Two-layer Network Analysis of Gender-Stratified Inquisitorial Testimonies

Network Analysis Across Disciplines - 9th of March, 2026 13:00

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Masaryk University • Centre for the Digital Research of Religion

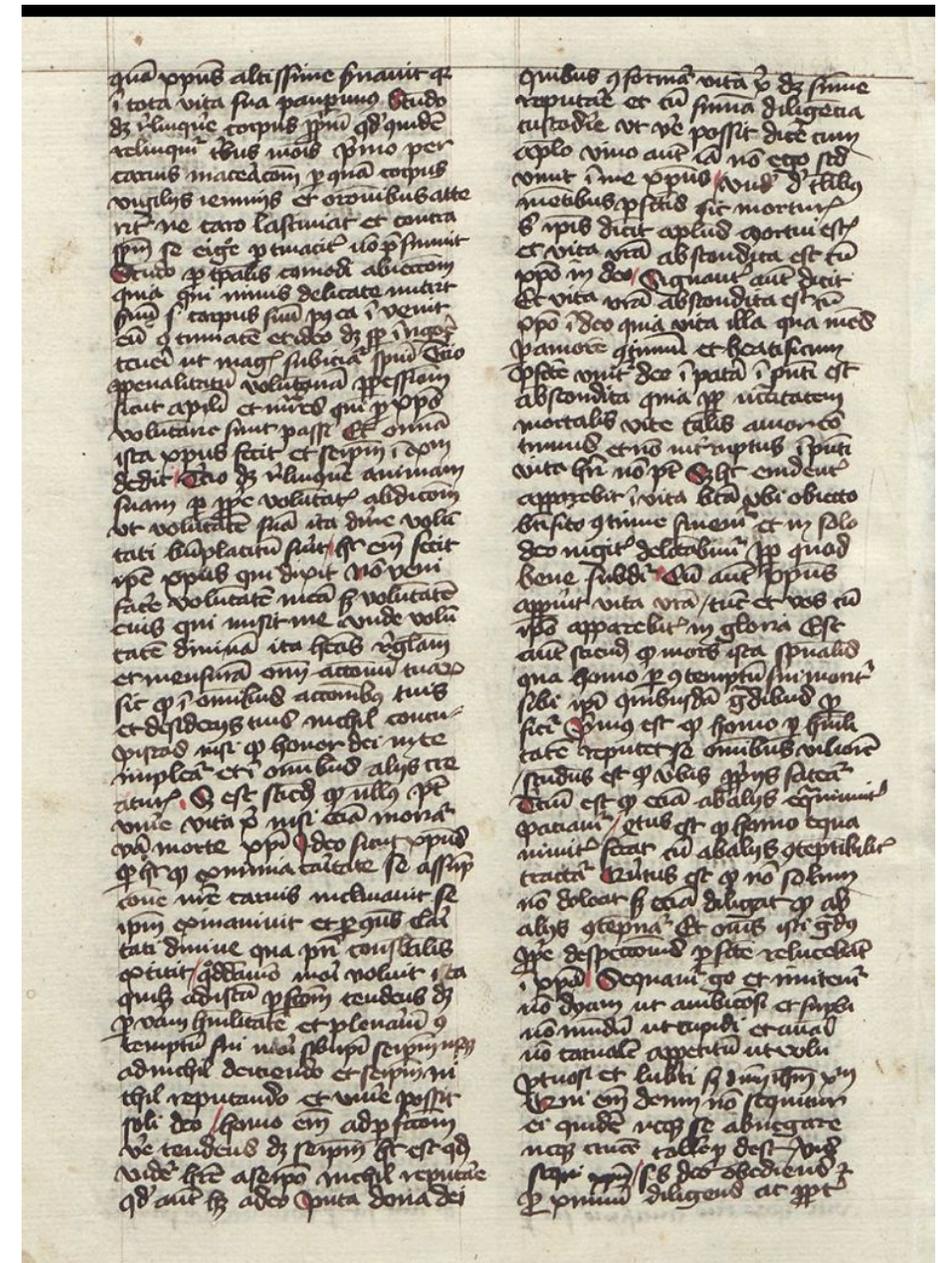DISSINET – Dissident Networks Project

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Papal inquisition

1) applied pressure to obtain information about deponent and also about the community (beliefs/events)

2) documentation via notaries
3) interrogated people from all social levels

De Biasio (2018) , Given (1997), Arnold (2001), Heimann (2004), Rehr (2019), Hill (2019), Zbíral (2007).

Petrus Bonus, stated that he preached to a certain man named *Guizardinus.*

Iohannes Albertini reported that *Rolandinus de Ollis* spoke with the priest *Vivianus.*

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Petrus Bonus, stated that he preached to a certain man named *Guizardinus.*

$u \rightarrow v$ *(u)*

Iohannes Albertini reported that *Rolandinus de Ollis* spoke with the priest *Vivianus.*

$u \rightarrow v$ *(i)*

Network type		Edge information comes from
Observed networks	($\forall\, i = c$)	i is a constant, and independent observer
Classroom networks	($\forall\, i = u$)	$i \in V(G)$ but only reports on $i\text{->}j$ connections
Multivoiced networks	($i,u,v \in V(G)$)	i can report on any $E(G)$
Gossip networks	($i,j,u,v \in V(G)$)	i talks to j about attr(u) or about $u\text{-}v$ dyadic edge or about a hyperedge

Network

1) source: all (73) "Apostolic" depositions (from 55 deponent)
   among 922 Latin documents (Paolini & Orioli, 1982)

