Party Polarization in Congress:
A Social Networks Approach

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We use the network science concept of modularity to measure polarization in the United States Congress. As a measure of the relationship between intra-community and extra-community ties, modularity provides a conceptually-clear measure of polarization that directly reveals both the number of relevant groups and the strength of their divisions. Moreover, unlike measures based on spatial models, modularity does not require predefined assumptions about the number of coalitions or parties, the shape of legislator utilities, or the structure of the party system. Importantly, modularity can be used to measure polarization across all Congresses, including those without a clear party divide, thereby permitting the investigation of partisan polarization across a broader range of historical contexts. Using this novel measure of polarization, we show that party influence on Congressional communities varies widely over time, especially in the Senate. We compare modularity to extant polarization measures, noting that existing methods underestimate polarization in periods in which party structures are weak, leading to artificial exaggerations of the extremeness of the recent rise in polarization. We show that modularity is a significant predictor of future majority party changes in the House and Senate and that turnover is more prevalent at medium levels of modularity. We utilize two individual-level variables, which we call “divisiveness” and “solidarity”, from modularity and show that they are significant predictors of reelection success for individual House members, helping to explain why partially-polarized Congresses are less stable. Our results suggest that modularity can serve as an early-warning signal of changing group dynamics, which are reflected only later by changes in formal party labels.

1 Introduction

A great deal of recent research on Congress has been devoted to partisan polarization (McCarty, Poole & Rosenthal 1997, Herrnson 2004, Jacobson 2004, Fiorina, Abrams & Pope 2005, Jacobson 2006, McCarty, Poole & Rosenthal 2007, Zhang, Friend, Traud, Porter, Fowler & Mucha 2008) and
the influence of party on roll-call voting (Rohde 1991, Cox & McCubbins 1993, Snyder & Groseclose 2000, McCarty, Poole & Rosenthal 2001, Cox & Poole 2002, Cox & McCubbins 2005, Smith 2007). With few exceptions, such research has suggested that party leaders are able to successfully influence the voting behavior of legislators, that this influence has resulted in increased partisan polarization in Congress over the past 20 years (following a period of party decline), and that polarization in Congress has increased polarization in the electorate (Jacobson 2000, Jacobson 2005).

However, this wealth of attention has resulted in few concrete measures of partisan polarization. In fact, nearly all studies of Congressional polarization rely on a single measure, which was developed by McCarty, Poole, and Rosenthal (MPR) (2007) using DW-Nominate scores (Poole & Rosenthal 1997, Poole 2005). DW-Nominate, a multi-dimensional scaling technique (Borg & Groenen 1997), was designed to measure the ideological positions of individual legislators. It has been successfully applied to study party influence in Congress, but it relies on a number of assumptions about the nature of the party system and the preferences of individual legislators. Although these assumptions might have value in estimating the ideal preferences of individual legislators, it is unclear whether they are appropriate for measuring a Congress-level phenomenon such as polarization. In particular, the assumption of a party-system structure constrains the MPR analysis to the current Democratic-Republican two party system. By construction, this makes it difficult to use such methods to investigate the ebb and flow of polarization over the course of American history.

Here we use methods from network science to reconceptualize polarization. Suppose each legislator is a “node” in the network and the similarity in their roll-call voting behavior indicates the strength of a “tie” between them. In a highly-polarized legislature, individuals in groups like parties have very strong ties within the groups but very weak ties between them. For example, in the extreme case of pure party-line voting, all members of the same party are perfectly similar and therefore have the strongest possible ties between each other. They also have the weakest possible ties to members of the other parties. In contrast, individuals in a legislature with low polarization tend to have ties both to their own group and to other groups, reducing the gap between within-group and between-group tie strength. In a legislature completely free of party-line voting,
individuals are just as likely to vote with members of the other party as with members of their own.

Network scientists have recently developed a measure called “modularity” (Newman & Girvan 2004, Newman 2006a) that uses information about the ties between each pair of individuals in a network to compare the strength of ties within each group to those between each group. “Modular” networks contain groups that have many ties within them but few between them. Network analysts call such groups “modules” or “communities” because they form strongly connected and cohesive subnetworks that, in the extreme, are nearly separated from other parts of the network (Porter, Onnela & Mucha 2009, Fortunato 2009). As the ties within groups become stronger and those between groups become weaker, the network becomes more modular. Conceptually, this is exactly what it means when one claims that groups are becoming more polarized. In a polarized legislature, people stick to the party line and rarely cross the aisle.

An advantage of this new way of thinking about political polarization is that it also allows us to quantify the number of cohesive groups or communities in a legislature and identify which individuals belong to each group. Previous work has used similar procedures to study communities formed by the network of legislative cosponsorships (Zhang et al. 2008), House committee memberships (Porter, Mucha, Newman & Warmbrand 2005, Porter, Mucha, Newman & Friend 2007), and a large variety of other real-world and computer-generated networks (Porter, Onnela & Mucha 2009, Fortunato 2009). Other applications of network analysis have also flowered in the political science literature (see, e.g., Huckfeldt 1987, Fowler 2006a, Fowler 2006b, McClurg 2006, Baldassarri and Bearman 2007, Koger et al. 2009).

Unlike the MPR measure of polarization, modularity does not require any assumptions about the structure of the party system or the nature of legislator preferences. Indeed, modularity can be calculated for any assignment of nodes into groups in any specified network, allowing us to measure polarization across the whole history of the U.S. Senate and House of Representatives. We use community detection procedures to identify group assignments that maximize modularity for each roll-call network for both the House and Senate in the 1st–109th Congresses and then compare maximum modularity to the modularity that results when we assume that party membership defines
the relevant voting groups. Using this procedure, we can show the extent to which party divisions drive polarization over time. Using regression analyses, we then find that maximum modularity is a significant predictor of future majority party changes in both the House and the Senate.

By deriving group structures directly from the data rather than imposing them in the form of an assumed party system, we observe communities as they exist based on behavior instead of labels. With this methodology, we find several periods in American history—most notably, during the 75th–95th Congresses from 1937 to 1979—in which a large discrepancy exists between formal party divisions and real voting coalitions. We suggest that such discrepancies, and the corresponding changes in maximum modularity, might serve as an early warning signal for changes in the partisan composition of Congress. This is because community structure can reveal informal changes in partisan alliances before they change formally through party labels. In order to test this hypothesis, we use modularity values in Congress $t$ to predict changes in the majority party for Congressional term $t + 1$. We find a nonmonotonic relationship between modularity and the stability of the majority party in both chambers of Congress. At low levels of modularity, there is little impetus to coordinate a change in majority control, while at high levels there is little the minority can do to overcome the majority’s cohesion. In both of these cases, majority status changes are infrequent. However, at medium levels of modularity, there is a mix of impetus and relaxed majority cohesion, yielding a party system that is significantly less stable. We call this the “partial polarization hypothesis.”

