

Party Cohesion and Cross-Party Antagonism in U.S. Senate Co-Voting Networks, 50th–119th Congresses

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Abstract

Roll-call votes are the most complete public record of how members of Congress behave, and they have long been used to measure how legislators divide by party. The most widely used measure of this places each member of Congress on a liberal-conservative scale and reports polarization as the distance between the average positions of the two parties. By that measure, the Democrat and Republican parties have drifted together in the early twentieth century and have moved apart since the late 1970s, to their widest gap since Reconstruction. We built a signed senator-senator voting network from the U.S. Senate Voteview roll-call records for the 50th through 119th Congress. A pair of legislators is joined by a signed edge, with the sign given by whether the pair of Senators agreed more often or disagreed on roll calls. We report three party-partitioned edge ratios and one party-blind triadic statistic. Cross-party negativity is high at both ends of the record (0.984 in the 50th, 0.995 in the 119th) and falls to a low of 0.451 in the 72nd Congress, with fifteen Congresses falling below 0.6. The two within-party ratios and the cross-party ratio are different measurements that correlate moderately, with $r \approx 0.69$ and 0.71, and the cohesion metrics for the two parties are weakly correlated with $r \approx 0.29$. The triadic metric and the cross-party ratio are strongly associated with $r \approx 0.950$. The central claim is that within-party cohesion and cross-party antagonism are separable quantities that may not move together, verifiable by results seen analyzing the Senate voting graphs.

1 Introduction

Much work that takes a quantitative approach to measuring congressional polarization puts legislators individually on a linear scale, generally with *liberal* and *conservative* endpoints, and measures polarization as the distance between the ideological averages of the members within each party [12, 17] [16, 11].

A second approach treats the chamber as a network of pairwise relationships between legislators. Mucha and Porter [14] built roll-call similarity networks that covered two centuries of the Senate and found that the communities detected in them mostly follow party lines. Glonek et al. [8], starting only from the two party leaders, recovered party labels from co-voting networks of both chambers. They found that the parties were completely separable in every Senate from the 110th Congress onward. Similarity networks discard disagreement, and ignoring negative ties changes which groups are found [13], so other studies use signed networks, in which each pair of legislators is joined by a positive or a negative tie, and evaluate them against structural balance theory [9, 5]. Capozzi et al. [4] measured balance in House and Senate co-voting networks from 1945 to 2020 and found it increasing from the late 1960s onward. Neal [15] inferred signed networks of both chambers from bill co-sponsorship for 1973–2016 and reported steadily increasing polarization, and Aref and Neal [1] found that a partition into three coalitions fits the House better than the conventional

two. Outside the United States, Baker and Benevenuto [2] applied a triangle census close to the one used here to the Brazilian Chamber of Deputies and found that $(+, -, -)$ triangles overtook $(+, +, +)$ triangles from the 2015–2019 legislature onward, as polarization rose.

This work applies this previous research to the U.S. Senate, by treating the Senate as an undirected graph, one graph per Congress, in which each pair of senators is joined by a signed edge. The sign is determined based on net agreement or disagreement between senators on roll calls throughout that Congress, determining whether that pair of Senators, across the roll calls that both attended, agreed more often or disagreed. Baker and Benevenuto [2] employ a similar definition of edge sign based on net agreement. Our time series spans the 50th through the 119th Congress (1887–2026), and starts almost sixty years earlier than the starting point of the longest signed network time series of Congresses mentioned above [4]. We ask the question: How do those pairwise patterns relate to the three-member structure of the network where balance theory defines a two-bloc structure?

We calculate two families of statistics. The first set is called *party-aware* and is calculated by partitioning edges by party affiliation of their end points (Democrat–Democrat, Republican–Republican, Democrat–Republican) and counting signs within these partitions, giving a measure of within-party cohesion for each party and cross party antagonism. Separate measures of cohesion and antagonism follows the precedent of studies on other legislatures where these are considered separate quantities [6, 10]. The second set is *party-blind* and is calculated by counting all signed triangles in the network and measuring the proportion of $(+, -, -)$ triangles. A network that divides into two internally positive and mutually negative groups will have only $(+, +, +)$ and $(+, -, -)$ triangles [5], while a $(-, -, -)$ triangle would be compatible with balance only, in the case of Davis’s generalization, to three or more groups [7]. Thus, the proportion of $(+, -, -)$ increases as the chamber divides into opposing groups, irrespective of whether these are the parties.