2) collected:

   attributes trial subjects (gender, minister status, informant status)

   reported social interactions among trial subjects

Paolini, L., & Orioli, R. (Eds.). (1982). Acta S. Officii Bononie ab anno 1291 usque ad annum 1310

Fruchterman–Reingold layouts of the reported Apostolic social interactions reconstructed from the Bologna inquisition register (1291–1310).
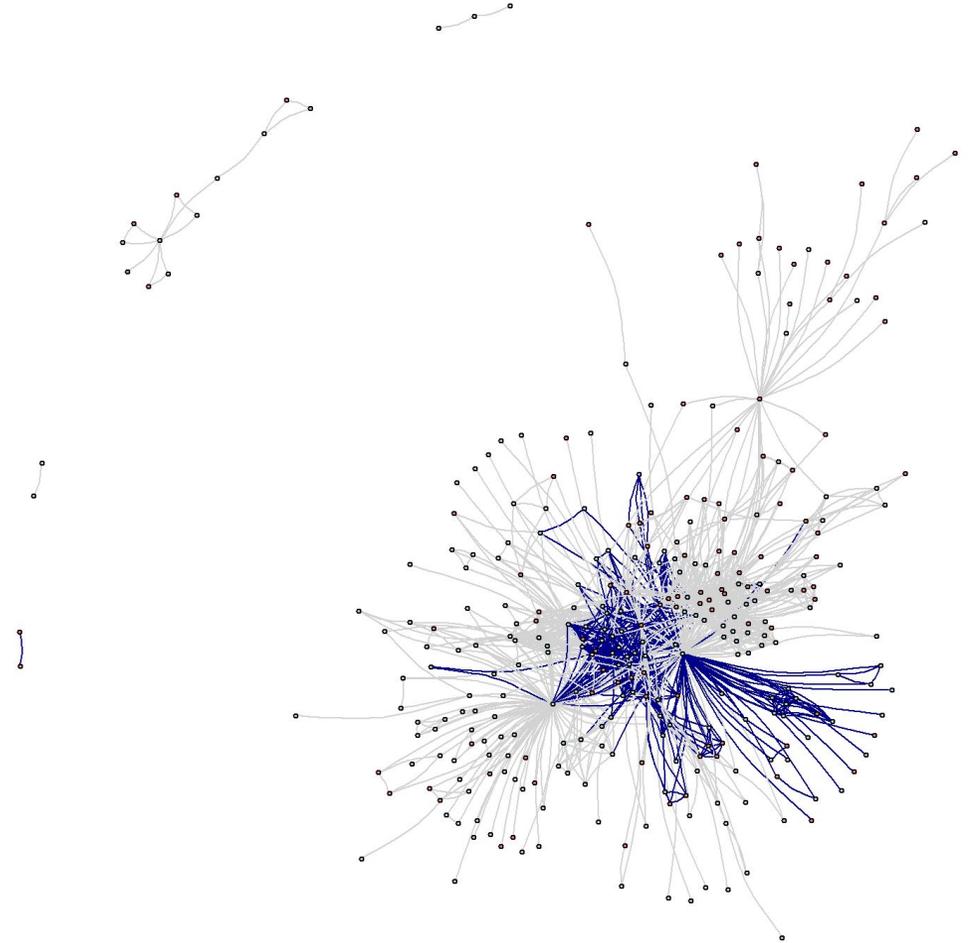
Nodes represent individuals mentioned in the register.