Finally, our analysis helps to explain why partially-polarized Congresses exhibit the greatest instability. First, modularity allows us to identify those legislators who are most polarizing (i.e., who are most “divisive”) and those who align most closely with their group (which we call “solidarity”). Second, we show using these ideas that divisiveness has a negative impact on individual reelection chances but that the effect is mitigated for polarizing legislators who exhibit strong solidarity with their group. This, then, yields instability in partially-polarized Congresses.
2 Modularity

2.1 Generating Adjacency Matrices

To measure modularity, the first step is to use roll-call votes to generate a network in the form of an adjacency matrix (Wasserman & Faust 1994, Newman 2003) that describes voting similarities among Congressmen. The roll-call (compiled by Keith Poole and Howard Rosenthal, 1997, 2007) for a given two-year term of Congress is encoded in an $n \times b$ matrix, in which each element $M_{ik}$ equals 1 if legislator voted yea on bill $k$, $-1$ if he/she voted nay, and 0 otherwise. Because we are interested in characterizing the affiliations between legislators (rather than those between legislators and bills), we transform the voting matrix into an $n \times n$ adjacency matrix $A$, whose elements $A_{ij} \in [0,1]$ representing the extent of voting agreement between legislators $i$ and $j$. We define these matrix elements by

$$A_{ij} = \frac{1}{b_{ij}} \sum_k \alpha_{ijk},$$

(1)

where $\alpha_{ijk}$ equals 1 if legislators $i$ and $j$ voted the same on bill $k$ and 0 otherwise, and $b_{ij}$ is the total number of bills on which both legislators voted. Because the perfect similarity between a legislator and herself provides no information, we set all diagonal elements to be zero (i.e., $A_{ii} = 0$). The matrix $A$ thereby encodes a network of weighted ties between legislators, with weights determined by the similarity of their roll-call records in a single two-year Congress.

We generated two types of adjacency networks for our study. In the first type, we use all available roll-call votes (including unanimous and near-unanimous votes). This set of networks thus makes no assumptions about the quality or content of lopsided roll-calls and lends conceptual clarity to the resulting modularity calculations. In the second type, we follow the guidelines of Poole & Rosenthal (1997) and consider only “non-unanimous” roll-call votes. A roll-call vote is classified as “non-unanimous” if greater than 3% of legislators are in the minority. For modern Congresses, this implies that a roll-call minority must contain at least 4 Senators or at least 13 Representatives to yield a “non-unanimous” vote. While we make no substantive claim about the importance of dropping unanimous votes, we concentrate primarily on non-unanimous roll-call adjacency matrices. This ensures that the data sets we analyze mirror those used by McCarty,
Poole, and Rosenthal (2007), permitting more explicit comparison of our polarization measure with theirs.

2.2 Definition of Modularity

Having generated $n \times n$ networks of weighted connections between legislators, we can now calculate modularity values for any partition of these graphs. Several software packages are available to perform such calculations. In this paper, we use the *igraph* package developed by Gabor Csardi and Tamas Nepusz (2006).

Modularity can be used to measure the quality of a given partition of a network into specified, non-overlapping communities (Porter, Onnela & Mucha 2009, Fortunato 2009, Newman & Girvan 2004, Newman 2006a). Modularity relies on the intuitively-plausible notion that communities within networks ought to consist of nodes with more intra-community ties than extra-community ties (Newman & Girvan 2004, Newman 2006a). For a given network partition, the modularity $Q$ represents the fraction of total tie strength $m$ contained within the specified communities minus the expected total strength of such ties. The expected strength depends on an assumed null model. Here we use the standard Newman-Girvan null model that posits a hypothetical network with the same expected degree distribution as the observed network (Newman 2006a, Newman 2006b). One can alternatively use other null models, such as ones that assume uniform connection probabilities or signed ties (Traag & Bruggeman 2008).

The standard null model gives a modularity of

$$Q = \frac{1}{2m} \sum_{ij} \left[ A_{ij} - \frac{k_i k_j}{2m} \right] \delta(g_i, g_j), \tag{2}$$

where $m = \frac{1}{2} \sum_i k_i$ is the total strength of ties in the network, $k_i = \sum_j A_{ij}$ is the weighted degree (i.e., the strength) of the $i$th node, $g_i$ is the community to which $i$ belongs, and $\delta(g_i, g_j) = 1$ if $i$ and $j$ belong to the same community and 0 if they do not.

Large positive modularity values indicate that a given network partition has much stronger intra-community tie strengths than would be expected by chance. In other words, the legislators
within the communities voted more often with each other than with legislators belonging to other communities. This, in turns, indicates that a legislature is more polarized.

2.3 Modularity Maximization

Although one can calculate the modularity of any network partition, it is important for the purpose of measuring the level of polarization in a given Congress to identify the partition that maximizes the modularity (or, at minimum, one that nearly maximizes modularity). Because optimizing modularity is an NP-complete problem (Brandes, Delling, Gaertler, Goerke, Hoefer, Nikoloski & Wagner 2008), a number of computational heuristics have been developed (Danon, Diaz-Guilera, Duch & Arenas 2005, Fortunato 2009, Porter, Onnela & Mucha 2009). In this paper, we use the walktrap algorithm, which was developed by Pons and Latapy (2005) and has been implemented in the R package igraph (Csardi & Nepusz 2006).

The walktrap algorithm starts by partitioning the network into \( n \) communities, which each contain a single node (i.e., a legislator). It calculates a measure of the distance between each pair of communities and begins merging groups by taking short random walks between them, operating under the principle that such walks should connect closely-tied nodes and identify relevant communities. After each merging step, one calculates the modularity score for the current partition. The algorithm finishes after \( n - 1 \) steps when the nodes have been merged into a single community consisting of the full network. Although the algorithm always begins with \( n \) communities and ends with a single community, it returns the maximum-modularity network partition that it was able to find. The walktrap algorithm requires the user to specify the length of the random walk, and Pons and Latapy (2005) recommend walks with 4 or 5 steps. However, we found that for many Congresses, these lengths did not provide the maximum modularity score. To be thorough in attempting to optimize modularity, we performed the walktrap algorithm 50 times for each Congress (using random walks of lengths 1–50) and selected the network partition with the highest modularity value from those 50. We will call this the “maximum modularity partition” (though, strictly speaking, this cannot be proven to be the optimum without computationally-prohibitive

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1In practice, the fast greedy algorithm developed by Newman (2004), which is also implemented in igraph, recovers nearly-identical partitions for almost every Congress, though other algorithms can identify different best partitions.
exhaustive enumeration (Brandes et al. 2008)).

One can represent the results of the walktrap algorithm graphically (for a random walk of specified length) in the form of a tree, or dendrogram, which shows the group mergers in a hierarchical fashion and identifies communities of legislators who tend to cluster together. Horizontal bars in such a plot are assigned a height depending on when they occurred in the algorithm (later steps have a larger height). We show a dendrogram for the 75th Senate in Figure 1. This Senate, which had an overwhelming Democratic supermajority (far exceeding the 2/3 majority necessary at the time for a filibuster override) achieves its maximum modularity when partitioned into three communities. The largest community (on the right) contains the majority of the Democrats and some third-party Senators, the second-largest community (on the left) contains all of the Republicans and 12 Democrats, and the smallest community (in the center) contains 10 Democrats and 1 Farmer-Labor member.

We found that for most Congresses, the maximum modularity occurs in a network partition consisting of two communities, although several Congresses had a maximum-modularity partition with three communities. Using only non-unanimous votes, the walktrap algorithm identified three communities in Senates 2, 4, 13, 40, 41, 60, 63, 73, 75, and 77 and Houses 3, 17, 19, 43, 52, 74, 75, 81, and 98. Such three-community Congresses are rare, conforming to the expectation that single-member districts tend to yield two-party systems (Duverger 1954, Cox 1997). Congresses with three communities tend to occur when the party system is unstable and the maximum modularity is low, suggesting that both modularity and three-community Congresses might be early indicators of changes in the party-system structure. We explore this in more detail in Section 4.