2 Data and network construction

2.1 Source and preprocessing

Roll-call records come from Voteview [11]. A member-vote CSV dataset and a member-metadata CSV dataset per Congress were used. Votes in the data source files are given cast codes, given by the numbers 1 through 6, which indicate what type of roll call each senator has casted. These codes can be simplified to yea, nay, or abstain. The data processing in this project simplifies cast codes to $+1$, -1 , and 0 for aggregation by edge weight between senators. The codes are mapped as follows: $\{1, 2, 3\} \rightarrow +1$ (yea), $\{4, 5, 6\} \rightarrow -1$ (nay), and all other codes become 0 and are dropped. For each roll call the majority fraction

$$\text{mf} = \frac{\max(\text{yea}, \text{nay})}{\text{yea} + \text{nay}}$$

is computed over nonzero votes, and roll calls with $\text{mf} > 0.90$ are discarded, to remove near-unanimous votes. The number of retained roll calls ranges from 72 (Congress 60; 1907–1909) to 1,028 (Congress 94; 1975–1977).

2.2 Population

The node list contains identifiers of senators that cast a nonzero ballot on a roll call that was retained (retained after roll calls with $\text{mf} > 0.90$ are removed). The node list contains only Senators until the 84th Congress, at which point it also starts to include a presidential node. There is

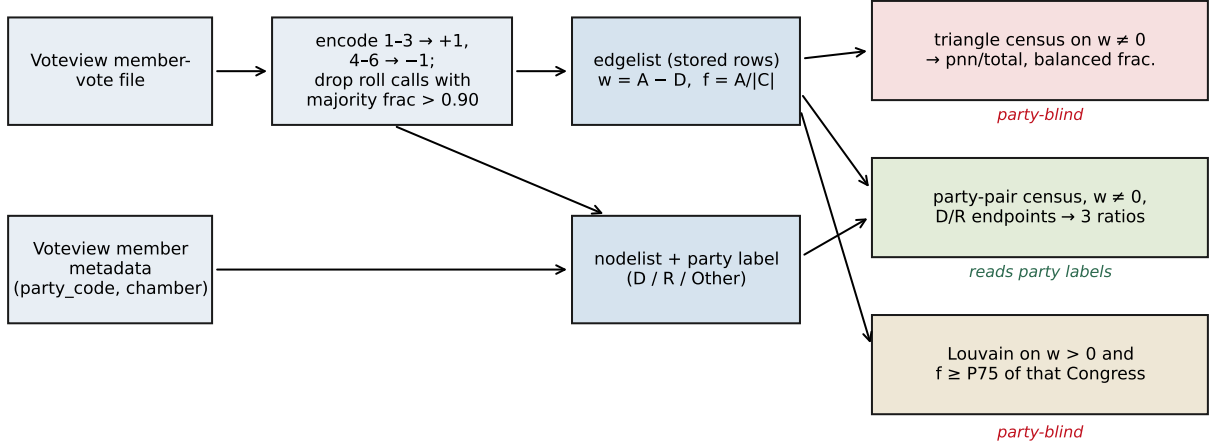


Figure 1: Implemented pipeline. The node list is drawn from voters present after the roll-call near-unanimous filtering. Party labels come from member metadata and are only read by the party-pair census.

no attendance or tenure threshold included. Node counts are member records over a Congress, including mid-term replacements as an extra node, keeping the Senator that was replaced. Party labels map `party_code` 100 to Democrat, 200 to Republican, and everything else to Other. Third-party presence is relatively high in some parts of the 70-Congress record, but close to zero almost everywhere else.

3 Metrics

The formulas for all computed metrics are below as the code computes them.

