40 | 9.49*** | 1.08 | 2.37* |
| *Structure Effects* | | | | | | | | |
| 4 Degree (density) | .31 | 3.92*** | -.23 | -3.88*** | .26 | 6.19*** | .16 | 5.59*** |
| 5 Transitive triads (clustering) | .11 | 6.68*** | -.21 | -15.20*** | -.05 | -19.00*** | .02 | 9.06*** |
| 6 Degree of alter (centralization) | .01 | 2.30* | .001 | .23 | .001 | 1.20 | .001 | 1.66 |
| 7 Degree assortativity (stratification) | -.02 | -3.26** | .02 | 2.96** | .001 | .06 | -.01 | -7.90*** |
| *Individual Effects* | | | | | | | | |
| 8 Age (older) | -.001 | -.99 | .003 | 2.23* | .004 | 4.53*** | .003 | 4.37*** |
| 9 Male (ref. = female) | -.07 | -1.58 | -.02 | -.45 | .06 | 2.40* | -.09 | -4.68*** |
| 10 Minority group (ref. = White) | .08 | 1.48 | -.0001 | -.002 | .07 | 2.05* | .01 | .42 |
| 11 STEM (ref. = non-STEM) | .01 | .08 | -.19 | -3.30** | -.27 | -9.13*** | .06 | 3.10** |
| 12 Untenured (ref. = tenured) | .17 | 3.95*** | .24 | 5.86*** | .09 | 3.53*** | .17 | 8.22*** |
| 13 Clinical faculty (ref. = tenured) | .09 | 3.10* | .19 | 7.27*** | -.12 | -5.49*** | .27 | 17.78*** |
| *Dyadic Effects* | | | | | | | | |
| 14 Same affiliations (Opportunity) | -.26 | -10.48*** | .13 | 5.42*** | .10 | 6.01*** | -.04 | -2.64* |
| 15 Similar age | -.17 | -1.51 | .07 | .60 | -.29 | -4.22*** | .17 | 2.99** |
| 16 Same gender | -.03 | -.55 | .01 | .29 | .02 | .64 | .02 | 1.01 |
| 17 Same race | -.09 | -1.56 | .12 | 2.44* | -.05 | -1.23 | .04 | 1.43 |
| 18 Same rank | .29 | 8.06*** | -.15 | -4.63*** | .14 | 6.12*** | .16 | 8.74*** |
| *Cross-Network Effects* | | | | | | | | |
| 19 Existing tie X → New tie Y | -.08 | -1.35 | .221 | 3.94*** | .05 | .90 | -.23 | -4.49*** |

*Notes.* Positive $\Delta$ = Est. later period > Est. earlier period. $*p \le .05$, $**p \le .01$, $***p \le .001$ (two-tailed test).
[a]The z-score test assumes equal variance across groups: $z = (Est._{.a} - Est._{.b}) / \sqrt{s.e._a^2 + s.e._b^2}$, with $a$ = later period, and $b$ = earlier period. Under the null-hypothesis of equal parameters, the test has an approximately standard normal distribution (Ripley et al. 2020).

## Appendix E: Figures Depicting Selection for Collaborations and Shared Language Based on Faculty's Gender, Race, and Age



Selection on Collaborations Based on Faculty's Age (1994–1997)

Selection on Language Similarity Based on Faculty's Age (1994–1997)

Selection on Collaborations Based on Faculty's Age (1998–2001)

