Structural Balance and Signed International Relations

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Abstract

We use balance theoretic ideas to study the dynamics of the international system of nations in a network of signed relations from 1946 through 1999. Using the Correlates of War data for this period, we apply pre-specified signed blockmodeling to characterize the fundamental structure of this network. Even though the system expanded greatly with many ties being created and/or destroyed, the basic structure remained the same but with new positions being added over time. The blockmodels generated temporal measures of imbalance, as did the counts of imbalanced triples. Regardless of using the line index of imbalance or the number of imbalanced 3-cycles, the results provided decisive evidence contradicting the balance theoretic hypothesis of signed networks moving towards balanced states. Structural balance theory remains very useful by pointing to the more important study of how and why signed networks move towards and away from balance at different points over time. Some major methodological problems for studying signed networks, regardless of whether they involve nations or human actors, were raised and addressed. Proposals for future research are suggested for modeling and understanding the dynamics of signed networks.

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1. Introduction

A considerable effort (see below) has gone into the study of international relations between nations as sovereign entities.[1] This work has included the use of structural balance theory for signed social relations in the version based on the work of Heider (1946) and its formalization by Cartwright and Harary (1956). Within the structural balance approach there are several prominent concerns. Given a definition of a balanced network (defined below), one is whether an empirical signed network is balanced or not. A second concern, for imbalanced networks, is to measure the extent to which they depart from being balanced. A third concern is to understand the dynamics of movement towards (or away from) balance with the presumption that signed networks move towards a balanced state.[2] Using balance theory to study international relations was a natural application. Here, we consider these three concerns but use temporal global signed networks rather than partial networks for local regions for a particular point in time. This permits a more extensive study of the dynamics of structural balance and sheds considerable light on the dynamics of international signed relations.

Our primary objective was to apply structural balance theory to the signed networks of states from 1946 through 1999 in order to study the evolution of this network as it expanded in size to 64 states to a high of 155 states. In addition to changing size of the network, ties were created, dropped or changed in sign for states already in the network. Section 2 provides an outline of the key balance theoretic ideas informing this study. In Section 3, a variety of broad general theoretical approaches to studying the system of nations are presented. While these theories are seen as rivals to each other, we did not intend to enter the many debates about how nations behave and how the overall system operates. Nor did we see balance theoretic ideas as necessarily antithetical to those endeavors. However, given our results, we were drawn into these substantive debates. Section 4 contains a description of the data we used and the methods we employed. Signed blockmodeling results are reported in Section 5. They reveal the overall structure of the evolving network as it expanded. Section 6 presents measures of imbalance through time along with discussion of them. Overall summaries of our results are given in Section 7. A discussion of their implications for future work concludes our presentation in Section 8.

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[1] Henceforth, we use nation and state interchangeably.

[2] Marvel et al. (2011) claim "Structural balance is a static theory—posits what a 'stable' signing of a social network should look like." This is largely incorrect. In the foundational statement of structural balance, Heider (1946) was concerned with forces inducing change in signed social relations. Cartwright and Harary (1956) stated what the partition structure would be if the network was perfectly balanced. There was no claim about an ideal state.

2. Balance Theoretic Ideas

Although there have been a variety of approaches to studying signed relations among human actors, Heider (1946, 1958) is credited with the first systematic statement of consistency theories (Taylor, 1970). His early statement provided the foundation for the Cartwright and Harary (1956) and Davis (1967) formalizations creating the two structure theorems that became the foundation for a fruitful approach for studying signed networks (Doreian and Mrvar, 1996). They drive the blockmodeling approach for partitioning signed relations described in Section 4.2. Of critical concern in the early work was the extent to which signed structures were balanced or consistent with regard to the pattern of signs. Ways of doing this are described in Section 2.2. The results of some earlier empirical work based on balance theoretic ideas is described in Section 2.3.

2.1 Foundations

The core ideas of Heider (1946) are located in triples of actors, denoted by *p, o,* and *q,* as shown in Figure 1. A triple consists of the ties *p → o, o → q* and *p → q.* These are the eight possible *poq*-triples where solid lines represent positive ties and dashed lines represent negative ties. The sign of a *poq*-triple is the product of the signs in the triple. A *poq*-triple is balanced if its sign is positive and imbalanced if its sign is negative. A complete signed network is balanced if all its triples are balanced. Figure 1 shows the four possible balanced triples in the top row and the four possible imbalanced triples in the bottom row. Cartwright and Harary (1956) proved a complete balanced signed network can be partitioned into two subsets such that all positive ties are within these subsets and all negative ties are between subsets. Davis (1967) extended this result to one having multiple subsets with this pattern of signed ties by redefining the all-negative triple as balanced. Doreian and Mrvar (1996) introduced the terminology of *k*-balance where *k* is the number of clusters. For *k*= 2 it is the Cartwright and Harary version and for *k* > 2 it is the Davis version.
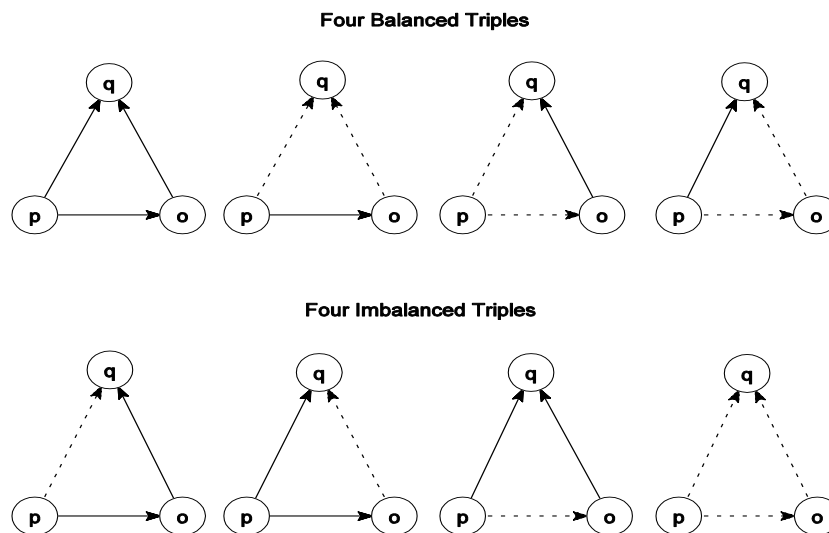

Figure 1. The eight signed triples in Heider's formulation of structural balance theory

2.2 Measuring Imbalance in signed networks

There are two ways of measuring the imbalance in signed networks. One uses counts of triples or of cycles or semi-cycles (depending on whether the network is undirected of directed)[3] while the other is based on the blockmodeling approach which works in the same fashion for all signed networks. Both approaches are less than straightforward when signed networks are large. Triples (and semi-cycles) are considered for directed signed networks and cycles for undirected signed networks. One form of an imbalance measure is the proportion of balanced triples or cycles in the network. The blockmodeling measure is the number of lines inconsistent with a blockmodel for a balanced network when a signed blockmodel is fitted. In essence, this is the line index of balance introduced by Harary *et al.* (1965): The line index is the smallest number of lines whose removal (or change of sign) creates a balanced network. In general, determining this index is a polynomial-time hard problem. Counting all cycles in an undirected network is computationally complex also. Even when this is completed, there is the issue of how to weight cycles of different lengths. A much simpler measure is to count only triples in directed networks, or 3-cycles in undirected networks, and compute the proportion of balanced triples or 3-cycles. Ways of doing this are described in Section 4.3.

2.3 Empirical Applications

Our goal here is not to provide a survey of the many empirical examples applying structural balance to signed networks of human actors. Rather, our focus is on one central substantive concern running through these applications. Based on Heider's intuition that achieving balance in a signed triple resolves tensions for the actors involved, the presumption has been that signed networks move towards a balanced state over time. Assessing this claim requires temporal data, a feature missing from most applications of structural balance theory. When this issue has been studied with temporal data, the evidence has been mixed regarding a universal tendency towards balance. See, for example, Doreian *et al.* (1996) for a partial statement.