3 Modularity as a Measure of Polarization

In Figures 2 and 3 we compare maximum modularity values to an existing polarization measure that was introduced by McCarty, Poole, and Rosenthal (MPR) (1997, 2007). The MPR measure is given by the absolute value of the difference between the mean first-dimension DW-Nominate score (Poole 2005, Poole 2009) for members of one party and the same mean for the other party. For comparability, we rescale both modularity and the MPR measure to lie in the range [0, 1].
Figure 1: Dendrogram of the 75th Senate. The walktrap algorithm found three communities in the 75th Senate (1937-1939) with a maximum modularity value of 0.0821. The largest group contains primarily Democrats, the second largest is composed mainly of Republicans, and the smallest contains a coalition of Democrats from mainly agricultural states.
Figure 2: [Color online] Longitudinal comparison of modularity and MPR measures in the House of Representatives. Each measure has been rescaled here to the $[0, 1]$ interval for visual convenience. Unscaled, maximum modularity ranges from $[0.032, 0.363]$.

Figure 3: [Color online] Longitudinal comparison of modularity and MPR measures in the Senate. Each measure has been rescaled here to the $[0, 1]$ interval for visual convenience. Unscaled, maximum modularity ranges from $[0.006, 0.278]$. 

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Observe that unlike the modularity measure, the MPR measure assumes a competitive two-party system (McCarty, Poole & Rosenthal 2007) and therefore cannot be calculated prior to the 46th Congress. Another difference is the year-to-year variance in the measure. MPR assumes that legislators always remain in the same voting block and have fixed ideologies from year to year (unless they switch parties), resulting in a time series that is smoother than that for the modularity measure. In principle, one can achieve the same smoothness in the modularity measure using the same assumptions, but as we discuss below, we believe that this variance is informative. Finally, note that although the MPR and modularity measures both tell the same general story during the 46th–109th Congresses, the former suggests a much lower level of Congressional fractionalization during the so-called ‘party decline’ era between the 75th–95th Congresses (Petrocik 1981, Ware 1985, Coleman 1996).

3.1 Comparison of Modularity and MPR Measures

The maximum modularity values in Figures 2 and 3 are consistent with several stylized facts about polarization in Congress. Most notably, they capture the spike in fractionalization at the turn of the 20th century caused by the end of Reconstruction and the recent spike in fractionalization since the 95th Congress (Snyder & Groseclose 2000, McCarty, Poole & Rosenthal 2001, Cox & Poole 2002, Jacobson 2004, Jacobson 2005, Jacobson 2006, McCarty, Poole & Rosenthal 2007, Smith 2007, Zhang et al. 2008). The curves also show the lull in fractionalization that corresponds to the party decline era during the 75th–95th Congresses (Petrocik 1981, Ware 1985, Coleman 1996). By contrast, the MPR measure shows a much lower fractionalization during this period.

The period during the 75th–95th Congresses is one in which the maximum modularity differs substantially from party modularity, which is simply the modularity of the network under the assumption that legislators are assigned to groups that contain all of their fellow party members. Figure 4 tracks the percentage $100 \times P/Q$ of the maximum modularity value $Q$ that is explained by the party modularity value $P$. While maximum modularity measures the overall polarization of a Congress, the percentage in Figure 4 indicates the relative contribution of party differences to total polarization. The party partition captures the vast majority of the maximum modularity
in all modern Houses, with one notable exception consisting of the period during the 85th–95th Congresses. Party importance varies more in the Senate, where it oscillates from one Congress to the next between the 67th and 75th Congresses and is again a smaller part of maximum modularity during the 85th–95th Congresses.

Figure 4: [Color online] Longitudinal plot of the percent of modularity explained by party for both the House and Senate. The contribution of party to maximum modularity varies considerably over time, particularly in the Senate.

Interestingly, although the MPR measure suggests substantially lower polarization than the modularity measure for the 75th–95th Congresses, the party partition explains 90% or more of the aggregate modularity for the 75th–84th Congresses before dropping to around 60% during the 85th–95th Congresses. This result conveys the clearest difference in modern times between the MPR measure and the modularity measure. The MPR measure suggests that party decline began around the 70th Congress and continued until approximately the 90th, whereas the modularity measure—particularly the proportion of modularity explained by party—suggest that the importance of party did not start to wane until the 85th or 86th Congress. Notably, this is the only period in which a fixed partition with three groups (Republicans, Southern Democrats, and Northern Democrats) results in a higher modularity score than the normal two-party partition. These results suggest
that party was less important to Congressional fractionalization during the 75th–95th Congresses than it was in other periods and that intra-party coalition tensions were generating heightened polarization during this period that are not captured by the MPR measure.

This comparison yields at least two important substantive conclusions. First, the MPR underestimation of polarization during the 75th–95th Congresses makes the subsequent rise in party polarization seem more dramatic than that described by the modularity measure. This result likely arises from the decision to calculate the MPR measure using only the first dimension of the DW-Nominate scores. As Poole and Rosenthal identify, the second dimension of DW-Nominate, usually attributed to civil rights issues, tends to explain a significant amount of variance in the roll-call decisions of individual legislators over this period (1997). By creating an aggregate polarization measure using only the first dimension, the MPR measure neglects this additional variance. In contrast, the modularity measure avoids this problem because it does not require one to specify dimensionality. As a result, it captures important divisions within parties in Congress during the party-decline era, as legislators sought to forge new coalitions that ultimately yielded the current, highly-polarized party system. Second, when viewed longitudinally, the MPR measure derives much of its visual impact from its limitation to post-Reconstruction Congresses. The modularity measure shows that modern-day polarization is high but not to a greater extent than in many other periods. In fact, taking the entire history of Congress into account, it is the low-modularity period of the 75th–95th Congresses that appears to be the exception rather than the rule.

4 Modularity as a Predictor of Changes in Majority Status

4.1 Changes in Group Dynamics

The modularity-maximization algorithm generates both a community structure and a measure of the strength of that structure that can be compared to the strengths of alternate groupings such as parties, caucuses, and committees. Modularity gives us the opportunity to measure the gap between stated political allegiances and actual political behavior. We chart this gap in Figure which demonstrates the proportion of maximum modularity that can be attributed to party
divisions.

The existence of such a disparity is unsurprising. We do not expect legislators to be perfect partisan agents, and we know that group dynamics have shifted and that the parties have reorganized themselves several times in United States history (Burnham 1970, Merrill III, Grofman & Brunell 2008). The most prominent partisan realignments have been captured in numerous longitudinal studies of public opinion and voting behavior. These realignments represent changes in the formal allegiances of Members of Congress. We assume that such changes are costly to politicians and are thus unlikely to be undertaken without prior exhaustive effort to salvage the existing party order. As a result, we expect informal tensions within parties to arise before formal changes occur.

As party bonds disintegrate, some legislators seek to preserve dying alliances while other, opportunistic legislators seek new alliances that reflect (or perhaps help create) a different order (Riker 1986). Measures of polarization based on DW-Nominate are ill-equipped to identify these shifts for two reasons. First, such measures assume a party-system structure to orient their legislator coordinates in space. Second, such measures are weighted dynamically, which constrains the spatial movement of legislators over time: like pawns in chess, legislators start on one side of a space or the other and DW-Nominate permits them to move in only one direction over the course of their careers. This restricted movement is a technical necessity that allows one to identify ideal points on a consistent spatial metric over time (Poole 2005). Substantively, Poole defends this constraint by appealing to evidence of party switchers in Congress. Namely, many legislators have changed parties over their careers, but none have ever changed back (Cox & Poole 2002, Poole 2005). This defense is justifiable if exogenously-defined group structures, such as party, are sufficiently fine-grained to capture group dynamics or if the aim is to measure differences between modern Republicans and modern Democrats. However, to measure changes in informal group dynamics that anticipate changes in formal group structures, a consistent measure of group structure and strength is needed that does not assume a party system or prevent politicians from wavering in their beliefs over time. Modularity provides such a metric.