Edges are colored by informants, darkred = reported by *Benvenuta de Montebellio de Plumatio*, gray = all others.
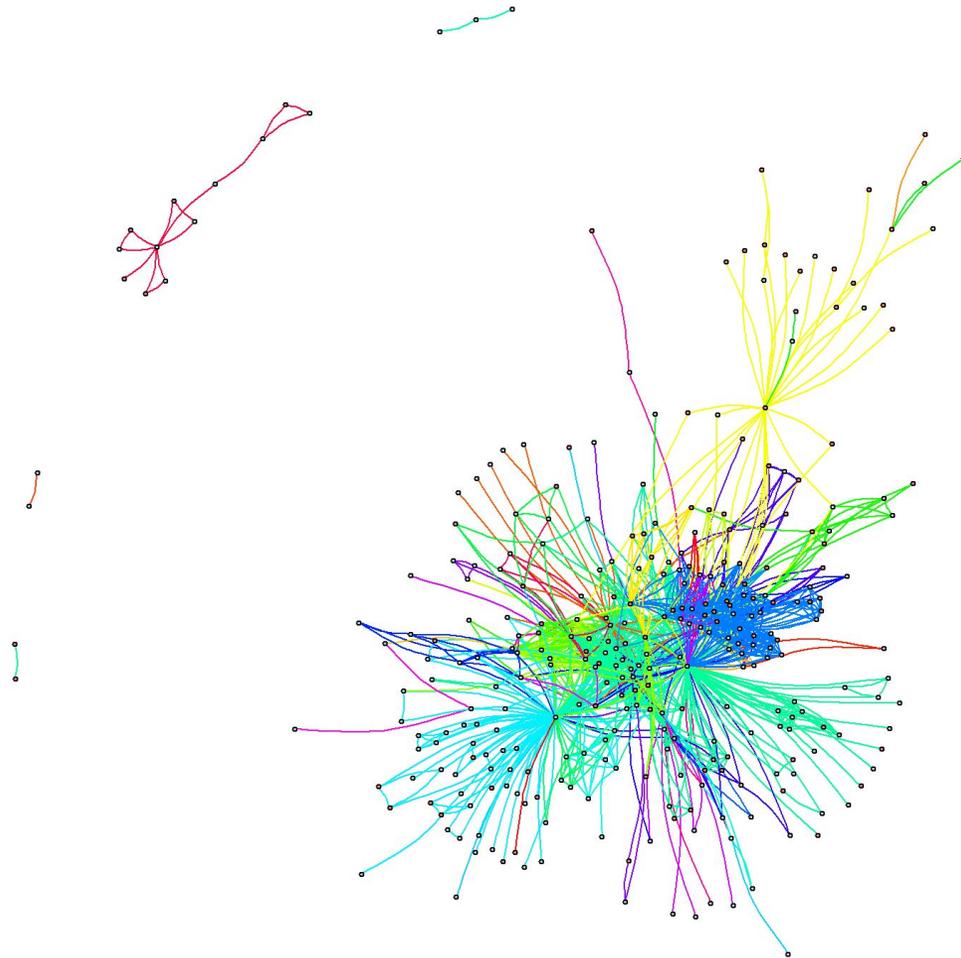
Benvenuta de Montebellio de Plumatio
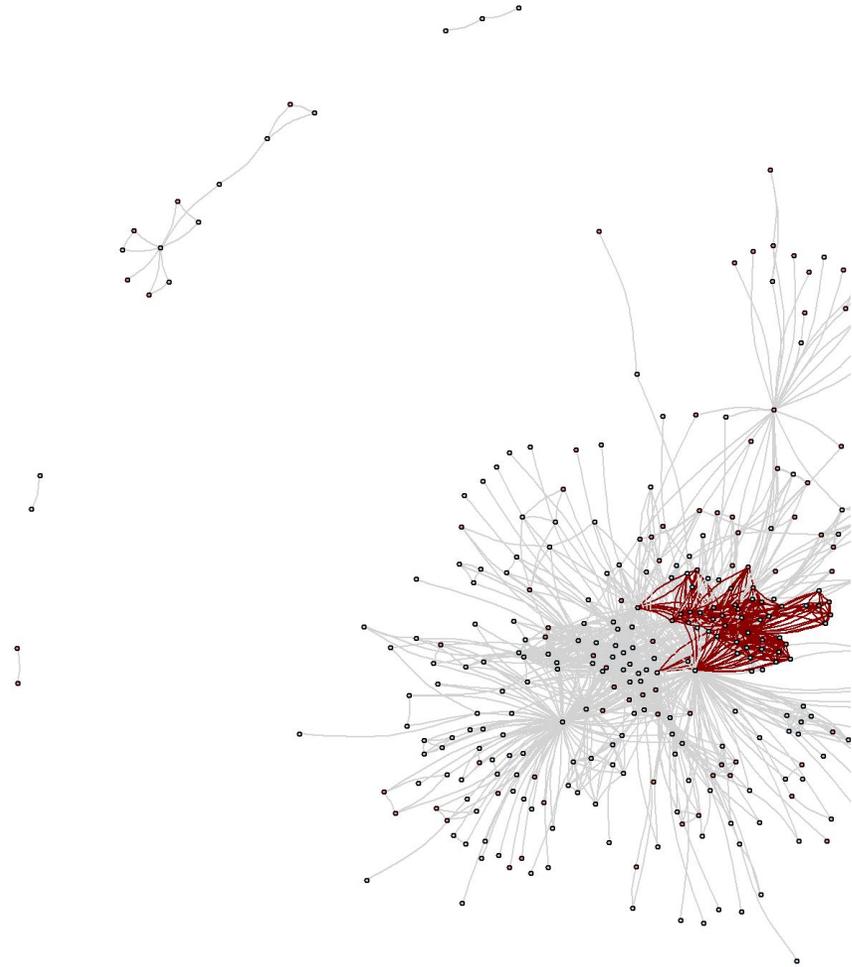
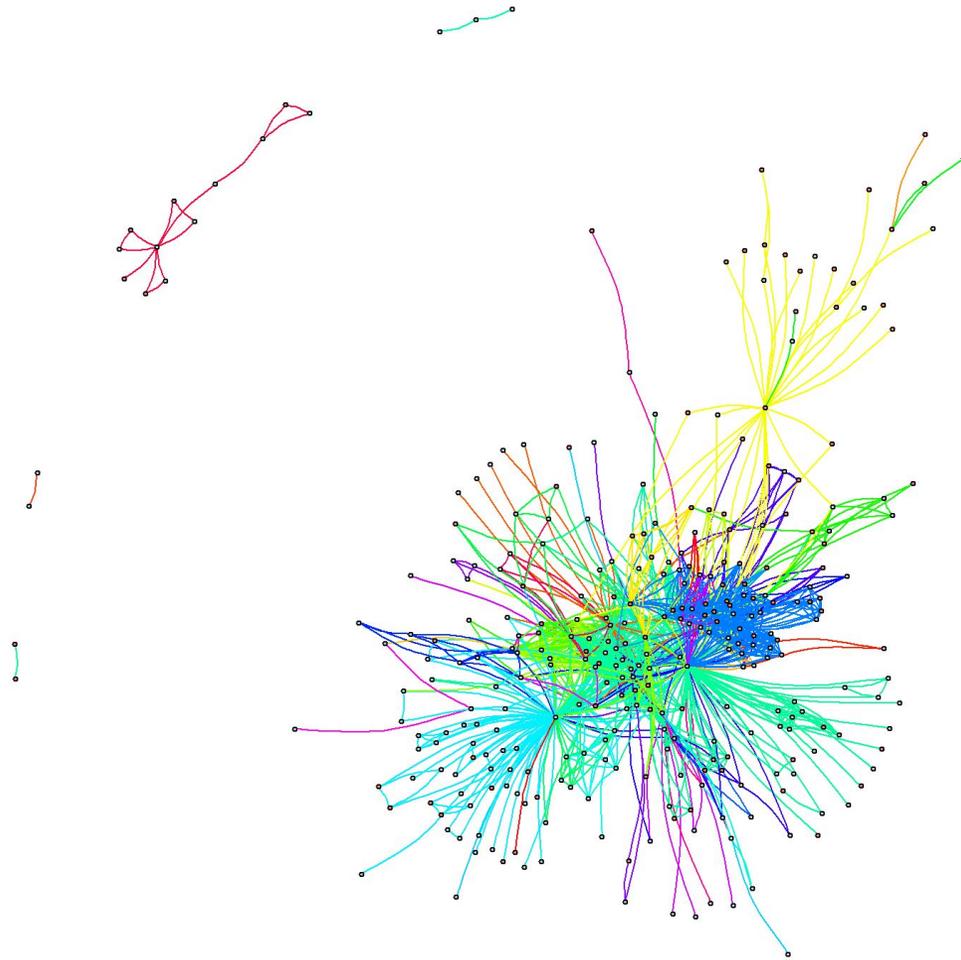Benvenuta de Montebellio de Plumatio