Using longitudinal data from the well-known Newcomb study (Nordlie, 1958), Doreian and Krackhardt (2001) examined the distributions of the triples shown in Figure 1 over time. If there is a universal tendency towards balance, it is reasonable to expect all of the balanced triples will become more frequent over time while all of the imbalanced triples will become less frequent. However, they found two of the balanced triples became *less frequent* and two of the imbalanced triples became *more frequent* over time. Although the line index of imbalance declined overall these drops were not monotonic. It was clear that a uniform tendency towards balance was illusory. At best, there were multiple mechanisms in play whose behavior need not be consistent. Abel and Ludwig (2009) note that change in one triple or 3-cycle to achieve balance can trigger changes in other triples of 3-cycles rendering them imbalanced. Changes towards balance need not be consistent nor uniform. Hummon and Doreian (2003) simulated actors behaving *exactly* as envisioned by Heider in groups of various sizes under a variety of starting conditions. The through time trajectories of signed structures were long, with many of the simulated groups *not* achieving balance. As shown below, signed relations among nation states do not move uniformly towards balance. Nor was it ever achieved in this system. This basic, intuitively plausible, hypothesis has seldom been supported in an unequivocal fashion when temporal empirical data were considered.

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[3] For three vertices, *p, o* and *q*, a cycle is a sequence of arcs $p \rightarrow o, o \rightarrow q, q \rightarrow p$. The starting and ending vertices of the cycle are the same, in contrast to triples. The concept extends to cycles of any length in a natural way. The same extends to undirected networks. For semi-cycles, the direction of the arcs is ignored for directed networks.

3. Structural Balance and International Relations

Our focus here is on using structural balance theoretic ideas as a way of examining signed international relations. However, we are mindful of alternative conceptions for studying international relations and outline some of them briefly in Section 3.1 before moving to a discussion of signed ties in Section 3.2. Applying balance theoretic ideas for studying the world composed of nations is described in Section 3.3.

3.1 General Approaches to International Relations

As noted by Healy and Stein (1973), the study of the balance of power is very old, dating back at least to Ancient Greece. Theories abound even though, or perhaps because of, the concept of 'balance of power' has been vague and inconsistent both in its definition and application. There are many, indeed a dizzying array of, broader theoretical frameworks for studying international relations including realist and neorealist approaches, liberal and neoliberal approaches plus constructivist, functionalist and institutionalist perspectives.

Realists posit nation-states as the primary actors operating in an anarchic international system in which no authoritative overall government exists. In such a world, each state pursues its own interests by competing with other states to ensure control over resources important to it while ensuring its own survival. Outcomes for a state are the result of its power relative to the power of other states. In this kind of world order, states are the primary actors with intergovernmental organizations (IGOs) and non-governmental organizations (NGOs) either secondary actors or merely reflective of the powers of the states in them. Neorealism is a modified version in which the structure of the world order also constrains state behavior (Waltz, 1979). While the anarchy of the world system is retained, Waltz expanded the notion of power to include broader state capabilities not limited solely to raw power.

Liberal thinking about international relations takes a different tack. Within this perspective, the preferences of states are the primary determinants of state behavior. These preferences vary across states depending on their types of government, their economic systems and their cultures, broadly construed. Accordingly, this allows room for cooperation between states with state's interests shaped by the structure of international relations (Moravcik, 1997). Under a neoliberal formulation, interdependence and cooperation are stressed for facilitating trade, cooperation given similar preferences and trying to ensure peaceful resolutions of conflict. A clear role for IGOs and NGOs is included.

According to Hopf (1998), adherents of constructivism locate their work between the realist and liberal approaches. Barnett (2011) argues that ideas take central stage by viewing structure through the operation of persuasive ideas, collective values, culture and social identities. Constructivists claim social norms increasingly shape policies rather than resource or security concerns.

Functionalism as a theory of international relations gives primacy to the operation of the international system to create order according the needs of the overall system. See Mitrany (1933, 1948) and Wolf (1973). Operationally, common interests shared by states drive integration in a cumulative fashion. As a part of this, globalization is viewed as a process creating international order. In essence, the needs of the *system* dominate the interests of state actors where the incentives of national actors conform to norms dictated by the operation of the international system as whole.

An institution is a persistent structure or social order governing the behavior of all actors within a particular community. Institutions are thought to have laws as a formal mechanism for creating rules and possessing ways of enforcing them. Institutional power assumes having enforceable rights (Lenski, 1996). From the institutionalist perspective, institutions are deemed to have some social purpose with operational rules governing behavior. When this approach is focused on the international community of nations, it comes very close to a functionalist approach.

Adherents of these rival frameworks debate their relative merits and, in doing so, assemble evidence purporting to support their own approach against claims made by their rivals. The overall outcome is mixed regarding their predictions because different theorists raise different issues, focus selectively on evidence and consider different time periods in seeking support for their approaches. Using examples, Wimmer and Min (2006) point to short term studies of the order of two or five years as problematic. Also, many studies focus on specific conflicts in particular locations while ignoring the wider contexts of these conflicts. Their own study of war adopted a longer time frame (1881-2001) with a focus on broad regions and actors. We sought a middle ground by using a shorter, but still long, term view (1946-1999) and considered the world as a whole. As a background to this effort, we specify specific forms of signed ties between states.

3.2 Signed ties between nation states

We consider negative (conflictual) ties before examining positive ties. Conflicts between states are global, regional and/or local. Most of the period we study was dominated by the global clash between the USA and the USSR, two so-called 'super powers' seeking to expand their influence and access to resources while attempting to restrict the same efforts by their global rival. Their behavior appears to conform to the realist perspective. At a different level, the quintessential local conflicts are border disputes. Mandel (1980) examined when they are likely to arise, when they escalate and the likelihood of them spreading to involve other nations. Among the predictors he used were power disparities between states, their technological levels, the nature of their disagreements and the international alignment of states. When border disputes expand they become regional. Another source of regional conflict occurs when proxy wars are fought as 'smaller' nations become embroiled in globally driven conflict.

Diehl and Goetz (1988, 1991) examined conflict and territorial exchanges. Among the primary sources of these conflicts was territorial expansion by one or more states. Such expansions can be driven by economic pressures, security concerns, a desire to establish greater dominance, and also to unite people with a particular ethnic heritage or people with the same national origin within a common territory. Mandel (1980) argued that local border disputes have to be disentangled from global conflicts for a better understanding of them. Operationally, this entailed a focus on disputes over land borders while including rivers as international borders. This implied the use of restricted databases suited to the hypotheses in question. While useful for their intended purposes, such studies tend to ignore wider regional or global conflicts. It seems impossible to divide local, regional and global disputes cleanly. Instead, we simply include both local and global disputes as negative ties by including them in the international system as a whole but without differentiating them in our analyses of the data. However, interpreting the results requires a consideration of the different types of conflicts.

Positive ties take the form of alliances, ideological agreements and memberships in intergovernmental organizations (IGOs). An IGO is an organization with three primary features: being an explicit creation having nations as its members; having a permanent secretariat and having a headquarters and/or a permanent staff (Pevehouse *et al.*, 2004). Ingram *et al.* (2005)

add three criteria: an IGO has at least three members; it is formed through a treaty; and meets regularly.

IGOs are thought to have impacts in a variety of international arenas. One is the promotion of peace and non-violent resolution of conflicts (Boehmer *et al*, 2004). Pevehouse *et al.* (2004) note the results for this proposition are mixed, consistent with the disagreements between the disputing broad approaches listed in Section 3.1. They noted the results of Jacobson *et al.* (1986) who found memberships in multiple IGOs did not induce states to be less prone to engaging in warfare. More importantly for our analysis, they found different periods varied with regard to the general idea of IGOs membership affecting the likelihood of engaging in conflict. Diehl and Goetz (1991) note also the variation in the levels of border disputes following WWII.

Hafner-Burton and Montgomery (2006) add cooperation designed to promote peace as another potential consequence of IGO memberships. Again, the evidence for this impact was mixed. Ingram et al. (2005) examined the proposition claiming IGO memberships help in promoting trade between nations. They show the evidence in support of this proposition also fell short of documenting a clear link between IGO membership and increased trade. It is not surprising that scholars working within the theoretical frameworks outlined briefly in Section 3.1 seldom find much common ground. In part, this is due to stressing differences between rival approaches rather than their communalities. However, despite these disagreements, the overwhelming majority of these scholars do agree about IGO memberships creating network ties between states. They disagree on what the implications, if any, are for determining outcomes. Ingram et al. (2005) note most studies seldom pay attention to the operational links between international institutions and the networks they may create. From a structural perspective, these ties are more important in their own right than thinking of their numbers as a part of national attributes. We give these ties primacy in our analyses.

Pevehouse *et al.* (2004) noted the growth in the number of IGOs both at the global and regional levels, as do other authors studying the impacts of IGO memberships. They argue IGOs cannot be ignored. Indeed, this one of their motivations for creating the Correlates of War (CoW) database. As a result, we use IGO membership as one of the operationalizations of a positive tie between states in addition to formal treaties.