Triadic: Build graph G on all edges with edge weight $\neq 0$. Find every closed triple and classify them by groups into $(+, +, +)$, $(+, -, -)$, and other (which includes $(+, +, -)$ and $(-, -, -)$). Then calculate:

$$\text{pnn_over_total} = \frac{\text{PNN}}{\text{PPP} + \text{PNN} + \text{other}}$$

The denominator is all triangles present in the graph, not only balanced triangles.

Party Partitioned:

$$\text{cross_party_negative_ratio} = \frac{\# \text{ of } DR_-}{\# \text{ of } DR_- + \# \text{ of } DR_+}$$

The cross-party denominator is cross-party edges, not total edges.

$$\text{dem_dem} = \frac{\# \text{ of } DD_+}{\# \text{ of } DD_+ + \# \text{ of } DD_-} \quad \text{rep_rep} = \frac{\# \text{ of } RR_+}{\# \text{ of } RR_+ + \# \text{ of } RR_-}$$

Community detection: The Louvain algorithm [3] was used on the positive edge subgraph (Section 6).

4 Results

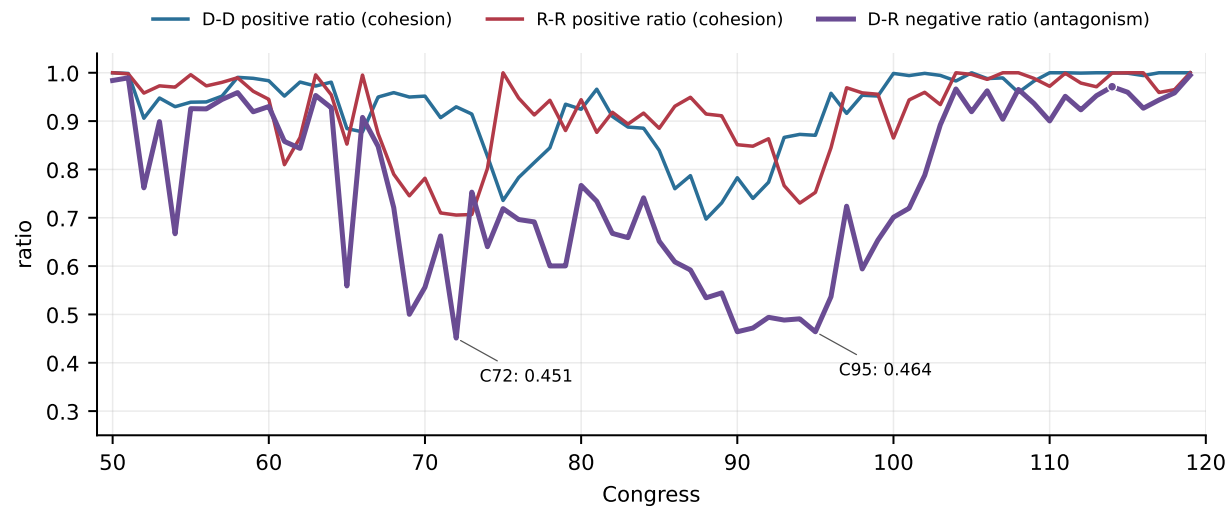


Figure 2: The three party-partitioned ratios over all 70 analyzed Congresses.