A clear indicator of a formal power shift in Congress is a change in the majority party. When majority status changes hands in Congress, it is normally the result of major political or economic
failure on the part of the previous majority, reflecting the fact that voters no longer feel comfortable with that party maintaining institutional control. One important way for a majority party to remain effective is for its caucus members to coordinate on policy, as reflected in roll-call votes. The House and Senate majorities resolve their coordination problems through various institutional means, such as the delegation of agenda control to leaders and the appointment of party whips (Rohde 1991, Cox & McCubbins 1993, Aldrich 1995, Cox & McCubbins 2005). However, the willingness of caucus members to coordinate depends on a variety of forces, including electoral pressure, ideological cohesion, and career ambition (Aldrich & Rohde 2001, Jacobson 2004).

If party membership is personally costly, then members might hedge their bets by seeking new voting coalitions—either within their party or in other parties. Such fractures are captured in the modularity-maximizing group structure by the emergence of third groups or the replacement of party-dominated communities by more heterogeneously mixed groups. However, the effect of such changes on the maximum modularity can be be quite variable, depending significantly on the strength of the outgoing majority party. For example, the majority party in a low-modularity Congress, in which group divisions are not particularly strong, might evolve into a more partisan system, which leads to higher modularity scores. On the other hand, the majority in a high-modularity Congress might suffer discontent that lowers aggregate modularity and leads to the emergence of a less-partisan system.

As group structures in Congress evolve into forms that do not reflect party labels, interest groups, party organizations, and ultimately voters begin to notice the gap, making the political environment unstable. If these political actors support the party, then the legislator might be replaced and the party system preserved. If, however, they support the legislator, then he or she can either switch parties or attempt to drag the current party toward the policy preferences of his or her district. If the legislator succeeds in moving the party, it will unsettle the electoral prospects of fellow partisans in other districts. As a result, electoral volatility increases and changes in majority status become more likely.

One empirical implication of this argument is that the modularity measure of the strength of the group structure has the potential to yield predictive power over majority-party changes in
Congress. Below we perform a regression analysis that provides evidence that this is indeed the case. To set the stage, we first offer a descriptive example of the ability of modularity to capture changes in group dynamics before they are reflected in the formal party system.

4.2 A Descriptive Example from the 19th Century

As we discussed in Section 3, the modularity measure can be used to investigate party polarization even during periods of history that include more than two dominant parties (i.e., before Reconstruction). By construction, the MPR measure is not able to do this. Accordingly, we use the modularity measure to consider an illustrative 19th century example.

In the early 19th century, the fledgling party system of the United States was going through a transitional period. The existing party system, which pitted the dominant Democratic-Republicans against a dying Federalist party, finally broke down in the 18th Congress (1823–1825) as the Democratic-Republicans broke ranks based on their affiliations with national leaders, most notably John Quincy Adams and Andrew Jackson. This resulted in a new period, reflected by partisan conflict between supporters of Adams and supporters of Jackson, which lasted until the emergence of the Whigs and the Democratic party in the 25th Congress (1837–1839) (Kernell, Jacobson & Kousser 2009). The time series of the modularity measure captures this transition quite nicely and provides evidence that group structures began to change as early as the 14th Congress, before the Democratic-Republicans divided into the aforementioned camps. The Adams-Jackson party system finally emerged in the 19th Congress, representing a change in majority party status in both chambers.

One can see using modularity that the breakdown of the Democratic-Republican Party first becomes apparent in the transition from the 13th to 14th Congress (i.e., with the 1814 election). The second largest negative shift in modularity over the last 200 years occurs during this transition in both chambers (−0.156 in the House and −0.127 in the Senate). This decline is particularly interesting given that the country was experiencing a unified Democratic-Republican government and that the Democratic-Republicans held huge majorities in both chambers. Some of this decline is likely due to the end of the War of 1812 during the 13th Congress. With the war over, the
Democratic-Republicans no longer needed to maintain a united front, freeing individual Congressmen or groups of Congressmen to pursue alternate agendas. In the Senate, this breakdown yielded a maximum-modularity structure with three communities, suggesting that Democratic-Republicans in the Senate were already beginning to explore alternate alliance structures.

In the House, this transition becomes further apparent in the 17th Congress (1821–1823), where we again identify three communities when the Democratic-Republican party is nominally whole and maintaining large majorities in both chambers of Congress. By the 18th Congress, the divisions within the Democratic-Republican party become formally acknowledged, as three camps emerge behind the leadership of Adams, Jackson, and William Crawford. This formal recognition results in a dramatic increase in the maximum modularity of the House compared to the previous Congress, demonstrating the impact that formal party divisions can have on legislator behavior. The same basic groups had emerged during the 17th House, but had not yet formally consolidated into well-defined camps. After this consolidation, however, the cost to coordinate had become lower, with an accompanying increase in modularity and the elimination of the third community in the modularity-maximizing structure. The elimination of the third community despite the emergence of a third party is especially interesting, as it demonstrates that two of the parties saw the institutional value in coordinating on roll-call votes in order to pursue their respective agendas in a majority-rule institution. Thus, the modularity time series identifies the presence of a coalition government in the 18th House. By the 19th House, however, the party system reforms into the pro-Adams and pro-Jackson divisions. A change in majority status occurs, as the pro-Adams party assumes control of both chambers. The House again achieves maximum modularity with three communities, suggesting that the formal change in party label that had occurred was not yet salient to legislators. By the 20th Congress, however, a two-community partition emerges once more, and the House remains a two-community body until the 43rd Congress (1873–1875), which took place during the throes of Reconstruction.

We see from this anecdote that there is a lag between formal definitions of party and the emergence of coalitions in Congress, and that this lag can work in both directions. In the 14th Senate and 17th House, we identify three distinct communities in a period in which only two
parties nominally existed. When a three-party system becomes recognized in the 18th Congress, modularity increases and the number of communities in the House reduces to two. Finally, when a new two-party system becomes formalized in the 19th Congress, the House again devolves into a three-community body. Modularity thus captures a fascinating distinction between the formal, self-identifying claims of political parties and what coordinating activities are revealed by actual voting behavior.

4.3 Data and Variables

We continue our analysis of group dynamics and polarization in Congress by conducting logistic regression analyses. We compiled a time-series data set that covers each of the 4th–109th Congresses. The data set contains both the key independent variable (maximum modularity) and the key dependent variable (change in majority status) for each House and Senate. Change in majority status is a binary variable that takes the value 1 if a switch occurred as a result of the previous election and a 0 if it did not. Using information provided in Kernell et al. (2009), we identified 27 switches in the House and 26 switches in the Senate. We provide information about majority status in Tables 4 (House) and 5 (Senate).