We turn now to consider earlier attempts applying structural balance theory to international relations.

3.3 Applying balance theoretic ideas to signed relations between nations

As relations between states, in principle, can be coded as positive or negative, it seemed natural to use signed networks featuring states for an application of balance theoretic ideas. Balance theory can provide also an organizing framework for studying these signed networks. Harary (1961) contributed an early example of this approach. He focused on the Middle East in 1956. The actors he included were Egypt, 'the other Arab countries', Great Britain, Canada, France, Israel, India, USA, USSR and Hungary. He coupled specific events and actions by states, especially the nationalization of the Suez Canal by Egypt, to assemble a sequence of signed networks featuring this (rather arbitrary) set of 'states'. Despite an emphasis on movement towards balance, one sequence of his figures showed movement to a balanced configuration and then movement away from it. We view this is an important, but overlooked, result for showing balanced configurations need not be stable. Another analysis of Harary's analyses of a different Middle East conflict focused on the subset: Great Britain, France, Israel, USA, USSR, Egypt and 'the other Arab states'

to describe a balanced network.

Moore (1978) focused on events reported in the New York Times during 1956-57 regarding the Middle East for an expanded set of 20 actors. Strangely, one of them was the Baghdad Pact, a formal pro-Western alliance of Turkey, Iraq, Iran, Pakistan, and Great Britain. Yet all of these members were included also as nations. Again, there was a focus on movement towards balance. Moore (1979) applied balance theoretic ideas to data on events culled from the New York Times Index for 1966, 1969, 1972 and 1976 for some international conflicts. One was the 1975 Angolan civil war featuring 16 actors. Of these, 13 were nations and three were insurgent movements seeking to overthrow the Angolan government also included without considering the ties between these rival movements beyond assuming they supported each other.[4] The only non-African states were Cuba, the USA and the USSR. The depicted network was balanced. Another 'network' regarding the 1968 Warsaw Pact invasion of Czechoslovakia had Warsaw Pact, Czechoslovakia, United Kingdom and 'Communist Bloc critics' as the four units with an alleged sequence of signed events driving relations. Again, balance was seen as evident.

Healy and Stein provided a detailed study of Europe from 1870 to 1881 under the so-called Bismarckian system. They tested a variety of hypotheses regarding the closeness of alliances and their actions, the existence of prominence in systems, coalitions forming to oppose the rise of dominant states, the choice of role partners in a multipolar system and the role of structural balance. Most of the propositions they outlined 'did not hold up well under detailed testing' (1973:33) although they claimed some support for structural balance theory. More specifically, they found unbalanced 'weak' cycles were subject to change while 'strong' cycles were the most stable.

Alas, while suggestive, these studies were far from being satisfactory for a variety of reasons. First, the selection of actors was often arbitrary, overly restricted or featured a mixture of states and sets of states containing states as separate actors in the networks. Second, specific short time periods were selected and studied without being attentive to the wider context in a systematic fashion. Third, it was assumed that longer temporal contexts were of little relevance. Fourth, the relations depicted were constructed through coding selected specific events or woven out of whole cloth. All claims about movement towards a balanced state appear to receive support by restricting the data severely—either through the selection of states or restricting the time—with a bias towards selecting acute events that *might* be expected to establish balance. Despite mentions of 'international relations', the studies were local and separated from broader temporal and geographical contexts.

It seems more reasonable to consider the whole international system of nations over a longer time frame using a consistent way of coding the signed relations between nations.

Data and methods

A very useful data set meeting the above criteria comes from the Correlates of War (CoW) project (http://www.correlatesofwar.org/). They are described briefly in Section 4.1. Section 4.2 outlines modifications to the signed blockmodel procedure to accommodate the analysis of signed international relations data. Of particular importance is the use of pre-specification of blockmodels (Doreian *et al.* 2005: 349-352) as described in Section 4.2. Section 4.3 presents ways

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[4] Given multiple movements seeking to topple a government, it is highly unlikely the ties between them are always positive because they each seek to dominate whatever new government forms.

of using fragments, as implemented in Pajek (Batagelj and Mrvar, 1998), to identify and count all 3-cycles in order to obtain a measure of imbalance.

3.4 The Correlates of War (CoW) data

The data used here feature nations in the world system following WWII.[5] The data cover 1946 through 1999. There were several alternatives for defining these data in terms of units and ties. Although Wimmer and Min (2006) also started by using the CoW data, they took issue with the notion of states being treated as continuous, relatively stable entities in the international order. They argued that territorial domains can change dramatically over time. They defined units in terms of geographic space rather than nation labels. We opted to use the nations as defined in the CoW data while being cognizant of some entities breaking up or being unified over time.

Another issue concerns the treatment of time with at least two options. One is to use the annual data as provided by CoW with the second being the use of a short sliding window in order to ensure the blockmodeling results are less affected by unusual very short term fluctuations and data errors. We opted for the latter by using a sliding window (Doreian, 1980) with a four-year width. See also Batagelj *et al.*, 2014: Chapter 5) for another sliding window application. There are 51 such windows of signed network data for this period with successive pairs overlapping. Consistent with the arguments in Section 3.3: i) positive ties are defined by joint memberships in alliances, being in unions of states and sharing inter-governmental agreements; ii) negative ties are for two states being at war, or in conflict with each other without military involvement, or being involved in border disputes or having sharp ideological or policy disagreements; iii) when there is a negative tie between states that otherwise have a positive tie, the negative tie is used.

Table 1. Through time sizes of the world system signed network

Window	Number of Nations	Number of Positive Ties	Number of Negative Ties	Count of all ties
1946-1949	64	320	42	362
1947-1950	66	320	56	376
1948-1951	68	374	76	423
1949-1952	70	347	74	421
1950-1953	72	361	76	437
1951-1954	66	320	56	376
1952-1955	75	409	82	491
1953-1956	79	416	113	529
1954-1957	80	418	74	492
1955-1958	81	426	84	510
1956-1959	81	419	89	508
1957-1960	91	431	90	521
1958-1961	103	506	108	614
1959-1962	104	515	111	626
1960-1963	105	536	114	650
1961-1964	106	539	109	648
1962-1965	109	540	102	642
1963-1966	109	532	94	626
1964-1967	112	578	95	673
1965-1968	107	489	101	590
1966-1969	111	504	103	607
1967-1970	109	502	98	600
1968-1971	113	577	93	670
1969-1972	113	575	88	663
1970-1973	111	595	82	677

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[5] The data were provided to us by Daniel Halgin of the Links Program at the University of Kentucky. They were constructed as part of a large project on signed networks. His generosity is appreciated greatly.

1971-1974	114	614	83	697
1972-1975	119	637	88	725
1973-1976	121	642	98	740
1974-1977	123	699	114	813
1975-1978	130	796	114	910
1976-1979	132	852	116	968
1977-1980	130	850	108	958
1978-1981	134	907	92	999
1979-1982	137	933	92	1025
1980-1983	135	906	105	1011
1981-1984	137	934	104	1038
1982-1985	136	935	108	1043
1983-1986	138	932	113	1045
1984-1987	139	934	107	1041
1985-1988	139	940	95	1035
1986-1989	139	989	90	1079
1987-1990	139	1112	103	1215
1988-1991	141	1179	95	1274
1989-1992	151	1183	102	1285
1990-1993	155	1160	128	1288
1991-1994	155	1101	145	1246
1992-1995	153	1049	129	1178
1993-1996	148	1048	133	1181
1994-1997	150	1099	125	1224
1995-1998	150	1106	124	1230
1996-1999	151	1100	147	1247

These data are far more complicated than previously used datasets for studying structural balance in international relations. The dimensions of these networks through time are shown in Table 1. These numbers change dramatically. This network was smallest in 1946-49 with 64 nations and 362 dyadic ties. Its maximum size was in 1990-93 with 155 nations and 1288 dyadic ties. There were always far more positive ties than negative ties. Given the high number of alliances and inter-governmental alliances this is not surprising. The reasons for the data being more complex than those used in the studies described in Section 3.3 are clear. First, by covering the globe, these datasets are much larger. Second, the size of the system changes dramatically over the 50 years as new nations become independent and former units, notably the USSR and the former Yugoslavia broke up. Also, new states appeared, for example the unification of East Germany and West Germany to create Germany. Third, the signed data reflect both global and local processes. Rather than separate specific regions and short periods, e.g. the Middle East in 1956 or Czechoslovakia in 1968, for separate analyses, the international system as a whole was studied over half a century.