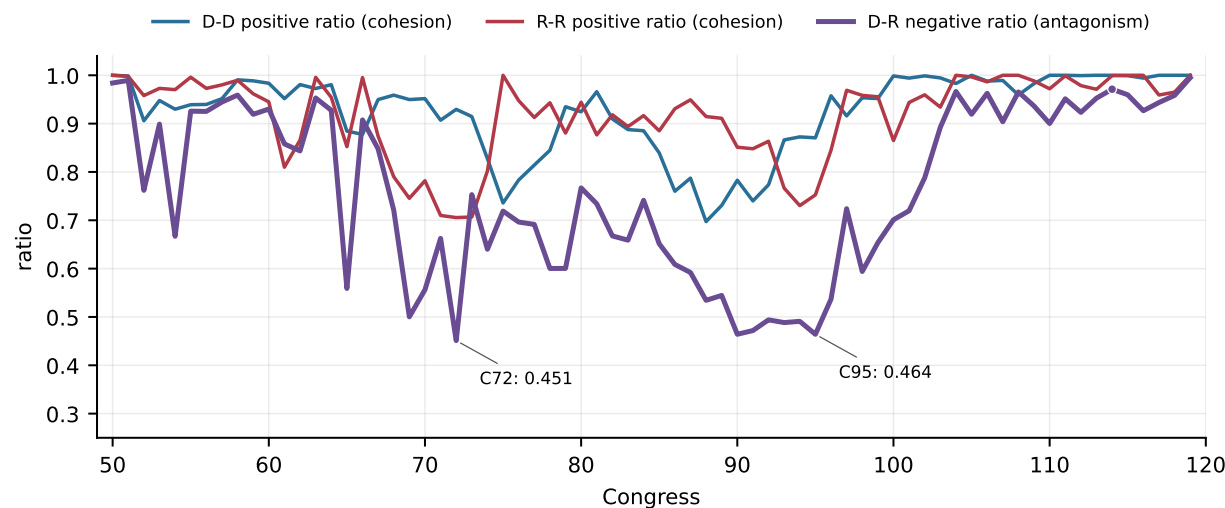


Figure 3: The three party-partitioned ratios over all 70 analyzed Congresses.

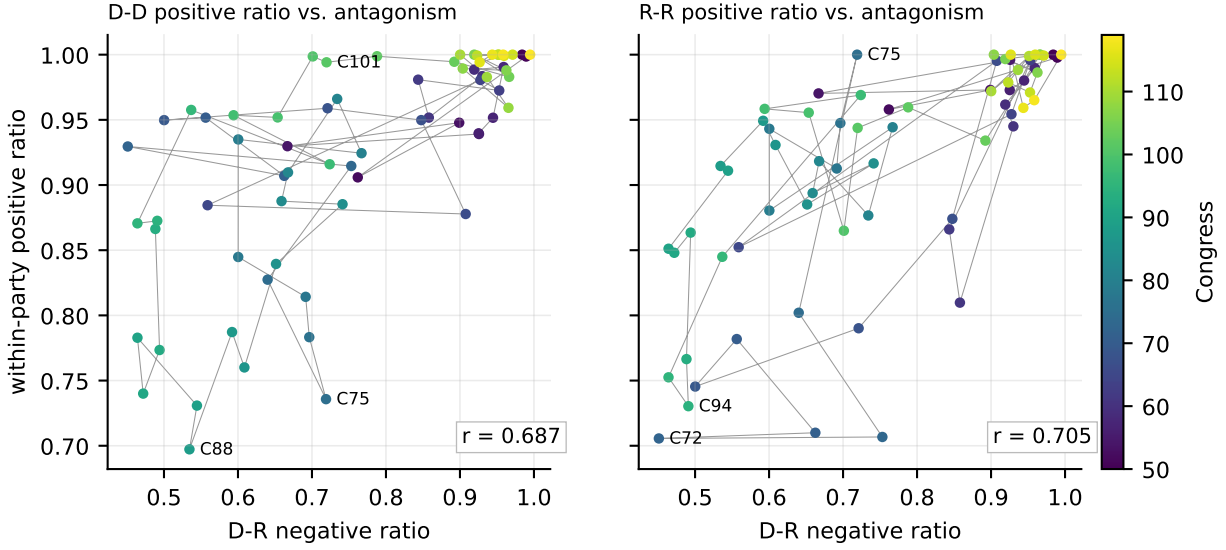


Figure 4: Each party's cohesion against cross-party antagonism. Each Congress is one point, colored by Congress number. The upper right cluster is C104–C119. The relationships are positive but loose.