To control for the economic environment, we employed variables from historical data on relevant economic indicators such as gross domestic product (GDP), consumer price index (CPI), and national debt (as a percentage of GDP). These data can be found in the Historical Statistics of the United States, Millennium Edition (2009). Additionally, we constructed a number of variables representing particular structural features of the government. These include indicator (binary) variables for divided government, midterm Congress, and the presence of Republican or Democratic majority. We included the first two variables to control for the impacts of presidents on electoral outcomes, and we included the last two to capture any peculiar effects that a stable two-party system has had on modularity or the likelihood of majority-party changes. Finally, we include an indicator variable for Congresses that achieve maximum modularity with three communities, as these Congresses are likely to be particularly unstable.

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2The accompanying economic data that we gather were not available for the earliest Congressional sessions.
4.4 Analysis

Prior to conducting regression analyses, we examined the relationship between maximum modularity (measured in term $t$) and a majority status change in the next Congress (term $t+1$) using locally weighted polynomial regression (LOESS) plots (Loader 1999). Figures 5 and 6 show the presence of a nonmonotonic relationship between maximum modularity and changes in majority status. At low levels of modularity, few majority switches occur. As modularity increases, however, the majority switches become increasingly frequent. Interestingly, the likelihood of a majority switch peaks at medium levels of modularity and begins decreasing at higher levels of modularity (though with a broader distribution). The decrease at higher modularities is particularly prominent in the Senate. The plots suggest that the regressions should include a term based on the square of maximum modularity in addition to a linear term.

![LOESS plot of Maximum Modularity in term $t$ versus Majority Party Change in term $t+1$ for the House. Majority party changes are most probable during “medium” modularity Congresses.]

Figure 5: [Color online] LOESS plot of Maximum Modularity in term $t$ versus Majority Party Change in term $t+1$ for the House. Majority party changes are most probable during “medium” modularity Congresses.

We then fit several logit models. We first examined the relationship between maximum modularity and its squared term on future majority switches, while controlling for the lagged dependent variable and the presence of three-community modularity structures. We subsequently added structural and economic control variables for term $t$ and retested the model for majority status change.
Figure 6: [Color online] LOESS plot of Maximum Modularity in term $t$ versus Majority Party Change in term $t + 1$ for the Senate. Majority party changes are most probable during “medium” modularity Congresses.

In the next term ($t + 1$). We present our results in Table 1.

In all four model specifications summarized in Table 1, maximum modularity has a statistically significant ($p < 0.030$) positive impact on the probability of a change in majority party.

The squared term is significant ($p < 0.048$) and negative in both Senate specifications and the first House specification, and it is negative and approaching significance ($p \approx 0.068$) in the second House model. None of the covariates are particularly important, although it is interesting to note that increases in national debt as a percentage of GDP increases the likelihood of a switch in the House, whereas increases in GDP itself increase the likelihood of a switch in the Senate.

We also compared the results from maximum modularity to results generated using the MPR polarization measure (which is based on DW-Nominate). We show the results of these regressions in Table 2. It appears from these results that the MPR measure is not a significant predictor of changes in majority status. It should be noted, however, that the estimates for the MPR regression cover only Congresses 46–109, as the MPR measure is not used to estimate polarization for earlier Congresses.

The existence of a nonmonotonic relationship between modularity and changes in majority
### Table 1: Logistic Regression Results. Majority party change in term $t+1$ modeled by variables in term $t$, with indicated standard errors and significance levels. Notably, the key independent variable, maximum modularity is significant in each model. Maximum modularity squared is significant in three of the four models, and it almost reaching significance ($p \approx 0.068$) in the other.

|                      | House         | Senate        |
|----------------------|---------------|---------------|
|                      | (1)           | (2)           | (1)           | (2)           |
| Max Modularity       | 52.78 (22.59) * | 57.1 (26.3) * | 54.27 (23.81) * | 68.60 (27.4) * |
| [Max Modularity]$^2$ | −115.77 (59.06) * | −123.0 (67.4) . | −165.10 (76.53) * | −194.0 (86.0) * |
| Three Communities    | 1.45 (0.93)   | 1.80 (1.08)   | −0.91 (0.75)   | 0.16 (0.55)   |
| Divided Government   | −0.52 (0.56)  | 0.65 (0.54)   | −0.52 (0.56)   | 0.65 (0.54)   |
| Midterm Congress     | −1.22e−6 (3.19e−6) | −4.94e−6 (2.3e−6) * | −0.36 (0.20) . | −0.26 (0.16) . |
| 2 year ∆GDP          | 46.7 (19.6) * | 19.4 (14.6)   | −0.54 (0.72)   | −1.18 (0.73)   |
| 2 year ∆CPI          | 0.94 (0.69)   | 0.50 (0.60)   | 0.01 (0.67)    | −0.17 (0.71)   |
| 2 year ∆Debt (% GDP) | 46.94 (20.92) * | 14.59 (13.80) | 0.39 (0.51)    | 0.54 (0.53)    |
| Majority Change      | −1.18 (0.91)  | −0.02 (0.65)  | −1.17 (1.12)   | 0.12 (0.73)    |
| Intercept            | −1.89 (1.86)  | −2.12 (1.48)  | −6.34 (2.03) ** | −6.49 (2.16) ** |

Standard errors in parentheses. Significance codes ($p <$): *** 0.001, ** 0.01, * 0.05, . 0.1

### Table 2: Logistic Regression Results. Majority Party Change in term $t+1$ modeled by variables in term $t$, with indicated standard errors and significance levels. The key independent variable, MPR Polarization, appears to have no impact on majority party changes in the House or Senate.

|                      | House         | Senate        |
|----------------------|---------------|---------------|
|                      | (1)           | (2)           | (1)           | (2)           |
| Intercept            | −1.89 (1.86)  | −2.12 (1.48)  | −6.34 (2.03) ** | −6.49 (2.16) ** |
| Majority Change      | 1.44 (1.04)   | 1.02 (0.69)   | −5.01 (1.71) ** | −6.49 (2.16) ** |
| MPR Polarization     | 1.97 (2.46)   | 0.55 (2.06)   | −6.29 (2.48) * | −5.01 (1.71) ** |
| Divided Government   | −1.18 (0.91)  | −0.02 (0.65)  | −6.01 (1.71) ** | −6.49 (2.16) ** |
| Midterm Congress     | −1.17 (1.12)  | 0.12 (0.73)   | −5.01 (1.71) ** | −6.49 (2.16) ** |
| 2 year ∆GDP          | −1.93e−6 (3.41e−6) | 3.65e−6 (2.09e−6) . | −0.30 (0.22) | −0.15 (0.13) |
| 2 year ∆CPI          | 46.94 (20.92) * | 14.59 (13.80) | −6.34 (2.03) ** | −6.49 (2.16) ** |
| 2 year ∆Debt (% GDP) | 0.39 (0.51)   | 0.50 (0.60)   | −6.34 (2.03) ** | −6.49 (2.16) ** |

Standard errors in parentheses. Significance codes ($p <$): *** 0.001, ** 0.01, * 0.05, . 0.1
status in Congress has important implications for the study of legislative organization and party dynamics. It suggests, in particular, that partially-polarized Congresses experience the greatest instability. This relationship might be driven by the strategic behavior of legislators, candidates, and other partisans.

4.5 Discussion

The relationship between modularity and change in majority status is most easily explained by dividing Congresses into three categories—those whose maximum-modularity partition has low, medium, and high modularity scores. Recall that modularity quantifies the strength of the identified communities based on the relative number of intra-group connections versus extra-group connections. We observe that low- and high-modularity Congresses tend to have stable majorities, whereas the majorities in medium-modularity Congresses are less stable.