Rolandinus de Ollis de Mutina

Fruchterman–Reingold layouts of the Apostolic social network reconstructed from the Bologna inquisition register (1291–1310).

Nodes represent individuals mentioned in the register. Edges colored by informants.

Fruchterman–Reingold layouts of the Apostolic social network reconstructed from the Bologna inquisition register (1291–1310).

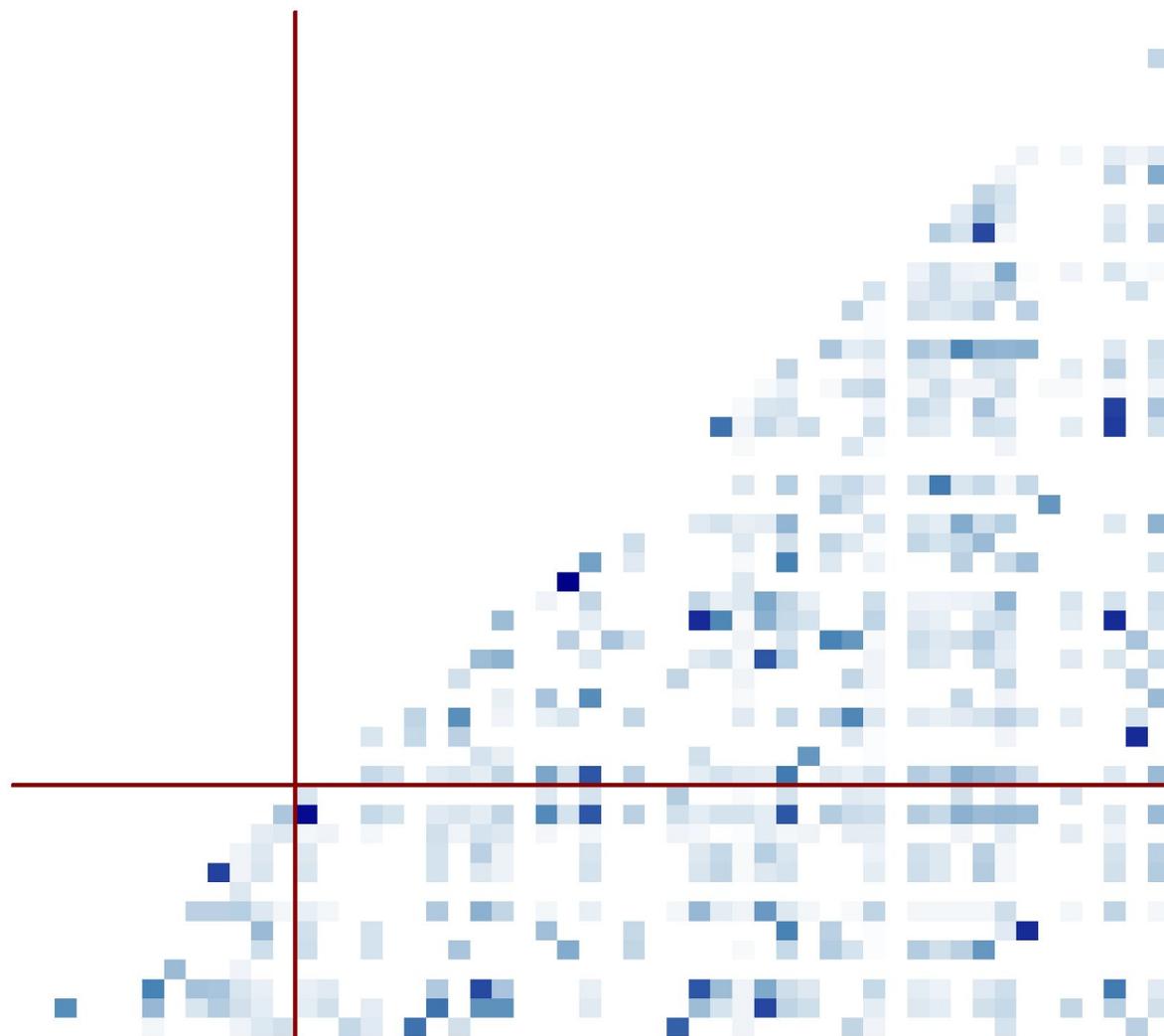Nodes represent individuals mentioned in the register. Edges colored by informants.