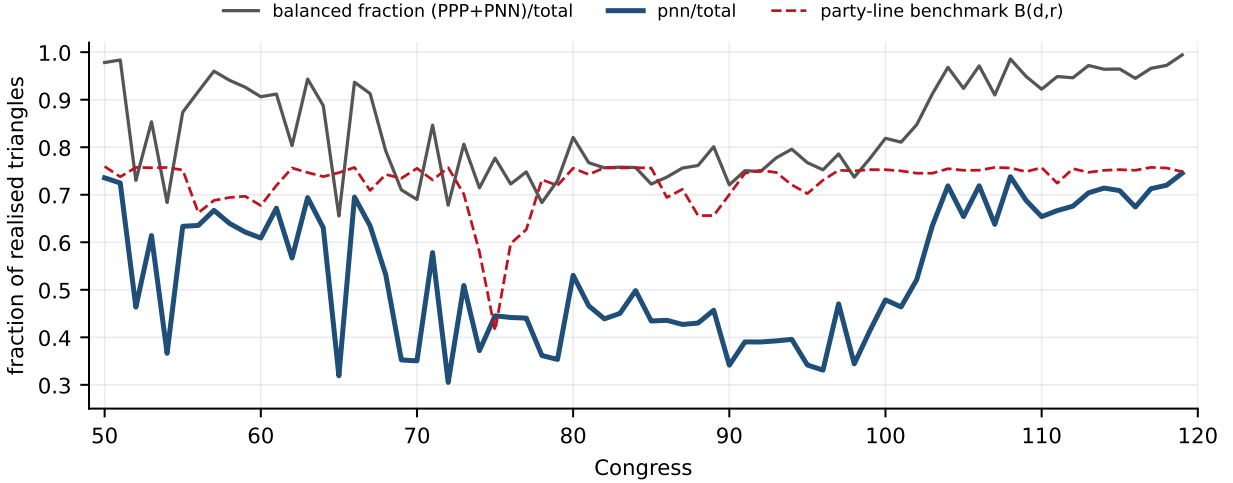


Figure 5: Triadic series by Congress. `pnn_over_total` spans 0.305 (C72) to 0.745 (C119). Two reference lines are also shown: the balanced fraction, $(PPP + PNN)/total$, and the party-line benchmark $B(d, r) = 3dr/[(d + r)(d + r - 1)]$, which is the value `pnn_over_total` would take if every within-party edge were positive and every cross-party edge negative.

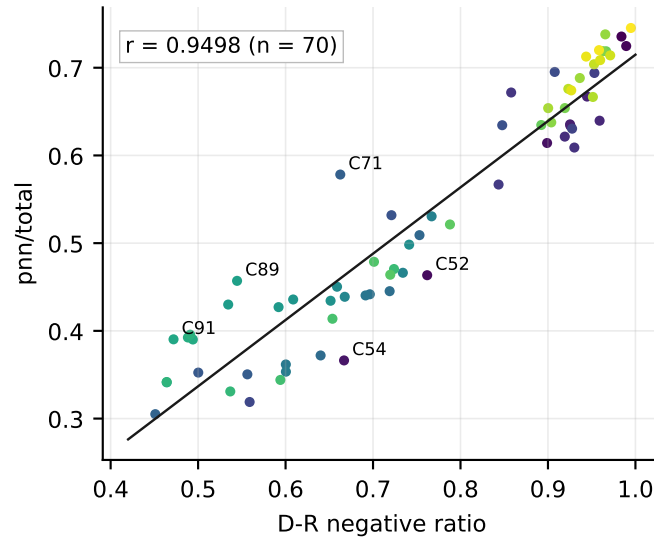


Figure 6: `pnn_over_total` against `cross_party_negative_ratio`, colored by Congress, with the line $\text{pnn_over_total} = 0.7561 \cdot \text{cross_party_negative_ratio} - 0.0413$ and the five farthest points labeled.