We consider positive and negative ties separately in addition to jointly when considering balance. We view the negative ties as the more interesting and more consequential due to their potential for disrupting the status quo. If the network had only positive ties, then the international order would be one of peaceful coexistence. Conflicts disrupt this—with history being full of them— consistent with the realist perspective. These conflicts can be local or global. Global conflicts can have also local consequences, especially in the form of proxy-wars, struggles to control resources or when large external states intervene by overthrowing local governments or attempting to do so. We do not discount positive ties and discuss the relative costs of forming positive and negative ties below. The distribution of negative ties in the international system are shown in Figure 2.

The lowest number of negative ties (42) came at the beginning in 1946 but jumped immediately. As the system expanded so did the number of negative (and positive) ties but not in a uniform way. The highest levels of negative ties occur from 1990 through 1996 with levels of 147 (1996); 145 (1991), 133 (1993), 129 (1992), 128 (1990) and 125 (1994). The remaining peaks are 116

(1976—with 1974 and 1975 being high and at 114 (1983) with 1982 and 1984 being similarly high.

Some of these peaks guided our choice of the blockmodels shown in Section 5.[6] There were also some local valleys. These changes focus on the *number* of negative ties but they do not indicate which states were tied to each other by negative ties.
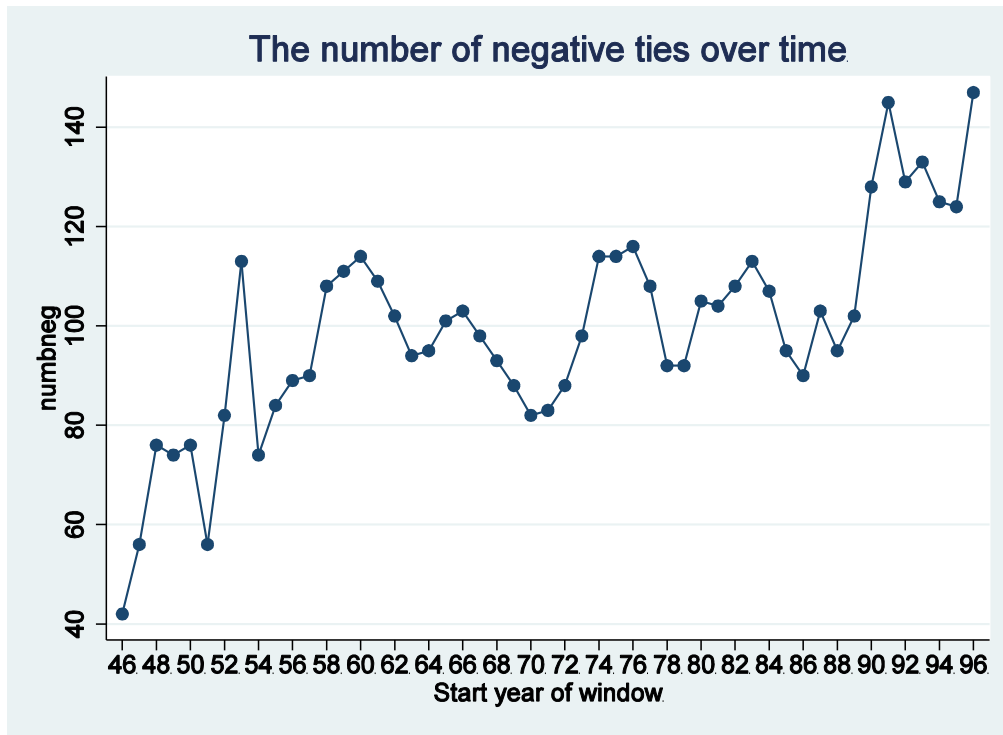

Figure 2. The distribution of negative ties through time for 1946-1999

This structural feature is shown in Movie 1 for all 51 windows.[7] We recommend copying the URL and pasting it into a web browser.

http://mrvar.fdv.uni-lj.si/pajek/SVG/CoW/

Movie 1. The network with only negative ties over time

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[6] A total of 51 blockmodels were fitted. There is no space to show them all. They are all consistent with our general narrative.

[7] This movie captures well the negative relations over time. The corresponding movie including both positive and negative ties is extremely slow given the preponderance of positive ties in the network. It is omitted. Even showing only the positive ties through time is far too slow.

(Control) clicking on this link will take viewers to the website containing this movie.[8] There is far more information in the movie than can be contained in a few paragraphs. Across the bottom of the display is an indicator of the years for each window that can be coupled to each network as the transformations occur in the structure. In general, there is one larger component plus some smaller components. The large component connected by negative ties changes in size, but over the long haul, the world is increasingly connected through negative ties *in addition* to positive ties.

There are also some dyads not connected to the rest of the structure depicted as it changes. We emphasize again that the movie contains *only* the negative ties over time. The nations in these dyads, in general, are connected to other states in the system through positive ties. Nearly all of these separated dyads with negative ties involve nations sharing a border. These include, at various time points: {Argentina, Chile}; {Argentina, Paraguay}, {Bolivia, Chile}, {Chile and Peru}; {Costa Rica and Nicaragua}; {Ecuador, Peru}; {Guatemala, Mexico}; {Guyana and Venezuela} and {Honduras and Nicaragua} in South America. Similarly, in Africa there are the dyads {Burkina Faso, Chad}; {Burundi, Rwanda}; {Cameroon, Chad}; {Cameroon, Gabon}; {Central African Republic, Chad}; {Chad, Sudan}; {Gambia, Guinea} and {Ghana, Togo}. Sharing a border implies these negative ties on both continents involve border disputes when other states are not involved. The same holds in Asia: {Afghanistan, India}; {Afghanistan, Pakistan}; {China, India}; {India, Pakistan} and {Laos, Vietnam}. Some of these ties involve longstanding animosities.

There are also conflictual dyads reflective of former colonial ties including {Indonesia, Netherlands}, {Morocco, Spain} and {Indonesia, Papua-New Guinea}. European states also have negative ties involving borders: {Albania, Yugoslavia}; {Austria, Yugoslavia}; {Greece, Turkey}; {Hungary, Yugoslavia}; {Italy, Yugoslavia (allowing for a maritime boundary)}; {Lichtenstein, Switzerland}; and {Turkey, Cyprus}. Again, some of these negative ties are not short term.

The sequence of figures for these negative ties[9] make it clear that certain nations are involved at some time points, and over the long term, in unusually large numbers of negative relations with other nations. This includes the USA and the USSR, China and North Korea plus Iran and Iraq. We pursue this further in Section 6.3.

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[8] Currently, this movie can be viewed in Internet Explorer, Chrome or Firefox. Prior to seeing the movie, the cited website provides brief descriptions of some differences regarding speed depending on which browser is used. The overall impressions of changes are still clear regardless of the browser used. Patience is needed at the beginning of this movie while it loads. Once the initial vertices are present and labeled the progression of images is rapid.

[9] For those finding this movie interesting, we recommend watching it multiple times to focus on different features including particular nations, pairs of nations and regions.

3.5 Pre-specified blockmodeling

There are two broad approaches for partitioning such signed networks. One is signed blockmodeling (Doreian and Mrvar: 1996, 2009) with the other being a variant of community detection (Traag and Bruggeman, 2009). In their unmodified forms, both fail as is shown in Figures 3 and 4 using data from the first window (1946-49), for the system at its smallest.