Characteristics of informants (i)	Male (n = 42)	Female (n = 13)
Minister	5	1
Median [range] number of reported social interactions	8 [0-111]	7 [2-44]

Jaccard similarity matrix of alter sets reported by 53 active deponents. Rows and columns are ordered by informant gender, with female deponents in the lower-left block and male deponents in the upper-right block. Red lines indicate the boundary between gender groups. Color intensity represents pairwise Jaccard similarity, ranging from white (no shared edges) to dark blue (maximum overlap).

	Mean value
Male <-> Male	0.036
Female <-> Female	**0.056**
Male <-> Female	0.048
General (wo diagonal)	0.036

$$E_m = \{\, (i, u, v) \in E \mid \text{gender}(i) = \text{male}\,\}$$

$$E_f = \{\, (i, u, v) \in E \mid \text{gender}(i) = \text{female}\,\}$$

$$V_f = V_m = V(G)$$

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In the male-reported network 58.3% of all ties,
and in the female-reported network, 71.2%,
did not involve the informant
(i.e., i reported an interaction between u and v and i ≠ u and i≠ v)

(vs random mixing 99%)

Table 2. Descriptive characteristics of the male- and female-reported Apostolic social network layers reconstructed from the inquisition register of Bologna.

Measure	Male-reported layer	Female-reported layer
Number of reporters	42	13
Number of nodes	322	322
Number of isolated nodes	55 (17.08%)	220 (68.32%)
Nodal characteristics		
Male ministers	16	16
Female ministers	5	5
Male supporters	105	105
Female supporters	196	196
Edge characteristics		
Number of edges	944	424
Average degree	5.86	2.63
Median [IQR] of degrees	3 [1–6]	0 [0–2]
Density	0.018	0.008
Transitivity	0.285	0.497
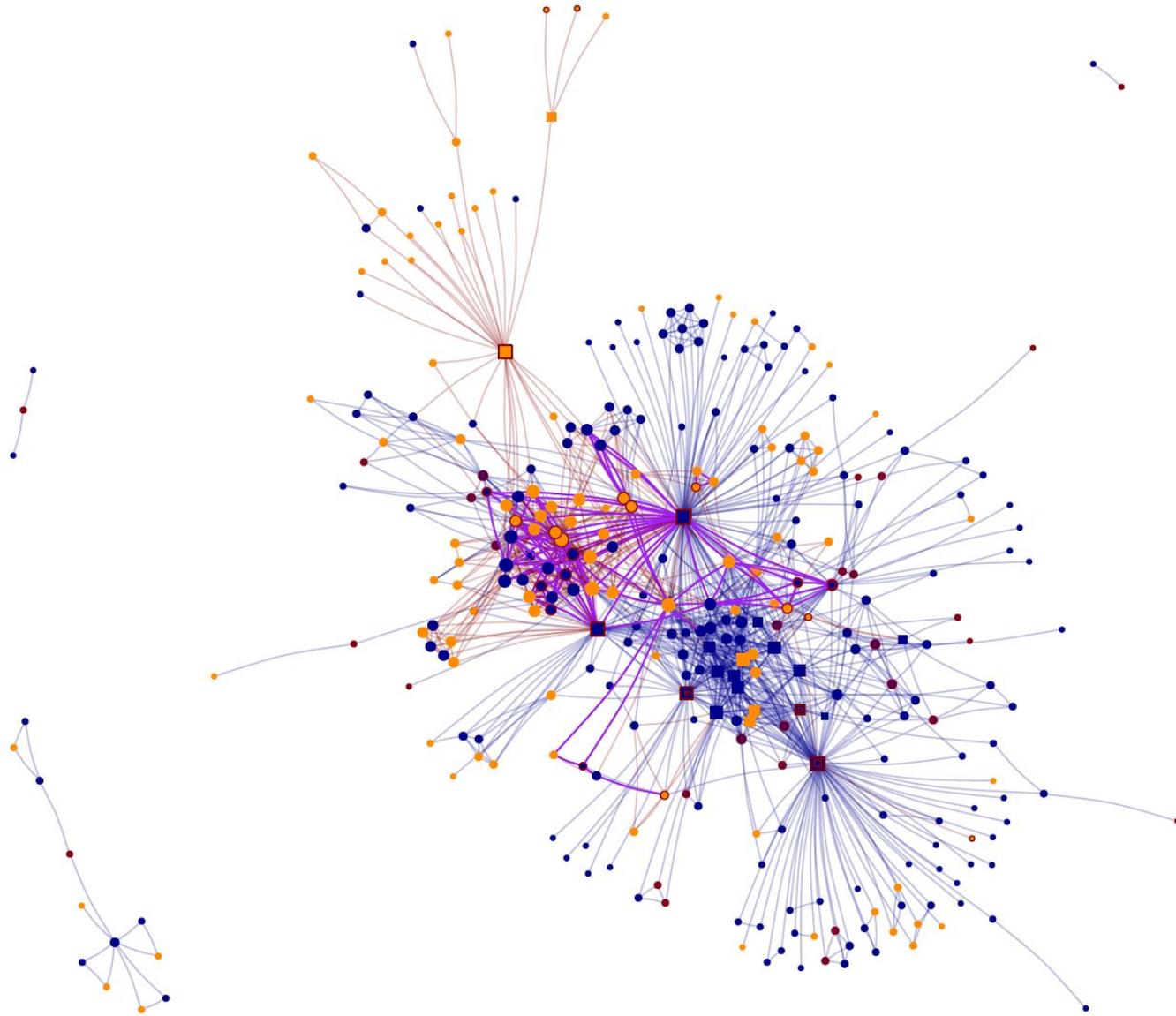
Fruchterman–Reingold layouts of the Apostolic social network reconstructed from the Bologna inquisition register (1291–1310).