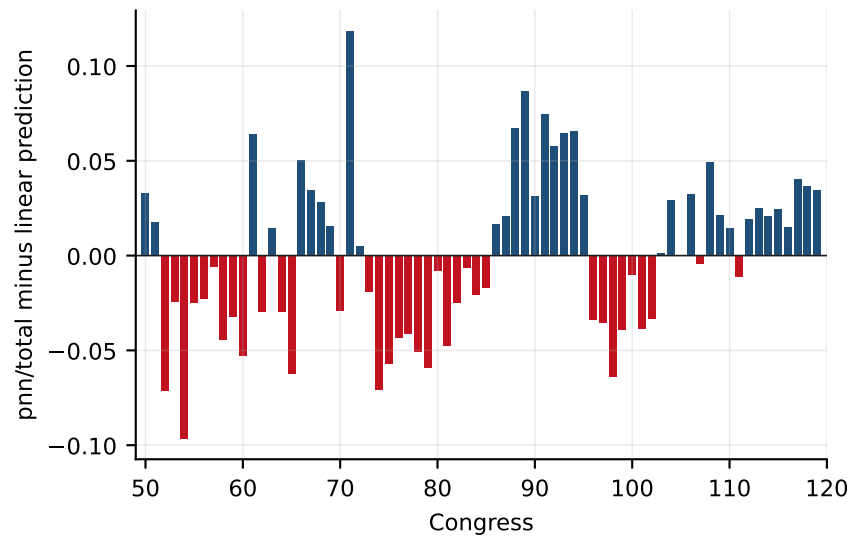


Figure 7: Residuals by Congress. Positive values mean more (+, -, -) structure than the cross-party ratio would suggest.

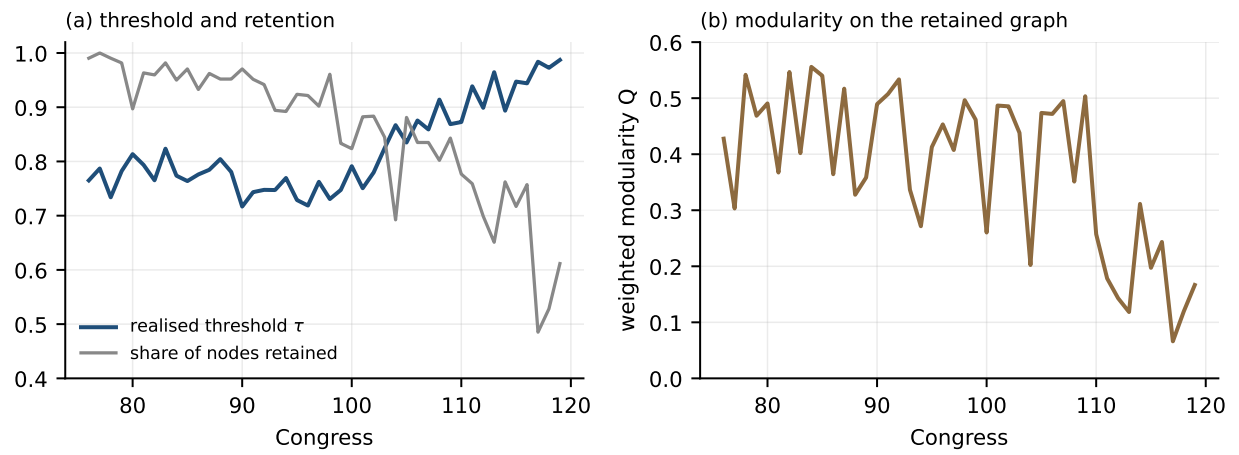


Figure 8: Louvain configuration, C76–C119. (a) The percentile threshold τ rises from a low of 0.717 (C90) to 0.987 (C119), while the share of nodes surviving it falls to 0.485 (C117). (b) Weighted modularity on the retained graph.

5 Conclusions

Figure 3 shows the `cross_party_negative_ratio` across all 70 analyzed Congresses. The series is high at both ends, and low through a long middle section. C50 and C51 record 0.984 and 0.989, and C119 records 0.995. These endpoints are both high, with C50 only slightly below C119. The historical minimum is C72 at 0.451. C65, C69, C70, C72, C87–C96, and C98 all fall below 0.6. From C96 onward the series rises with interruptions along the way, first passing the 0.9 mark in C104 and remaining above 0.9 to C119.

The pattern we can see is U-shaped. This means that the decreasing cross-party hostility in middle Congresses and the increase in hostility in Congresses post-C104 both need to be explained in further analysis.

In early Congresses, the metric is volatile, shown by the following values at various Congresses: C52 (0.762), C53 (0.899), and C54 (0.667). This can be partly explained, from a structural and data standpoint, by the fact that fewer than 200 roll calls passed the near-unanimous filter in the early Congresses.