In low-modularity Congresses, group definitions are weak and (presumably) less salient to political actors. If one imagines Congressional activity as a coordination problem, low-modularity Congresses are those in which coordination takes place between different coalitions on different issues and in which mechanisms to aggregate preferences within groups have little power. In such an environment, the transaction costs involved in collective action are likely to be very high—perhaps high enough that individual legislators see little or no benefit in pursuing more permanent group alliances. As in any collective action problem with high transaction costs, one danger is that individuals will fail to act collectively and government will stagnate. Furthermore, the candidate-centered electoral institutions of the United States (Herrnson 2004, Jacobson 2004) give individual legislators a powerful incentive to pursue particular benefits for their districts in order to win reelection, even at the expense of the public good. Any coordination that is accomplished likely occurs through individual logrolling efforts, pork-barrel projects, and other exchanges of district-level benefits.

High-modularity Congresses have the opposite problem. In such Congresses, group structures are well defined and usually party-oriented. Legislators in these Congresses have solved their coordination problem by coalescing into stable voting blocs, which they use to achieve common goals. However, individual legislators have less freedom to move across groups when group structures are
highly salient. Additionally, strong communities might be salient to members of the public as well as fellow legislators. Thus, defecting from a well-established community might not only result in ostracism from the group but might also be electorally costly. Donors, lobbyists, activists, and other interested parties who have invested time and energy in the development of the existing community structure might be less willing to support a legislator who has broken rank publicly. Loss of active support from activists and elites, in turn, translates into a decreased probability of reelection. We suspect that this pressure to conform drives the decrease in majority status changes that we observe in high-modularity Congresses.

In contrast to both low- and high-modularity Congresses, medium-modularity Congresses reveal environments that are in flux. These Congresses can take one of two forms: They either represent a highly modular environment that is in the process of breaking down or a poorly-structured environment in the process of consolidating. In such environments, when group structures exist but are not well-established, opportunistic politicians have a clear incentive to act strategically in an attempt to control the development of their communities. We suggest that conflict within these coalescing or fracturing communities drives instability that occurs during medium-modularity Congresses, as the communities frequently fracture and reconstitute themselves in the attempt to settle on durable coalitions.

5 Divisiveness, Solidarity, and Reelection

Though the aggregate partisan stability of Congress over time generates interesting results and suggests a general theory about the emergence and disintegration of legislative communities, it does little to reveal the electoral prospects of individual legislators. As a Congress-level variable, maximum modularity is too coarse to apply to legislator-level regressions, and it does not explain why any particular legislator would win or lose an election. However, the group structure revealed by the modularity-maximization process allows us to measure network attributes for each individual within the communities. Here we elaborate two such measures: divisiveness, given by the “community centrality” measure originally proposed by Newman (2006a), and solidarity, a measure designed to explain how much an individual’s voting behavior aligns with his or her group’s voting
behavior.

5.1 Definition of Divisiveness and Solidarity

Mathematically, the *divisiveness* of legislator *i* is measured by the magnitude of a vector \( x_i \), which is calculated through decomposition of the modularity matrix \( B \), with components \( B_{ij} = A_{ij} - \frac{k_i k_j}{2m} \), from equation (2) into a set of eigenvalues, \( \beta_j \), and associated eigenvectors encoded as a matrix with components \( U_{ij} \). From this decomposition, Newman (2006a) defines a set of vertex vectors \( \{ x_i \} \) of dimension \( p \), where \( p \) equals the number of positive eigenvalues of \( B \). The magnitude \( |x_i| \) of each vertex vector measures the potential positive impact on aggregate modularity of each individual legislator *i*. The vector magnitude is calculated using

\[
|x_i|^2 = \sum_{j=1}^{p} (\sqrt{\beta_j} U_{ij})^2
\]  

(with the underlying definition of the vertex vectors given similarly by these components). The divisiveness measure uses the roll-call adjacency matrices to estimate the potential effect that each individual legislator has on the aggregate polarization of his or her body of Congress but not necessarily the alignment of that legislator’s voting behavior to that of his or her own group. Estimating alignment requires us to compare the divisiveness measure with the associated group vector, obtained by summing over all vertex vectors corresponding to members of the group. This is accomplished by calculating the *solidarity*, \( \cos \theta_{ik} \), where \( \theta_{ik} \) is the angle between the vertex vector \( x_i \) and the group vector \( X_k \). When the solidarity is near 1, the legislator and community are in strong alignment; on the other hand, when the solidarity is near 0, the legislator is not strongly aligned with his or her community (Newman 2006a).

5.2 Divisiveness and the “Partial Polarization Hypothesis”

To examine the relationship between divisiveness, solidarity, and reelection, we begin with insights derived from our analyses in Section 4.5 concerning the effect of modularity on changes in the majority party in Congress. These results showed a nonmonotonic relationship between maximum
modularity and the survival of the majority party in Congress, with instability maximized at medium levels of modularity. As we discussed above, this yields our partial polarization hypothesis. We previously suggested that medium levels of modularity are unstable due to ongoing shifts in the group structure of Congress, with some legislative alliances breaking down and others being forged. We now wish to establish a connection between our Congress-level polarization measure (i.e., modularity) and our individual-level divisiveness and solidarity measures. Although we use majority party switches as a measure of political instability at the Congress level, at the legislator level we are able to link modularity and divisiveness directly to reelection probabilities.

In Figure 7 we show a two-dimensional (2D) LOESS plot of the relationship between divisiveness, modularity, and the probability of a legislator being reelected. The contours of this graph reveal a relationship between modularity and divisiveness as they interact to impact reelection. Divisive Congressmen who serve in medium-modularity Congresses are the most likely to fail in their reelection bids. However, in low-modularity Congresses and particularly in high modularity Congresses, divisiveness appears to be a more successful strategy than in the medium-modularity setting. We suspect that divisiveness in low-modularity Congresses remains successful because group solidarity is less valuable in situations in which group structure is not salient. In high-modularity Congresses, by contrast, we suspect that divisiveness is only successful in combination with strong group solidarity, as groups are highly salient in these Congresses and members are likely to be penalized for defecting from their groups. However, in medium-modularity Congresses, when the structure and salience of groups is less clear, we suspect that Congressmen make more errors in their voting decisions because of the more complicated legislative environment, resulting in more reelection failures.

Teasing out the relationship between divisiveness, solidarity, and modularity requires us to examine all three simultaneously. In Figure 8 we present a 2D LOESS plot that demonstrates the relationship between divisiveness, solidarity, and modularity. This figure shows that high-modularity Congresses are characterized by high levels of divisiveness and solidarity, implying that groups are highly structured and polarized in these environments. Importantly, high modularity is only sustained when both divisiveness and solidarity are high. If either divisiveness or solidarity
values dip, one observes a medium-modularity Congress. This suggests that instability in medium-modularity Congresses might be driven either by divisiveness without solidarity or solidarity without divisiveness. That is, in order for a group to be successful, it must be sufficiently divided from the opposition (highly divisive) and internally cohesive (highly solidary).