Nodes represent individuals, colored by gender (**blue = male**, **orange = female**), shaped by ministerial status (square = minister, circle = non-minister), and outlined in red if they are deponents; node size is proportional to ln(degree).

Edges are colored by layer origin: **blue for ties reported only by male informants**, **orange for ties reported only by female informants**, and **purple for ties reported by both**.

Table 1. Top five nodes by closeness centrality in the male- and female-reported networks concerning the Apostolic movement, reconstructed from testimonies in the inquisition register of Bologna, 1291–1310.

Name	Gender	Minister	Informant	CC
Male-reported layer				
Rolandinus de Ollis de Mutina	male	Yes	Yes	0.65
Zacharias Bondi Balbi de S. Agata	male	Yes	Yes	0.61
Iacobus de Magagnolis de Ponçano de Monçorgio	male	Yes	Yes	0.53
Petrus Dominici Dal Pra	male	Yes	Yes	0.53
Iohannes Trughi de Ponçano de Monçorgio	male	Yes	No	0.52
Female-reported layer				
Laçarina de Pede de Plumatio	female	Yes	Yes	0.52
Benvenuta de Montebellio de Plumatio	female	No	Yes	0.50
Bartholomea de Plumatio	female	No	No	0.49
Rolandinus de Ollis de Mutina	male	Yes	Yes	0.49
Bona de Ostis	female	No	No	0.47

```r
ergm_full_form <- as.formula(
  ml_net ~
    # layer-specific edges
    L(~ edges, Ls = ~ `male`) +
    L(~ edges, Ls = ~ `female`) +


    L(~ edgecov(lm_mat$female), Ls = ~ `male`) +
    L(~ edgecov(lm_mat$male),   Ls = ~ `female`) +


    # layer-specific nodematch
    L(~ nodematch("gender"), Ls = ~ `male`) +
    L(~ nodematch("gender"), Ls = ~ `female`) +


    # layer-specific nodefactor terms
    L(~ nodefactor("male_inf"),   Ls = ~ `male`) +
    L(~ nodefactor("male_inf"),   Ls = ~ `female`) +
    L(~ nodefactor("female_inf"), Ls = ~ `male`) +
    L(~ nodefactor("female_inf"), Ls = ~ `female`) +
    L(~ nodefactor("gender"),     Ls = ~ `male`) +
    L(~ nodefactor("gender"),     Ls = ~ `female`) +


    L(~ nodefactor("female_min"), Ls = ~ `male`) +
    L(~ nodefactor("male_min"),   Ls = ~ `male`) +
    L(~ nodefactor("female_min"), Ls = ~ `female`) +
    L(~ nodefactor("male_min"),   Ls = ~ `female`)

)
```

```r
ergm_full_form <- as.formula(
  ml_net ~

    # layer-specific edges
    L(~ edges, Ls = ~ `male`) +
    L(~ edges, Ls = ~ `female`) +


    L(~ edgecov(lm_mat$female), Ls = ~ `male`) +
    L(~ edgecov(lm_mat$male),   Ls = ~ `female`) +


    # layer-specific nodematch
    L(~ nodematch("gender"), Ls = ~ `male`) +
    L(~ nodematch("gender"), Ls = ~ `female`) +


    # layer-specific nodefactor terms
    L(~ nodefactor("male_inf"),   Ls = ~ `male`) +
    L(~ nodefactor("male_inf"),   Ls = ~ `female`) +
    L(~ nodefactor("female_inf"), Ls = ~ `male`) +
    L(~ nodefactor("female_inf"), Ls = ~ `female`) +
    L(~ nodefactor("gender"),     Ls = ~ `male`) +
    L(~ nodefactor("gender"),     Ls = ~ `female`) +


    L(~ nodefactor("female_min"), Ls = ~ `male`) +
    L(~ nodefactor("male_min"),   Ls = ~ `male`) +
    L(~ nodefactor("female_min"), Ls = ~ `female`) +
    L(~ nodefactor("male_min"),   Ls = ~ `female`)

)
```

measure	full model	null model or baseline
P-2LL	11,641	14,551
P-AIC	11,673	14,553
P-BIC	11,826	14,562
ROC-AUC	0.812	0.500
PR-AUC	0.177	0.013

```r
ergm_full_form <- as.formula(
  ml_net ~
    # layer-specific edges
    L(~ edges, Ls = ~ `male`) +
    L(~ edges, Ls = ~ `female`) +

    L(~ edgecov(lm_mat$female), Ls = ~ `male`) +
    L(~ edgecov(lm_mat$male),   Ls = ~ `female`) +

    # layer-specific nodematch
    L(~ nodematch("gender"), Ls = ~ `male`) +
    L(~ nodematch("gender"), Ls = ~ `female`) +

    # layer-specific nodefactor terms
    L(~ nodefactor("male_inf"),   Ls = ~ `male`) +
    L(~ nodefactor("male_inf"),   Ls = ~ `female`) +
    L(~ nodefactor("female_inf"), Ls = ~ `male`) +
    L(~ nodefactor("female_inf"), Ls = ~ `female`) +
    L(~ nodefactor("gender"),     Ls = ~ `male`) +
    L(~ nodefactor("gender"),     Ls = ~ `female`) +

    L(~ nodefactor("female_min"), Ls = ~ `male`) +
    L(~ nodefactor("male_min"),   Ls = ~ `male`) +
    L(~ nodefactor("female_min"), Ls = ~ `female`) +
    L(~ nodefactor("male_min"),   Ls = ~ `female`)
)
```