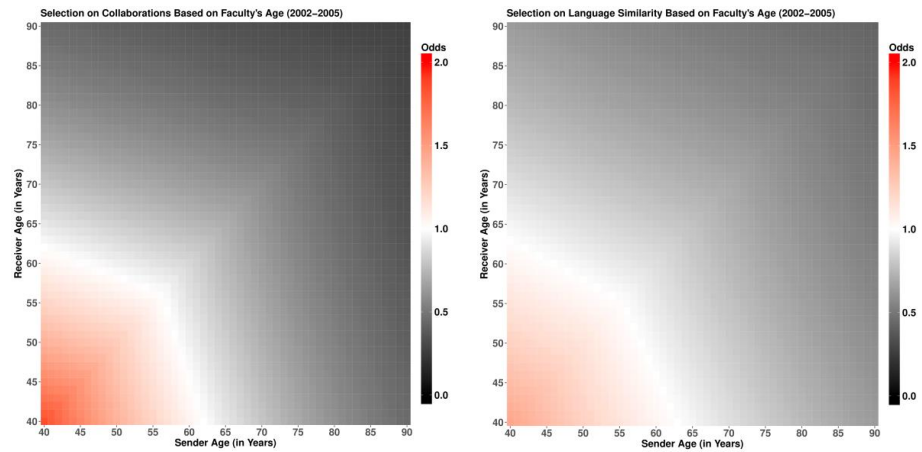Selection on Language Similarity Based on Faculty's Age (1998–2001)
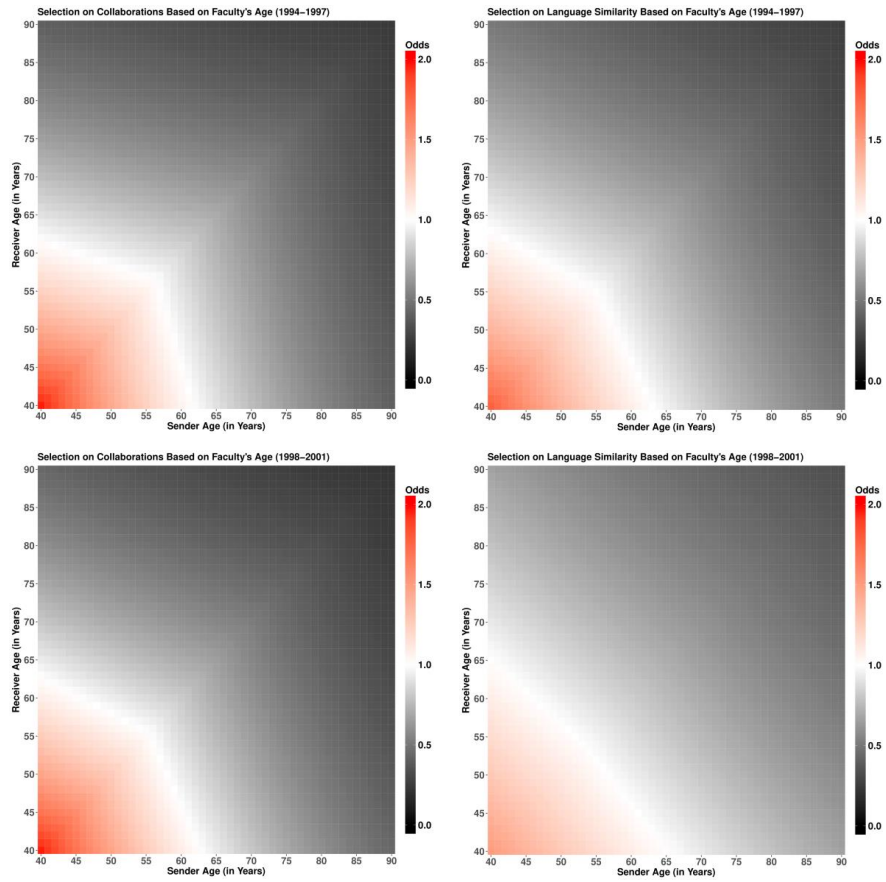
**Figure A4:** Ego-alter selection figures illustrating the effect of age homophily in the three periods (rows) for the two types of networks (first column: collaboration ties; second column: shared language ties).