Figure 3 shows the best relaxed structural balance[10] partition with $k = 9$. This partition fails because it clusters all states in the Western Bloc with nations from South America due to their positive links to the USA. The resulting positive block is far too large and is not reflective of a real divide between these two clusters of states. This holds, albeit to a lesser extent, for nations in the Middle East. This problem was evident in all subsequent windows.
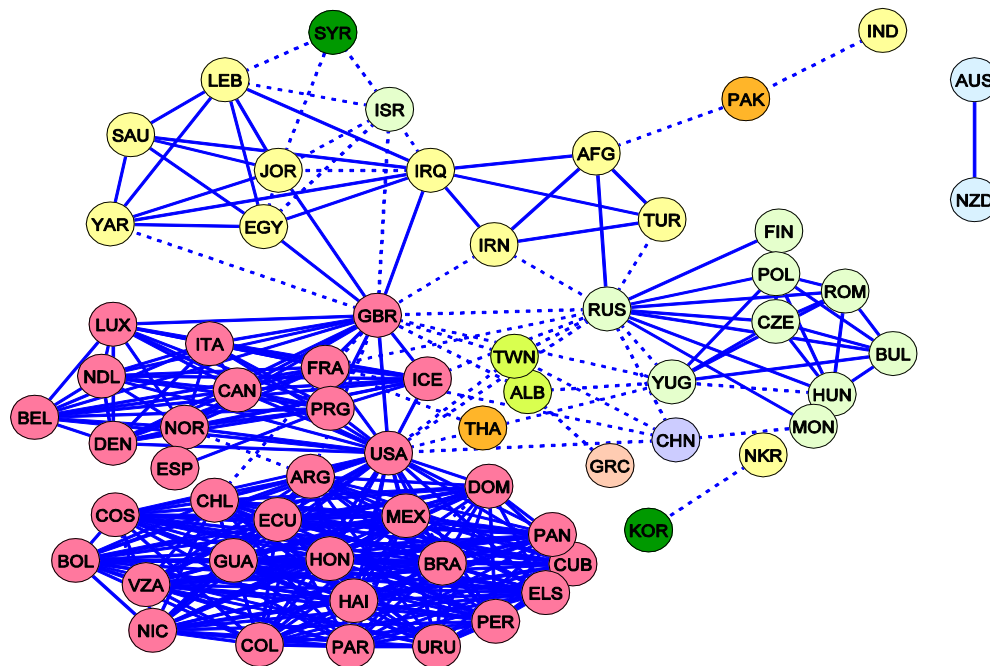
Figure 3. The optimal structural balance partition for 1946-49
The coloring of the vertices indicates membership in identified clusters.

The partition obtained using the Louvain method of Traag and Bruggerman is shown in Figure 4. This method is far better in its handling of the positive ties, especially as it separates the Western bloc from nations in South America. Unfortunately, it fails in its handling of negative ties by producing a large number of singleton positions making little structural sense. One feature of this algorithm is the use of modularity (Newman, 2006). For a given division of the network's vertices into some clusters, modularity reflects the concentration of edges within clusters compared with random distribution of links between all nodes regardless of clusters. Operationally, modularity is the fraction of the edges that fall within the given groups minus the expected fraction if edges

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[10] When fitting 'classical' structural balance, the structure of the blockmodel is given. Positive blocks are on the main diagonal with negative blocks being elsewhere (Doreian and Mrvar, 1996). Relaxed structural balance (Doreian and Mrvar, 2009) was formulated to allow positive and negative blocks to appear anywhere in the blockmodel.

were distributed at random. The community detection goal is to locate clusters (communities) such that the measure of modularity is as large as possible. It is positive if the number of edges within groups exceeds the number expected on the basis of chance. While this partitioning method can handle modularity very well for positive ties, this is not the case for negative ties as is shown in Figure 4. The result is an overly large number of clusters ($k = 17$) reflecting the method's inability to handle negative ties adequately.
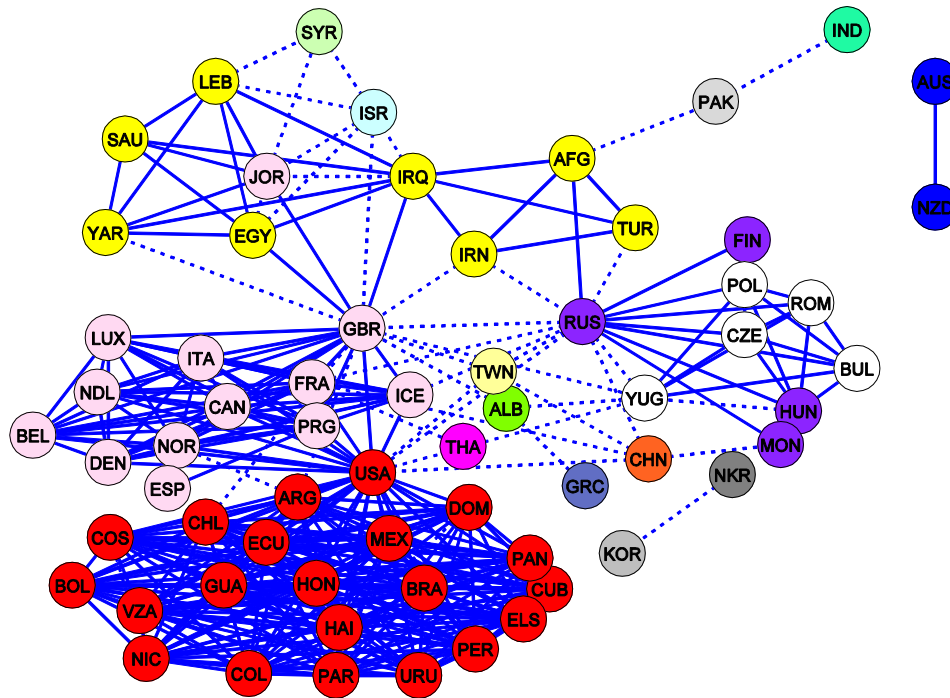
Figure 4. The Louvain community detection partition for 1946-49
The coloring of the vertices indicates membership in identified clusters.

It is clear from the above narrative that these two methods fail in different ways. One mishandles positive ties while the other handles negative ties poorly. Our proposed solution to these problems was to use pre-specification of blockmodels while taking into account some of the good features of the partitions of the sort shown in Figures 3 and 4. Additionally, we made some strategic choices regarding specific nations. This included pre-specifying both the USA and the RUS[11] as singleton positions throughout the fifty years following WWII and the creation of the UN to replace the ineffective League of Nations. Given its location in the world system as a colonial power after WWII, Great Britain (GBR) was specified as another singleton although this was changed when its status receded after most of its former colonies achieved full independence and its influence waned. Also, Israel (ISR) was specified as a singleton given its history and salience for the politics of the Middle East and also in the context of broader Cold War rivalries. This pre-specified blockmodel included also the pattern of signs for the blocks. It was fitted using relaxed structural balance. The resulting partition is shown in Figure 5 as a formatted array, an alternative presentational device.

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[11] In all of the figures herein, RUS denotes the USSR until its demise in 1991 and Russia thereafter.
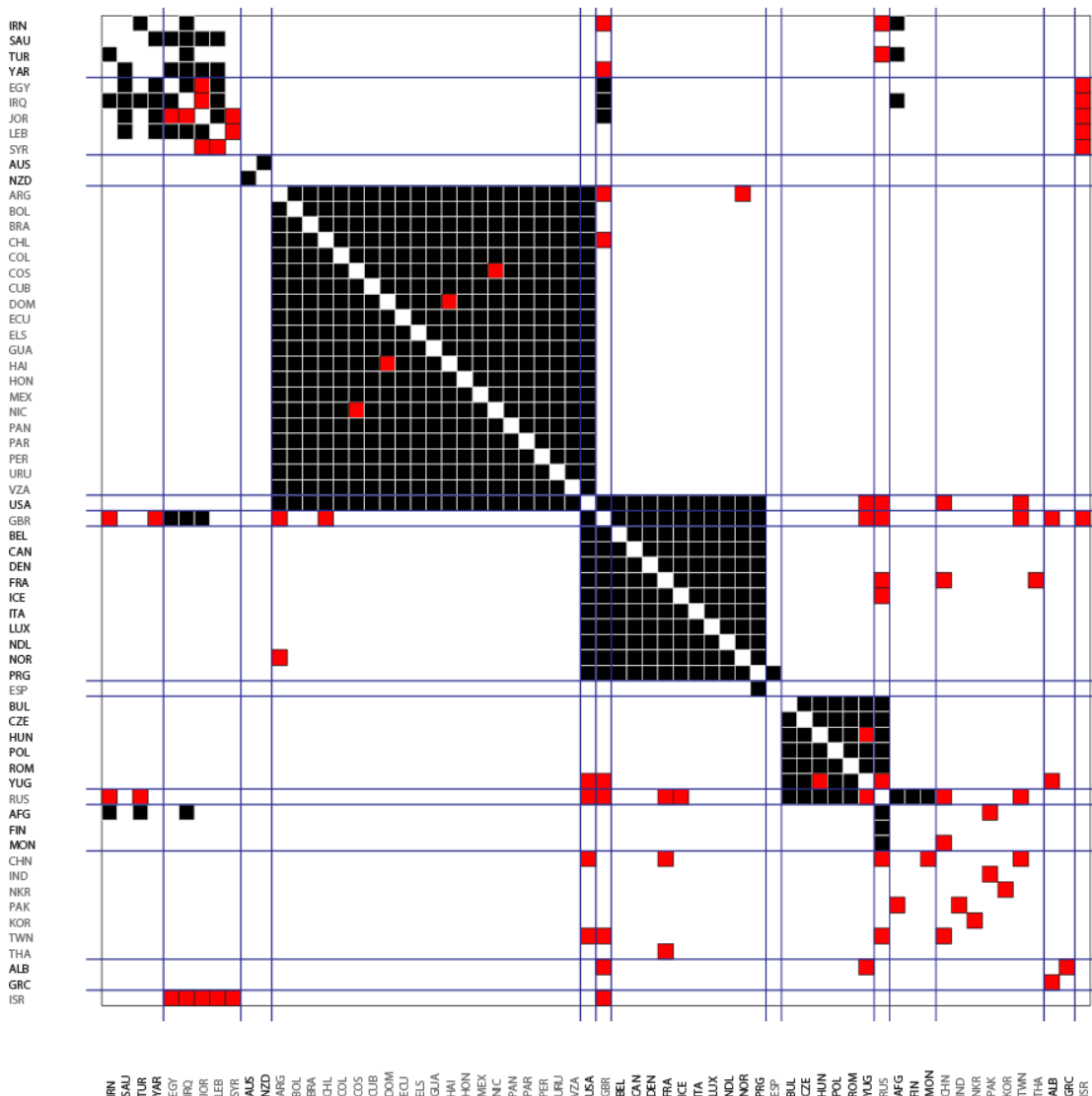
Figure 5. The pre-specified and fitted partition of the signed network for 1946-49
Positive ties are shown in black, negative ties in red and null ties in white.