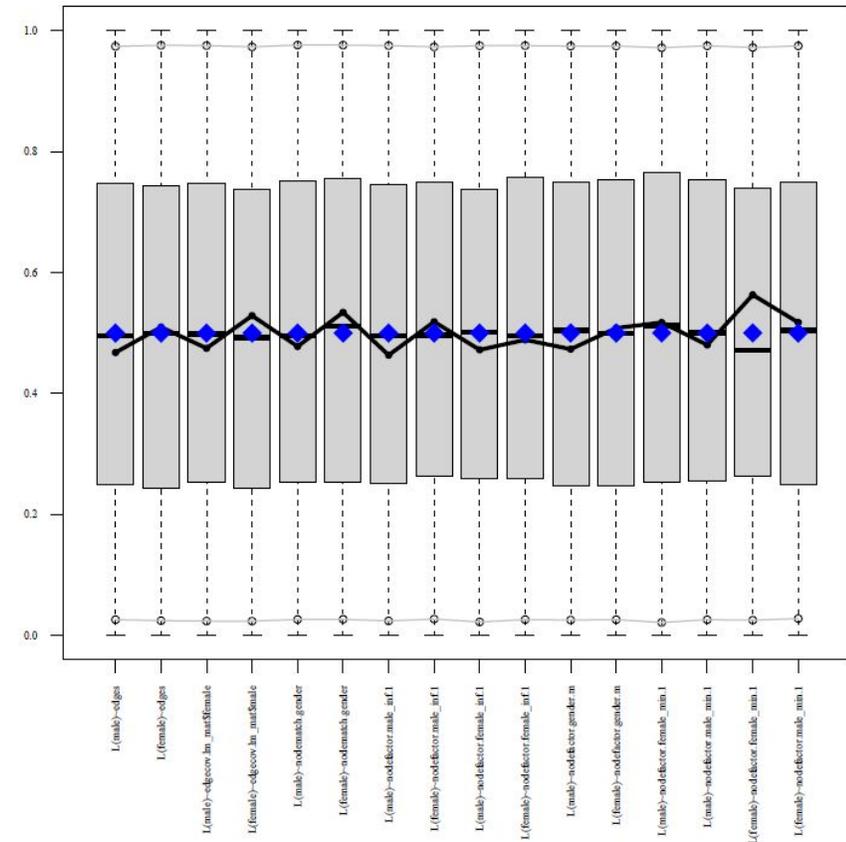| measure	full model	null model or baseline
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ROC-AUC	0.812	0.500
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Table 5. Multilayer Exponential Random Graph Model estimates for male- and female-reported layers of the Apostolic social networks reconstructed from the inquisition register of Bologna (1291–1310). N indicates the number of observed edges with the given property. Coefficients (β) represent conditional log-odds effects on tie formation. AME denotes the main-effect average marginal effect. SE is the standard error, p the significance level, ns marks non-significant AME values ($p \geq 0.05$), and VIF is the variance inflation factor.