We do not answer the question of the reason behind decreasing and increasing hostility throughout the series, or the volatility, in this report, as structural data is not sufficient to identify a historical cause.

The within-party (`rep_rep`, `dem_dem`) ratios are the simplest quantities in the project. Each ratio is normalized within each party and Congress, which means it does not depend on party sizes. It also does not use triadic theory. Democratic cohesion reaches its minimum at C88 (0.697), with low stretches seen in C74–C78 and C85–C92. Republican cohesion reaches a minimum at C72 (0.706), with low stretches in C68–C73 and in C93–C95.

The word polarization is used for two different things: parties becoming internally cohesive and parties becoming opposed to each other. The three ratios separate them, and the full series shows that cohesion and antagonism have not moved in exact synchronization in the 70 Congresses analyzed.

Over 70 Congresses, the `cross_party_negative_ratio` correlated 0.687 with the `dem_dem` ratio and 0.705 with the `rep_rep` ratio, but the two only correlated 0.292 with each other. This means that each party has its own trajectory in terms of cohesion, and that cannot explain strong trends in cross-party antagonism.

Three configurations were seen that provide structural evidence for the claim:

One party is cohesive, the other is fractured: In C75, `rep_rep` = 1.00 while `dem_dem` = 0.736. The 16-member Republican minority shows zero internally adversarial pairs, while the 82-member Democratic majority had many. Twenty Congresses later it flipped. In C93–C95, Republican cohesion was at 0.73–0.77, and Democrats are around 0.87.

Cohesion is seen before antagonism: In C100–C102, Democratic cohesion is at its maximum, at 0.994–0.999, but cross-party antagonism is only 0.70–0.79. Cross-party antagonism does not increase past 0.9 until C104. This shows that the Democratic group strengthened internal ties and ideology well before the parties turned against each other. If cohesion and antagonism were the same phenomenon, the increase in both metrics would occur in the same Congress, rather than antagonism rising after cohesion.

Parties split independently: In C72, Republicans disagreed with each other more than Democrats did, with cohesion at 0.706, while the Democrats stayed unified (cohesion at 0.930). In C72, more Democrat-Republican pairs ended the Congress as net allies than adversaries, with antagonism at 0.451. C88 has the same feature with the parties swapped, with Democrats more divided at 0.697, Republicans unified at 0.915, and cross-party antagonism low at 0.534. The two Congresses also are different in the party-blind triadic metric. C88 has a more two-sided (+, −, −)

structure than its cross-party ratio suggests, while C72 does not and has a large share of unbalanced triangles (32%). This suggests scattered disagreement rather than a two bloc structure with any kind of systematic disagreement.

Results seen in 4.3, establishes that cohesion and antagonism are distinct measurements with a documented history of instances where they diverge from one another. Combining the three metrics into a single polarization metric, relating antagonism and both parties' cohesion, would likely lead to an incomplete description of polarization where important parts of a full analysis may be lost in abstraction. Thus, all three parts must be analyzed separately for a full explanation of polarization.

This does not show that they are fully independent mechanisms, as that can only be claimed if one metric is fixed and the other moves independently, which is not possible in a descriptive series of a live and evolving Congress.

`pnn_over_total` and `cross_party_negative_ratio` correlate 0.9498 over all 70 Congresses and 0.9604 over C76–C119 (Figure 6).

The pairwise and triadic measures are linked by a counting rule as follows. If any senator is taken along with a list of senators they have a net-negative voting record with, each pair of names on that list will fall into one of three cases: The two are allies of each other, so the three senators form a $(+, -, -)$ triangle; The two are adversaries of each other, so all three are mutual adversaries, forming a $(-, -, -)$ triangle; The two never voted on the same retained roll call (after near-unanimous removal), so there is no edge and no triangle between them.

If these are added up for every senator, the sum over all senators is

$$\sum_i \binom{k_i}{2} = \text{PNN} + 3 \cdot \text{NNN} + W_{\text{open}}$$

where k_i is senator i 's number of adversaries, $\binom{k_i}{2}$ is the number of pairs that can be formed from the list, and W_{open} counts case 3, where two senators never voted on the same roll call. NNN is multiplied by three because an all-negative triangle is counted once from each of its three members' lists, while a $(+, -, -)$ triangle is counted only from the list of the senator at its point.