Having associated (i) medium modularity and high divisiveness with decreased reelection probabilities and (ii) high divisiveness and solidarity with high modularity, our final task is to demonstrate the impact of solidarity and divisiveness on reelection probability. If the partial polarization hypothesis is correct, we should observe that highly divisive Congressmen suffer in their electoral prospects unless they also have high group solidarity. We demonstrate in Figure 9 that this is indeed the case, particularly in the comparison between the middle right region and the upper right corner. Combining this finding with the fact that Congressmen who exhibit high divisiveness and low solidarity typically come from medium-modularity Congresses (recall Figure 8), we find evidence of legislators struggling to forge new groups and sometimes failing. Many legislators in medium-modularity Congresses appear to use votes to form coalitions (i.e., high divisiveness), but when they fail to coalesce into cohesive groups (i.e., low solidarity), their divisiveness cannot be
These figures suggest three hypotheses about the relationship between divisiveness, solidarity, and reelection that would benefit from further statistical analysis in the presence of control variables. First, increasing divisiveness causes a decrease in reelection probability. Second, increasing solidarity increases reelection chances. Finally, the impaired electoral probabilities of highly-divisive legislators can be mitigated if their divisive behavior is consistent with the voting behavior of their community. In other words, we expect a positive association between electoral probabilities and an interaction between divisiveness and solidarity.

5.3 Data and Variables

We test our three hypotheses using a mixed-effects logistic regression specification on data from the 56th–103rd Houses of Representatives. We choose a mixed-effects specification because it allows us to account for the fact that our data exist on multiple levels (Congress and legislator) and over multiple time periods (56th–103rd Congresses). By including random effects for each legislator and Congress, we are able to pool our data across time periods while still calculating accurate standard
Figure 9: [Color online] Two-dimensional LOESS plot of Reelection versus Divisiveness and Group Solidarity. Color transitions from white to red as probability of reelection declines. The lowest reelection rates occur under conditions of high divisiveness and low solidarity, suggesting that highly divisive Congressmen who do not adhere to a community have the hardest time winning reelection.

effects for our fixed-effects variables. Data availability limits our analyses to the 56th–103rd Houses. Data for the Senate and for Congresses 1-55 was not readily available.

Our key dependent variable in these analyses is an indicator for reelection to the House of Representatives, which takes a value of 0 if a legislator runs for reelection and loses and 1 if a legislator runs for reelection and wins. We exclude legislators who choose not to run for reelection or who are defeated in their party’s primary election. Our key independent variables are divisiveness, solidarity, and their interaction. These variables allow us to explicitly test each of our hypotheses. Divisiveness values have been rescaled to the $[0, 1]$ interval to make the regression results easier to interpret (with solidarity by definition in this interval). In addition to our key independent variables, we include several Congress-level and individual-level control variables in our final regression specification. At the Congress level, we control for Presidential election years and divided government. At the individual level, we control for party (Democrat/Republican indicators), partisan extremity (absolute value of first-dimension DW-Nominate score), seniority (number of Congresses served), party unity (McCarty, Poole & Rosenthal 2007), and previous margin of victory (%).
5.4 Analysis

After selecting variables, we evaluated three mixed-effects logistic regression specifications. Unlike our Congress-level regressions, in which we accounted for autocorrelation by including lagged dependent variables, the data for these regressions are measured at two levels—Congress and legislator—and then pooled over time. This data format, which is both cross-sectional and longitudinal, necessitates a model that can appropriately estimate errors for our explanatory variables while accounting for both Congress-level (across individuals) and individual-level (over multiple Congresses) effects. The mixed-effects logistic regression model allows us to account for both Congress-level and individual-level components as random effects by calculating random intercepts for these variables (Gelman & Hill 2007). We draw the random intercepts from a Gaussian distribution with mean 0 and standard deviation equal to that of the variable. The functional form of the model resembles a traditional logit with the random effects as additional parameters:

\[
Pr(y_i = 1) = \text{logit}^{-1}(\alpha_i^{\text{legislator}} + \alpha_i^{\text{Congress}} + \beta_i^{\text{fixed}} + \epsilon_i).
\]

The first specification simply regresses divisiveness and solidarity against our reelection indicator. The results in Table 3 show that divisiveness has a significant, negative impact on reelection chances and that group solidarity has a positive impact. In the second specification, we include a term that couples group solidarity and divisiveness. This model maintains the finding that divisiveness is associated with decreased reelection probability. It also shows that the combination of divisiveness and solidarity has a strong positive impact on reelection, as indicated by the LOESS plots. While the sign of solidarity flips from positive to negative, it is important to remember that the total effect of solidarity must include the interaction term. At even moderately low levels of divisiveness (starting around rescaled values of 0.2 or even lower), the effect of the interaction term exceeds the main solidarity effect, suggesting that most legislators benefit from increased solidarity with their community. Finally, the third specification reveals that the findings are robust to the

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3This interaction variable projects the vertex vector onto the group vector of its associated community, thereby indicating the actual contribution to aggregate modularity made by assigning the legislator to that specific group (Newman 2006a)
|                  | (1)               | (2)             | (3)               |
|------------------|-------------------|-----------------|-------------------|
| Divisiveness     | -4.548 (0.255) ***| -15.873 (1.195) ***| -17.261 (1.209) ***|
| Solidarity       | 1.809 (0.196) *** | -2.651 (0.513) ***| -2.297 (0.535) ***|
| Divisive×Solidarity | 14.166 (1.453) ***| 15.347 (1.463) ***|
| Presidential Year| -0.244 (0.202)    |                 |                   |
| Divided Government| -0.351 (0.214)    |                 |                   |
| Nominate (1st dim.) | 0.978 (0.240) ***|                 |                   |
| Democrat         | -1.383 (0.423) ** |                 |                   |
| Republican       | -1.268 (0.423) ** |                 |                   |
| Seniority        | -0.069 (0.009) ***|                 |                   |
| Party Unity      | -0.008 (0.002) ***|                 |                   |
| Victory Margin   | 0.037 (0.001) *** |                 |                   |
| Intercept        | 2.318 (0.194) *** | 5.814 (0.424) ***| 6.845 (0.620) ***|

Fixed-effects coefficients. Standard errors in parentheses.
Significance codes ($p <$): *** 0.001, ** 0.01, * 0.05, . 0.1
Random intercepts calculated at the Legislator and Congress levels.

Table 3: Mixed-Effects Logistic Regression Results for the 56th–103rd Houses. The dependent variable is reelection to the House. The key independent variables are divisiveness, solidarity, and their interaction. Note that divisiveness and solidarity individually have a negative impact on electoral prospects, but the interaction has a positive impact. This suggests that divisiveness may only be sustained by Congressmen who are also strong members of a community.

inclusion of common controls.

5.5 Discussion

The negative effect of divisiveness, which measures the potential for a Member of Congress to increase the total modularity of a legislature, suggests that it is not beneficial to become too involved in activities that create distinct voting blocs. Voters appear to penalize legislators whose voting records most polarize the Congress. Simultaneously, legislators who show the most solidarity with their communities appear to be protected from this penalty. It remains an open question for future work how this process happens, but one possibility is that polarizing legislators inspire enemies in other groups to work towards their defeat. Without the aid of a well-coordinated group, a divisive legislator will not be reelected.

Our analysis suggests that voters are willing to accept divisiveness from their legislators, but only to the extent that such divisiveness supports a strong group structure. It does not bode well
for reelection when a Congressmen is strongly aligned with a group but also violates acceptable voting behavior for membership in that group. Conversely, Congressmen cannot be highly divisive while simultaneously maintaining independence from a coalition. Only by appropriately balancing group solidarity and individual divisiveness do Congressmen maximize their chances at reelection.