The positive ties are shown by black squares, the negative ties by red squares and white squares indicate the absence of ties. The blue lines separate the positions (clusters of nations). The positions, in the same order for rows and columns, are: two Middle East clusters (Islamic 1 and Islamic 2); Oceania (Australia and New Zealand); South America, USA, Great Britain; the Western Bloc, Spain, the Eastern Bloc including Yugoslavia, USSR, East (a left leaning position); Non-aligned (Asia but having negative ties in a diagonal block); Adriatic (Albania and Greece) and Israel.

In the main, the diagonal blocks are positive but they do contain some negative ties which contribute to the measure of imbalance. One of the Islamic positions has a considerable number of negative ties. Among the South American nations there is a negative tie between Costa Rica and Nicaragua, neighbors to each other. The other negative tie involves Haiti and the Dominican Republic which share Hispaniola, a Caribbean Island. Under rival dictators they were bitter rivals

for much of the period studied here. The conflict contunued after the demise of the two dictators. Within the Eastern Bloc, Yugoslavia has a negative tie with neighboring Hungary as well as a negative tie with the Soviet Union.

While pre-specification provided far better partitions for all 51 windows, using it was a time consuming procedure. There is also the risk of over-fitting blockmodels with pre-specification. Even so, in general, researchers know far more about the networks they study than is reflected in a purely inductive use of blockmodeling. Such was the case here. We do not rule out the possibility of a more automated procedure for partitioning such signed networks. Indeed, we hope one will be created as it will be far more efficient for establishing coherent partitions.

3.6 Using fragments and 3-cycles

We noted the complex problem of identifying all cycles in a signed network in Section 2.2 and suggested using fragments for identifying 3-cycles. There has long been an interest in identifying some smaller parts of larger structures among network analysts. Such smaller parts are called fragments, patterns or motifs.[12] Searching for fragments to be identified and counted is a general approach for delineating the structure of large complex systems. In general, one type of fragment in an undirected network is a 3-cycle. For the CoW datasets studied here, there are only four possible 3-cycles. They can be constructed from the triples in Figure 1 using edges rather arcs. The only two possible balanced 3-cycles are the all positive 3-cycle and the 3-cycle with two negative edges. Similarly, from the bottom row, the only two types of imbalanced 3-cycles have either one negative or three negative edges.

These 3-cycles are shown, using the internal representation for networks used in Pajek (Batagelj and Mrvar, 1998), in Table 2. Doreian and Mrvar (2015) proposed a simple way of identifying and counting these four types of 3-cycles through fragment searching. The four types of 3-cycles are stored in a Pajek project file. Fragment searching was first implemented in Pajek in 1997 (see de Nooy, Mrvar and Batagelj, 2011) through a general backtracking algorithm. In general, if the selected fragments do not occur too frequently in a large sparse network the algorithm is extremely fast. Applying it to networks with the sizes shown in Table 1 is unproblematic. Indeed, it can be applied to much larger signed networks. A Pajek project file was created with the four fragments in Table 2. They can be searched for within each of the CoW signed networks. The commands for doing this are (Doreian and Mrvar, 2015):

Getting the data into pajek:

- Read the data from a network file (*.net) with * representing the file's name.
- Read a pajek project file (with the form (*.paj)). This contains the networks defined by the fragments to be identified. (For a signed directed network there are the eight triple types shown in Figure 1. For an undirected signed network there are only the four types of 3-cycles shown in Table 2.)

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[12] See Milo *et al.*, (2002) for a discussion of motifs from the perspective of physicists approaching network analysis.

Mobilizing pajek to determine and count the types of triples:

• Select each fragment type (one at a time) from the pajek project file as the first network.
• Select the network data as the second network.
• Check Networks from the top menu bar in pajek (to open a dialogue box).
• Check fragments (first in second) in this dialogue box.
• Select the appropriate options.
• Check Find.

Table 2. The four types of signed 3-cycles in an undirected signed network

Balanced 3-cycles	Imbalanced 3-cycles
*Network Only Positive Undirected *Vertices 3 *Edges 1 2 1 1 3 1 2 3 1	*Network Only Negative Undirected *Vertices 3 *Edges 1 2 -1 1 3 -1 2 3 -1
*Network Two Negative Undirected *Vertices 3 *Edges 1 2 1 1 3 -1 2 3 -1	*Network One Negative Undirected *Vertices 3 *Edges 1 2 -1 1 3 1 2 3 1

On using these commands, a count of each fragment type appears along with network containing only the fragments. This network can be saved for additional analyses. The results of using these commands for all 51 windows are provided in Section 6.

3.7 Summary of the methods used

Pre-specified blockmodeling was used to partition the international signed network for all 51 windows. Five selected partitions for different windows are provided in Section 5 to illustrate the structure of the network as it evolved over time. The line index (the number of lines whose sign when changed creates balance) obtained for these blockmodels is used to measure the extent of imbalance for each window. Two additional measures of imbalance are obtained by detecting and counting 3-cycles as fragments. One is the proportion of imbalanced 3-cycles with the second being the number of imbalanced 3-cycles. These are shown in Section 6.

4. Partition Structures in the World System

We report a sequence of five selected blockmodels and images for windows about a decade apart. One is for the first window immediately after WWII. It is shown in Figure 5 as a formatted array. The remaining four were selected because they included major international crises. Allowing for the expansion of this system as new nations join, the structure shows considerable consistency in its basic form even though the number of positions changed over time.