This rule does not mean that the triadic count is fixed when you know how many adversaries each senator has, but it depends on how those adversaries are arranged. If there are six senators, each with two adversaries, and the ties form a ring, each senator's two adversaries are allies of each other, resulting in six $(+, -, -)$ triangles and no $(-, -, -)$ triangles. If the six split into groups of three that are adversaries within their group, then two $(-, -, -)$ triangles will be present and no $(+, -, -)$ triangles.

When most adversarial ties run between the parties and all-negative triangles are rare, a senator's adversaries are mostly members of the other party, who are usually allies of each other (case 1). This would result in more $(+, -, -)$ triangles.

The triangle share and cross-party ratio differ, as the triangle count does not consider party labels, while the cross-party ratio is built fully from party labels.

The difference in party inclusion matters. If the Senate split into two opposing blocs that were not the two parties, the triangle share would be high because the chamber would be divided in two. In this scenario, the cross-party ratio would be low, as many Democrat-Republican pairs would now be allies rather than adversaries.

To look for such cases, we found the Congresses where the triangle share is higher than the cross-party ratio would predict. To do that, we fit a straight line predicting triangle share from the cross-party ratio (Figure 6):

$$\text{pnn_over_total} = 0.7561 \cdot \text{cross_party_negative_ratio} - 0.0413$$

For each Congress, the residual is how far the triangle share sits above or below that line (Figure 7). The typical distance, measured as the standard deviation of the residuals, is about 0.044.

The Congresses furthest above the line are C71 (+0.119), C89 (+0.087), C91 (+0.075), C88 (+0.067), and C94 (+0.066). Those furthest below the line are C54 (−0.097), C52 and C74 (both −0.071), C98 (−0.064), and C65 (−0.062).

The Congresses below the line are those that exhibit a less strict two-sided structure than the cross-party ratio would predict. The Congresses above the line are those that exhibit a more two-sided structure than the cross-party ratio suggests, which makes them worth investigating for camps that may cut across party lines. But being above the line does not necessarily show that such camps exist, since a Congress can stray from the line for other reasons as well.

6 Community detection – Extension

In this investigation, community detection was an extension and is not included in any conclusions. The goal of this extension was to find groups of senators who consistently vote together, without using party as a factor. If those groups matched parties, that would be evidence that party is how the Senate organizes itself, and of the organizational trend over time.

The Louvain algorithm [3] was used. Prior to implementing the algorithm, the network was trimmed:

1. All adversarial edges were removed, keeping only allied pairs.
2. For each pair, an agreement score was calculated, defined as the share of their common votes on which they voted the same way. Within each Congress, only the scores in the top quarter of the remaining allied pairs are kept.
 - (a) The cutoff is not a fixed number, but rather is recalculated for each Congress to find each top 25% agreement score threshold. This results in the cutoff changing drastically through the series. At C119 it is 0.987, so a pair needs to agree on nearly every shared vote. The lowest cutoff in the series is 0.717, at C90.

Louvain was run on the remaining network. Results are shown in Figure 8. No conclusion was taken from the results of the community detection extension.

7 Conclusion

Over the 50th–119th Congresses, cross-party antagonism in the Senate co-voting networks is high at both ends and low through a long middle period, with its minimum in the 72nd Congress. The word “polarization” is used to describe both cohesion and antagonism. The three party-partitioned ratios measure these separately, and the series shows that cohesion and antagonism have not moved exactly together across the 70 Congresses, correlating only moderately ($r \approx 0.69$ and 0.71). Within-party cohesion follows separate paths for the Democratic party and the Republican party, and the three party-partitioned ratios diverge in many Congresses.

Congresses that are distant from the fit line of cross-party antagonism and the triadic share can be candidates for deeper analysis in an effort to identify reasons why there is a discrepancy between the predicted triadic share based on cross-party antagonism values and the real triadic share.

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