These individual-level results support the Congress-level findings and suggest that there are indeed significant differences in the value of community attachment across different levels of polarization. In low-polarization environments characterized by the politics of logrolling and poorly-organized leadership, being a member of a group is positive. However, being too strongly attached to Congress as a whole is negative, suggesting that legislators in low-polarization environments are expected by their constituents to pursue constituency interests first and foremost. (In this case, legislators should recall Tip O’Neill’s adage that “All politics is local.”) However, in partially-polarized Congresses, when group structures exist but are either not fully established or are breaking down, legislators face a complex environment in which their choices about legislative alliance are subject to greater error and thus greater risk. Nevertheless, in such environments, it can be beneficial to effectively balance commitments to community with other concerns. In highly-polarized Congresses, the environment is more stable and the benefits and perils of alliance accrue primarily to those in the largest community, though legislators with high divisiveness are still generally penalized unless they are firmly embedded in their communities.

6 Conclusions

In this paper, we have presented a conceptually-clear measure of fractionalization and partisan polarization in Congress using roll-call voting data and the network-science concept of graph modularity. We use computational heuristics to calculate the community structure that maximizes modularity, thereby obtaining the membership and strength of communities in Congress. Because calculating modularity requires no assumptions about the structure of the party system or the nature of legislator preferences, we argue that it offers a clearer and more parsimonious measure of polarization than the (MPR) measure based on DW-Nominate that currently dominates the literature.
Unlike the measure based on DW-Nominate, the modularity-based measure can also be directly applied to pre-Reconstruction Congresses, thereby allowing investigation of polarization across a broader historical range. Here we investigated the quantitative similarities and differences between the two measures and demonstrated that there exists a nonmonotonic relationship between modularity and changes in the majority party in both chambers of Congress, which suggests that there exists a level of polarization at which party instability is maximal. We further examine this “partial polarization hypothesis” using two measures of community centrality—divisiveness and solidarity—which capture the individual-level impacts of legislative alliances on reelection chances for House members. Our results demonstrate the potential importance of the modularity-based polarization measure and call for additional in-depth analyses of Congressional polarization.

The introduction of modularity and its allied concepts of divisiveness and solidarity to the analysis of Congressional behavior has the potential to fundamentally alter the study of group dynamics and partisanship in legislatures. Researchers have long sought to separate the effects of party on voting behavior from electoral, interest group, and other pressures. These studies have either assumed the existence of parties and their concomitant structure (Cox & McCubbins 1993, Poole & Rosenthal 1997, McCarty, Poole & Rosenthal 2007) or assumed an alternate legislative ordering mechanism such as committees (Shepsle 1979) or institutionally-derived pivotal members (Krehbiel 1998, Tsebelis 2002), and then proceeded to make arguments about implications for the structure of roll-call voting. Typically, in these cases, the organizational mechanism—be it parties, committees, or veto pivots—is considered in isolation. Our results suggest that the complexities of Congressional behavior are not captured by the implications of any particular idealized model of legislative organization. Rather, by making simple assumptions about the nature of group strength, we are able to partition Congressmen into groups while remaining agnostic about any particular mechanism. We measure the strength of that group structure using modularity and the positioning of legislators within that structure using divisiveness and solidarity.

By its nature, modularity cannot offer a causal link between community strength in Congress \( t \) and majority party switch in Congress \( t + 1 \). However, it does provide a benchmark measure of voting polarization against which to compare alternate legislative orderings. By comparing
the modularity values of party divisions, committee divisions, or other exogenously-determined structures to the group structure revealed by modularity maximization, one might be able to identify the environmental and strategic conditions under which particular organizational concepts are likely to succeed and fail, allowing one to disentangle the complex interplay of environmental, ideological, and institutional pressures that impact the structure of the Congressional voting record.

Furthermore, although the task of establishing such a causal mechanism is left to future research, the strong correlation that our analysis reveals implies that this link takes place primarily in the electoral arena. We hypothesize that the community structure of Congress in term $t$ exerts a strong influence on the behavior of donors, candidates, party organizations, and activists. It causes them to strategically invest their energy either in preserving the existing order or in attempting to create a new order. We suggest that the willingness of political opportunists to pursue a new order depends on the presence of a community structure that is neither too strong to break nor too weak to identify. In future work, we intend to gain traction on this problem by examining the impact of modularity on the behavior of actors in Congressional elections. Meanwhile, we hope that other scholars will build on the efforts presented herein and use network science to explore the dynamics of coalition formation in the U. S. Congress and in other legislatures around the world.

7 Appendix: Changes in Majority Status

In this appendix, we present tables that summarize the changes in majority party in the House of Representatives (in Table 4) and Senate (in Table 5).
Table 4: Changes in Majority Status in the House of Representatives.

| Congress | Old Majority     | New Majority        |
|----------|------------------|---------------------|
| 3        | Federalist       | Democratic-Republican |
| 4        | Democratic-Republican | Federalist           |
| 7        | Federalist       | Democratic-Republican |
| 19       | Democratic-Republican | Adams               |
| 20       | Adams            | Jacksonian           |
| 25       | Jacksonian       | Democratic           |
| 27       | Democratic       | Whig                 |
| 28       | Whig             | Democratic           |
| 30       | Democratic       | Whig                 |
| 31       | Whig             | Democratic           |
| 34       | Democratic       | Republican           |
| 35       | Republican       | Democratic           |
| 36       | Democratic       | Republican           |
| 44       | Republican       | Democratic           |
| 47       | Democratic       | Republican           |
| 48       | Republican       | Democratic           |
| 51       | Democratic       | Republican           |
| 52       | Republican       | Democratic           |
| 54       | Democratic       | Republican           |
| 62       | Republican       | Democratic           |
| 66       | Democratic       | Republican           |
| 72       | Republican       | Democratic           |
| 80       | Democratic       | Republican           |
| 81       | Republican       | Democratic           |
| 83       | Democratic       | Republican           |
| 84       | Republican       | Democratic           |
| 104      | Democratic       | Republican           |

*Note: We don’t code the Republican’s temporary change of name during the Civil War Period as a majority switch.*
Table 5: Changes in Majority Status in the Senate.

| Congress | Old Majority       | New Majority       |
|----------|--------------------|--------------------|
| 7        | Federalist         | Democratic-Republican |
| 19       | Democratic-Republican | Administration (Adams) |
| 20       | Administration (Adams) | Jacksonian |
| 23       | Democratic         | Anti-Jacksonian |
| 24       | Anti-Jacksonian    | Jacksonian |
| 25       | Jacksonian         | Democratic |
| 27       | Democratic         | Whig |
| 29       | Whig               | Democratic |
| 37       | Democratic         | Republican |
| 46       | Republican         | Democratic |
| 47       | Democratic         | Republican |
| 53       | Republican         | Democratic |
| 54       | Democratic         | Republican |
| 63       | Republican         | Democratic |
| 64       | Democratic         | Republican |
| 66       | Republican         | Democratic |
| 73       | Democratic         | Republican |
| 80       | Republican         | Democratic |
| 81       | Democratic         | Republican |
| 83       | Republican         | Democratic |
| 84       | Democratic         | Republican |
| 97       | Republican         | Democratic |
| 100      | Democratic         | Republican |
| 104      | Republican         | Democratic |
| 107      | Democratic         | Republican |
| 108      | Republican         | Democratic |

**Note**: We don’t code the Republican’s temporary change of name during the Civil War Period as a majority switch.

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