1946-1949

A general practice within blockmodeling is to summarize a blockmodel by an image which is a much simpler network capturing its essential structure. See Wasserman and Faust (1994), Doreian *et al.* (2005) and Hanneman and Riddle (2011). Examining the partition shown in Figure 5 raises some practical questions even though the overall structure is clear.
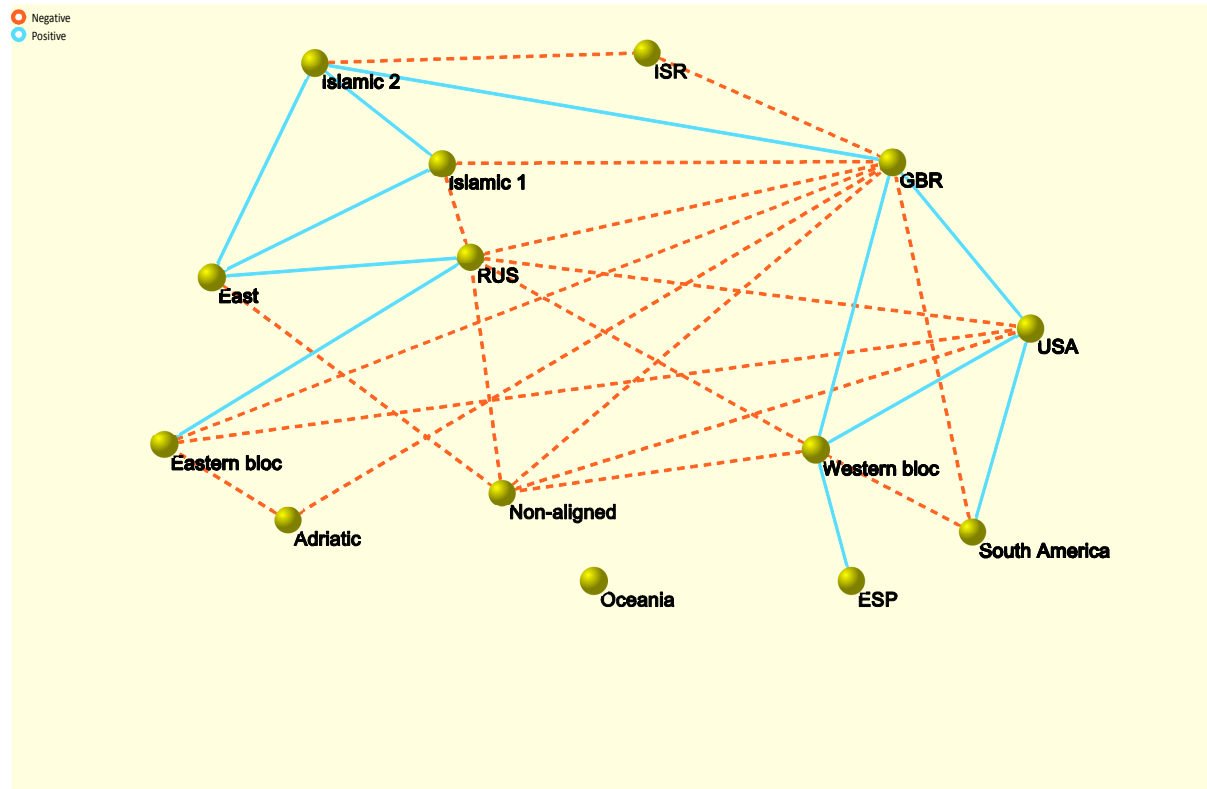

Figure 6. The initial image for the 1946-49 blockmodel
For each of the windows in Movie 2 (below), clicking on the positive or negative icons (top left) removes the ties of the selected type as this is useful for focusing on the positive or negative block signs.

By convention, the sign of a block is given by the majority of signs in it. Yet if there is only one tie in a block, it is inappropriate to consider the block as determined by its only signed tie, especially if it is a large block. We set a threshold to require the minimum number of ties to determine the sign of the block as at least two ties with the same sign[13]. For every singleton position, e.g. for the USA or the USSR, we required more than 25% of the possible ties be present in a block in order to determine its sign. There are two potential images. One comes directly from the formatted blockmodel of Figure 5. It is shown in Figure 6. The other is a 'pruned' image where ties between positions (in blocks where the number of signed ties fall below these two thresholds) are removed. This gives a more parsimonious image for the resulting blockmodel. Also, to focus on ties between positions, loops for positions containing multiple nations were removed.

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[13] If both positive and negative ties are present, they cancel each other out. So this threshold is the net number of ties of a given sign after such cancellations. This criterion can be made more stringent if needed.
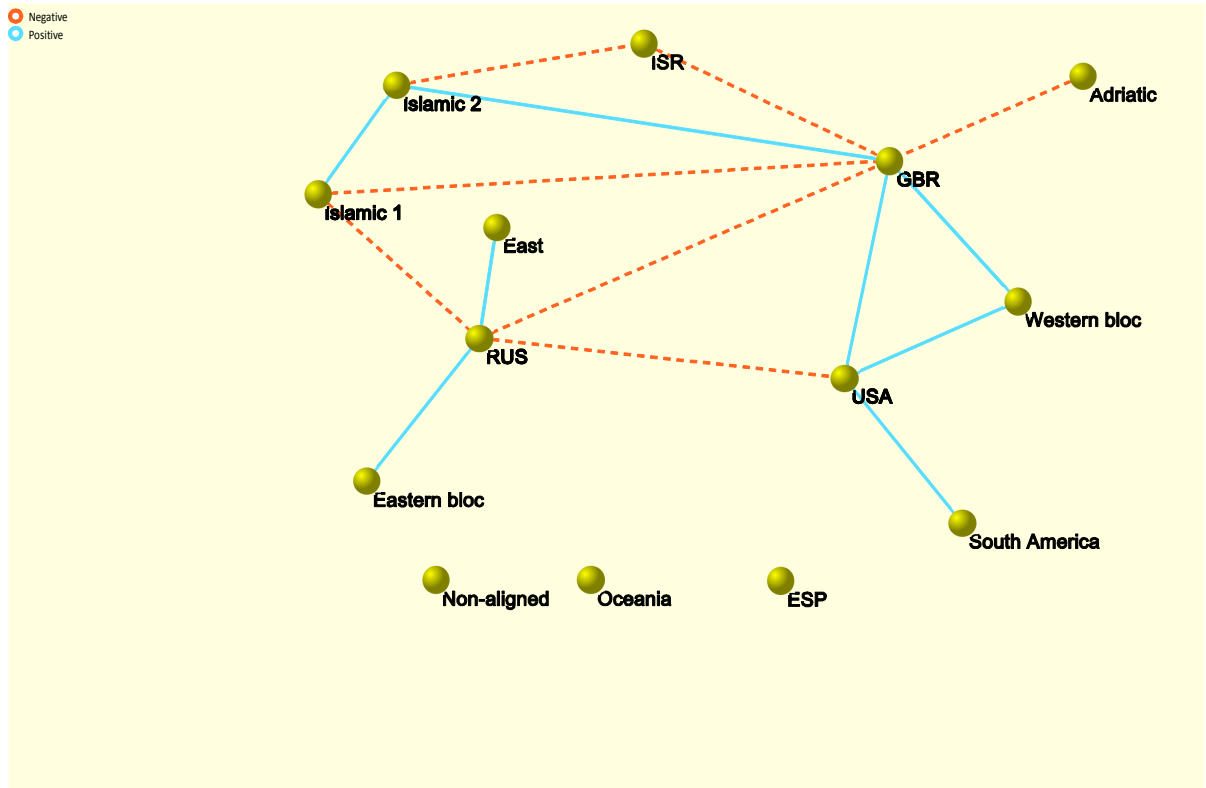
Figure 7. The pruned image for the 1946-49 blockmodel

From Figure 5, it is clear that this network is not balanced. There are positive ties outside the diagonal blocks, negative ties in positive diagonal blocks and a diagonal block with only negative ties. The fitted model is the best possible using the relaxed structural balance (RSB) procedure of Doreian and Mrvar (2009). There are two possible line index measures of imbalance measures for this network: one value is 16 obtained from using RSB and 26 is the measure obtained from using structural balance (SB). These measures are reported graphically in Section 6 for all 51 windows.

The pruned image for 1946-1949 is reproduced in Figure 7. Under pruning, some isolate positions were created and were relocated to the bottom of the figure. One general issue is whether the basic structure of the world system persists as the system expands, more alliances are formed and more conflicts erupt over time. Henceforth, we report only the pruned images.

As described above, there are ten positions in the images shown in Figures 6 and 7. We note Spain as a singleton being largely isolated under the regime of the dictator Franco and was connected by a positive tie only to Portugal under another dictator, Salazar. The Oceania position is comprised of Australia and New Zealand and is an isolate both in the original network and in the images for this window. The other isolates in the pruned image were produced by pruning. The process of pruning the image necessarily reduces the level of imbalance.[14] However, it does not reduce the measure to zero given the relations of Great Britain with nations in the Middle East.

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[14] We *recommend never* computing the line index of imbalance in the pruned image as a measure of imbalance in the overall network.

1955-1958

Figure 8 shows the signed blockmodel partition for 1956-1957, a period containing the Hungarian uprising against the control of the USSR through its domination of the Warsaw Pact. This network is larger by having 81 states and 510 dyadic ties compared to the 64 states and 362 ties in 1946-49. The number of positions expanded to 17: two (expanded) Middle East clusters; Oceania, Asia (Oceania/Asia) in which Australia and New Zealand were joined by Pakistan, Philippines and Thailand; South America (expanded), USA, Great Britain; the Western Bloc (expanded), Spain, the Eastern Bloc, Yugoslavia, USSR, Left leaning (expanded); three Asian positions (with one leaning to the West); a neutral position; and Israel. The earlier {Albania, Greece} position broke apart with the former joining the Eastern Bloc and the latter the Western Bloc.