| Term	N	β	SE	p	AME	VIF
Male-reported layer						
Baseline tie formation	944	−5.227	0.107	< 0.001	−0.062	9.489
Tie also present in the other layer	111	3.117	0.144	< 0.001	0.037	1.235
Gender homophily	629	0.213	0.090	0.018	0.003	4.380
Nodal attributes						
Male informant (local)	596	0.902	0.060	< 0.001	0.011	2.137
Female informant (non-local)	77	−0.041	0.144	0.775	ns	1.369
Male (vs female)	1,435	−0.017	0.080	0.831	ns	13.845
Female minister	58	1.205	0.153	< 0.001	0.014	1.212
Male minister	542	2.126	0.066	< 0.001	0.025	2.007
Female-reported layer						
Baseline tie formation	424	−4.775	0.127	< 0.001	−0.056	6.398
Tie also present in the other layer	111	3.137	0.141	< 0.001	0.037	1.767
Gender homophily	243	0.250	0.102	0.014	0.003	2.350
Nodal attributes						
Male informant (non-local)	141	0.481	0.115	< 0.001	0.006	2.051
Female informant (local)	162	1.447	0.106	< 0.001	0.017	1.795
Male (vs female)	385	−0.815	0.088	< 0.001	−0.010	4.318
Female minister	33	0.209	0.187	0.263	ns	1.120
Male minister	77	0.133	0.148	0.369	ns	1.737
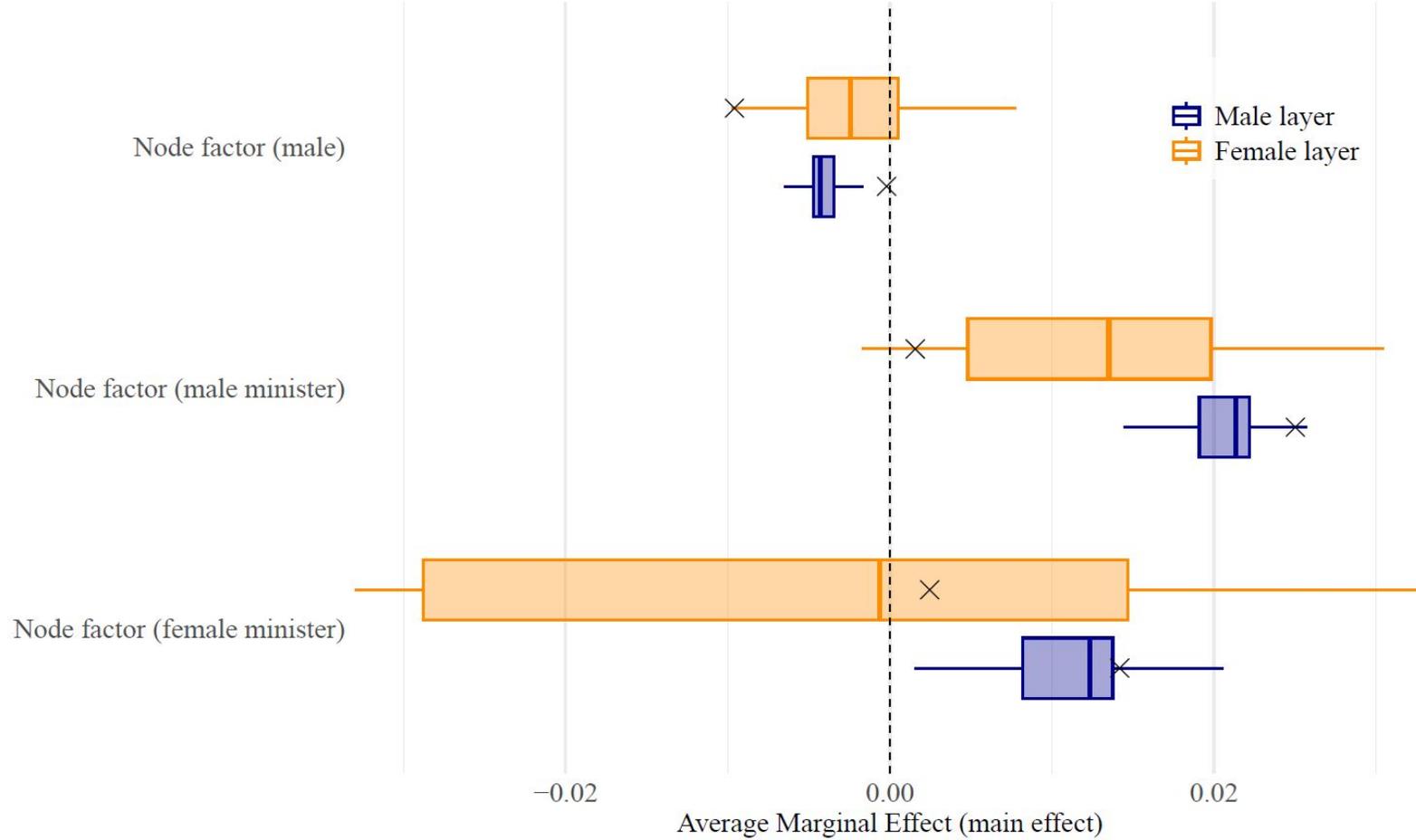
Fig. 3. Sensitivity analysis of multilayer ERGM estimates under random informant gender assignment (100 iterations). Distributions of average marginal effects (AME; main effects) from permuted models are shown as boxplots; black crosses indicate the corresponding observed estimates from the original model.

Conclusion

1) Male testimonies tend to portray
   a mixed-gender layer centered on ministers,

2) while female testimonies tend to portray
   inter-female relations with less attention paid to religious leadership.

Conclusion

1) Male testimonies tend to portray
   a mixed-gender layer centered on ministers,

2) while female testimonies tend to portray
   inter-female relations with less attention paid to religious leadership.

Possible reasons: inquisitorial focus and/or deponent perception/tactics
and/or underlying gendered social organization.

DISSINET - Dissident Networks Project

Dataset   Open

Data and R Code for Male- and Female-Reported Layers of the Social Network of the Apostolic Movement in the Inquisition Register of Bologna (1291–1310)

Brys, Zoltan[1] iD; Riccardo, Katia[1] iD; Zbíral, David[1] iD; Shaw, Robert L. J.[1] iD

Show affiliations

This deposit contains the dataset and R code necessary to reproduce all statistical analyses reported in a study of gender-differentiated perspectives on a medieval dissident religious network. The study reconstructs a two-layer multiplex social network from late thirteenth–early fourteenth-century inquisitorial testimonies in northern Italy, distinguishing ties reported by male and female deponents, and examines how reported interactions, central actors, and structural patterns of tie formation differ across the two gender-defined layers using descriptive network measures, closeness centrality, multilayer Exponential Random Graph Models, and permutation-based sensitivity analyses.

Repository structure (BolGenLay.zip)

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ergm.multi: Fit, Simulate and Diagnose Exponential-Family Models for Multiple or Multilayer Networks

A set of extensions for the 'ergm' package to fit multilayer/multiplex/multirelational networks and samples of multiple networks. 'ergm.multi' is a part of the Statnet suite of packages for network analysis. See Krivitsky, Koehly, and Marcum (2020) <doi:10.1007/s11336-020-09720-7> and Krivitsky, Coletti, and Hens (2023) <doi:10.1080/01621459.2023.2242627>.

Version:	0.3.0
Depends:	R (≥ 4.2.0), ergm (≥ 4.9.0), network (≥ 1.19.0)
Imports:	statnet.common (≥ 4.12.0), rlang (≥ 1.1.6), purrr (≥ 1.0.4), tibble (≥ 3.3.0), glue (≥ 1.8.0), rle (≥ 0.10.0), Rdpack (≥ 2.6.4), networkLite (≥ 1.1.0), Matrix, methods, parallel
LinkingTo:	ergm
Suggests:	rmarkdown (≥ 2.29), knitr (≥ 1.50), dplyr (≥ 1.1.4), testthat (≥ 3.2.3), ggplot2 (≥ 3.5.2), ggrepel (≥ 0.9.6), Rglpk, generics (≥ 0.1.4)
Published:	2025-06-15
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URL:	https://statnet.org
NeedsCompilation:	yes
Citation:	ergm.multi citation info
Materials:	NEWS