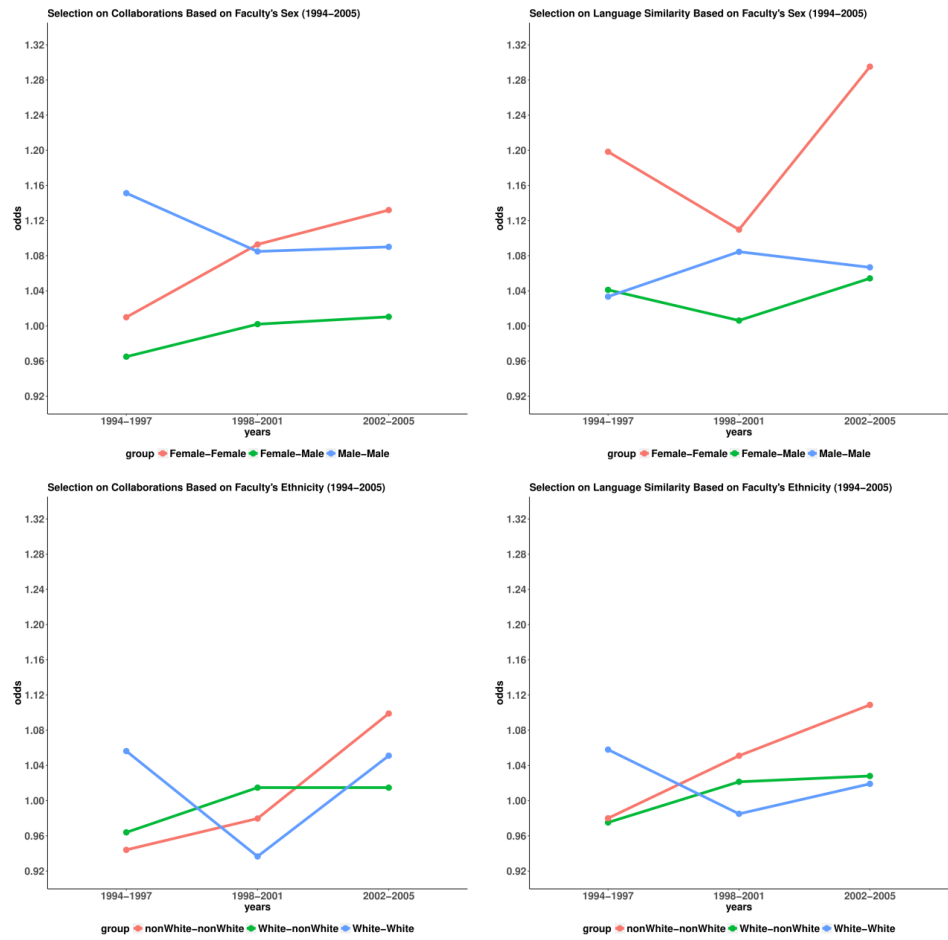
**Figure A5:** Ego-alter selection figures illustrating the effect of gender homophily (first row) and race homophily (second row) in the three periods. First column shows the homophily effects in the collaboration networks, second column in the shared language networks.

## Appendix F: Robustness Check with Co-Citation Networks instead of Shared Language Networks

Table A5
Results from Dynamic Multiplex Network Models Predicting Co-Evolution of Collaboration and Co-Citation Among Faculty Members Between 1994 and 2005.

| Effect Parameter | Hypothetical change (tx → tx + m) | Panel 1: Collaboration Network | | | Panel 2: Co-Citation Network | | |
|---|---|---|---|---|---|---|---|
| | | 1994-1997 Est. (SE) | 1998-2001 Est. (SE) | 2002-2005 Est. (SE) | 1994-1997 Est. (SE) | 1998-2001 Est. (SE) | 2002-2005 Est. (SE) |
| **Rate Parameter** | | | | | | | |
| 1 Network rate t1→t2 | | 5.55 (.21)*** | 8.17 (.27)*** | 5.11 (.15)*** | 12.27 (.36)*** | 11.71 (.32)*** | 11.41 (.25)*** |
| 2 Network rate t2→t3 | | 9.39 (.42)*** | 8.84 (.29)*** | 4.33 (.13)*** | 1.26 (.30)*** | 9.84 (.24)*** | 13.32 (.27)*** |
| 3 Network rate t3→t4 | | 4.50 (.18)*** | 4.87 (.15)*** | 6.76 (.20)*** | 7.79 (.22)*** | 1.83 (.24)*** | 12.71 (.26)*** |
| **Structure Effects** | | | | | | | |
| 4 Degree (density) | | -4.57 (.06)*** | -4.25 (.05)*** | -4.49 (.04)*** | -4.09 (.04)*** | -3.96 (.03)*** | -3.85 (.02)*** |
| 5 Transitive triads (clustering) | | .34 (.01)*** | .44 (.01)*** | .24 (.01)*** | .02 (.003)*** | .12 (.003)*** | .05 (.002)*** |
| 6 Degree of alter (centralization) | | -.004 (.002)* | .003 (.002) | .004 (.001)** | -.01 (.001)*** | -.01 (.001)*** | -.01 (.0004)*** |
| 7 Degree assortativity (stratification) | | .01 (.01) | -.02 (.01)*** | -.004 (.003) | .05 (.002)*** | .04 (.002)*** | .04 (.001)*** |
| **Individual Effects** | | | | | | | |
| 8 Age (older) | | -.02 (.001)*** | -.02 (.001)*** | -.02 (.001)*** | -.02 (.001)*** | -.01 (.001)*** | -.01 (.001)*** |
| 9 Male (ref. = female) | | .07 (.03)* | -.0004 (.03) | -.02 (.02) | .01 (.03) | -.01 (.01) | .04 (.01)* |
| 10 Minority group (ref. = White) | | -.06 (.04) | .03 (.03) | .05 (.03)+ | -.16 (.04)*** | -.06 (.03)* | .04 (.02)* |
| 11 STEM (ref. = non-STEM) | | 1.01 (.05)*** | 1.03 (.05)*** | .86 (.04)*** | .39 (.02)*** | .34 (.02)*** | .19 (.01)*** |
| 12 Untenured (ref. = tenured) | | -.42 (.03)*** | -.25 (.03)*** | -.02 (.03) | -.14 (.02)*** | -.14 (.02)*** | -.04 (.03)** |
| 13 Clinical faculty (ref. = tenured) | | -.24 (.02)*** | -.13 (.02)*** | .06 (.02)*** | -.23 (.02)*** | -.25 (.02)*** | -.19 (.01)*** |
| **Dyadic Effects** | | | | | | | |
| 14 Same affiliations (Opportunity) | | .86 (.02)*** | .62 (.02)*** | .75 (.02)*** | .61 (.01)*** | .47 (.01)*** | .54 (.010)*** |
| 15 Similar age | | .71 (.08)*** | .52 (.08)*** | .56 (.08)*** | .13 (.06)* | .07 (.05) | -.003 (.05) |
| 16 Same gender | | .11 (.04)** | .08 (.03)* | .10 (.03)*** | .05 (.03)+ | .13 (.02)*** | .07 (.02)*** |
| 17 Same race | | .04 (.05) | -.06 (.04) | .06 (.03)* | .07 (.04)+ | -.02 (.03) | .06 (.02)** |
| 18 Same rank | | -.36 (.03)*** | -.07 (.02)** | -.21 (.02)*** | -.09 (.02)*** | -.12 (.02)*** | -.07 (.01)*** |
| **Cross-Network Effects** | | | | | | | |
| 19 Existing tie X → New tie Y | | .92 (.05)*** | .96 (.05)*** | 1.23 (.05)*** | 1.59 (.05)*** | .95 (.05)*** | 1.16 (.04)*** |

*Notes.* Significance tests performed by dividing the estimates with its standard error resulting in *t*-Values which under the null hypothesis are approximately normally distributed (Ripley et al. 2020); $*p \leq .05$, $**p \leq .01$, $***p \leq .001$ (two-tailed test). Convergence statistics adhered to the usual criteria for convergence: all parameters had t ratios < .10; Overall maximum convergence ratio < .25. The dotted line means that the tie is being initiated unilaterally by the focal actor *i*, and then the solid lines means that the tie is being confirmed by the target actor *j*.