We note the presence of negative ties due to *both* local and global processes. There are negative ties within the Middle East (Islamic) positions. Also, more negative ties have appeared among the states in the South America position. Given the relative detachment of South American from the rest of the world in this network, these negative ties most likely involve local disputes. The small number of ties within the Western Bloc appear to be pairwise specific rather than being a part of a more regional pattern. The uprising in Hungary in 1956, seeking a break from dominance by the Soviet Union was initially local but other states became aligned over the resulting conflict.
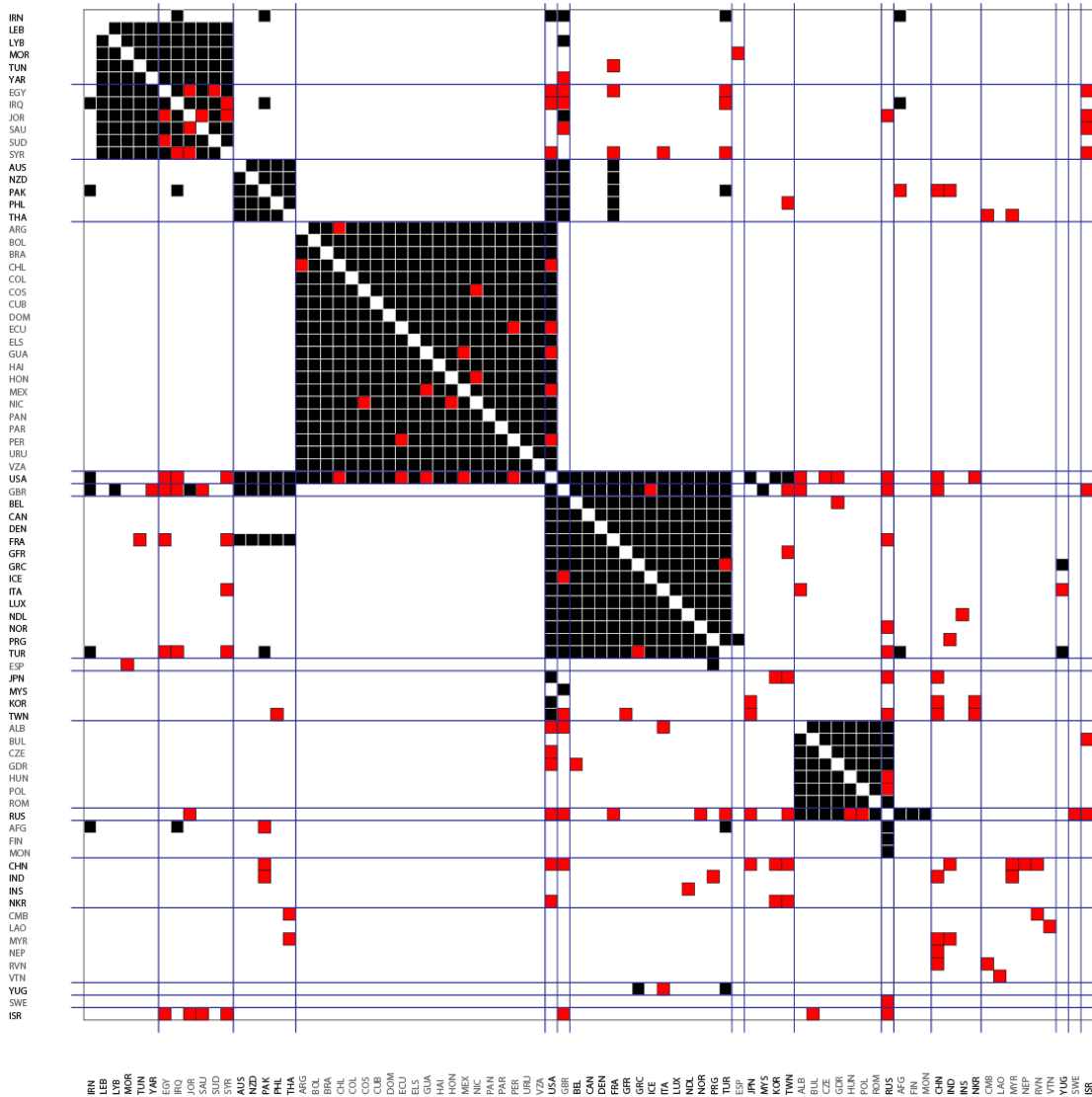
Figure 8. The pre-specified partition of the signed network for 1955-58
Positive ties are shown in black, negative ties in red and null ties in white.

The line index of imbalance under SB for this network is 54 with the RSB measure being 44. It was a more imbalanced network than for 1946-49. The pruned image is shown in Figure 9. It is balanced but this is a result of constructing a pruned image and *cannot* be used to claim the network is balanced. Necessarily, the line index of imbalance is smaller for the images. Such images are used *solely* as a simplified visualization of the network's fundamental structure. These images are combined into the movie of the image changes shown in Movie 2 (below).
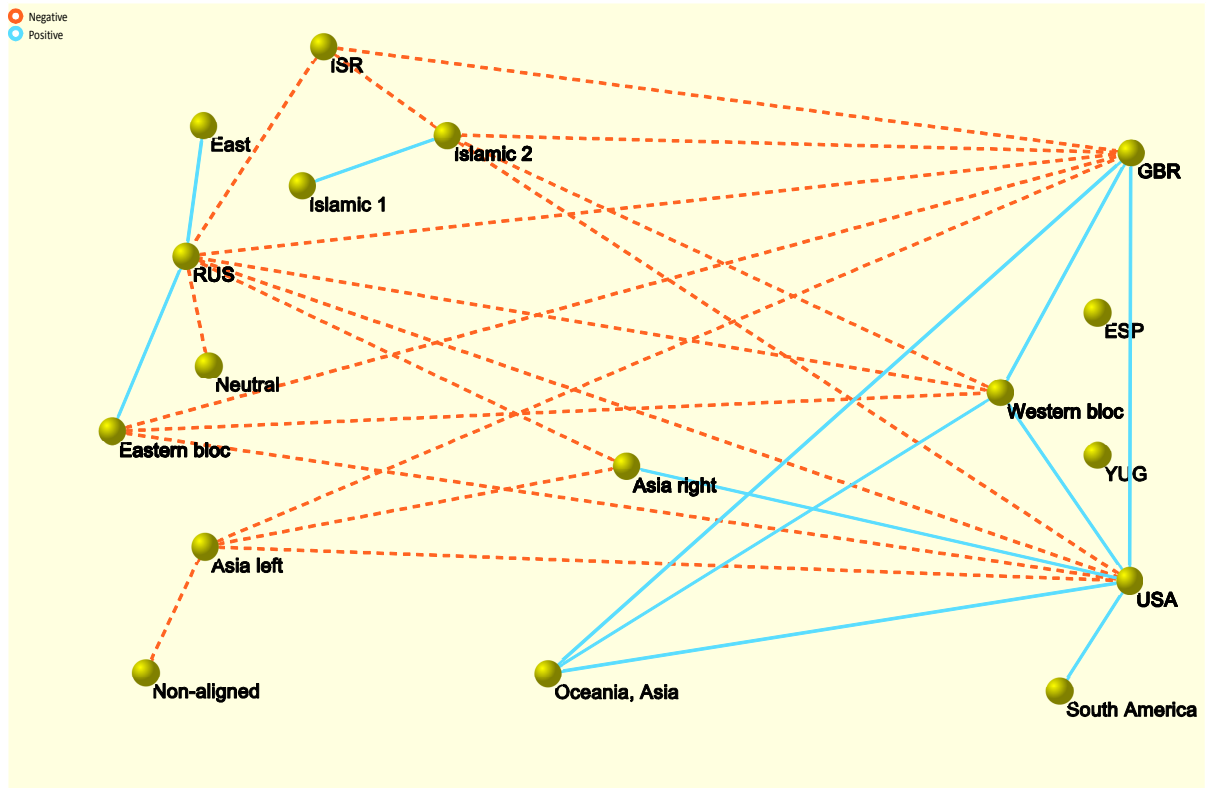
Figure 9. The pruned image for the 1955-58 blockmodel

1966-1969

Figure 10 shows the signed blockmodel partition for 1966-1969, a period containing the Warsaw Pact invasion of Czechoslovakia in 1968. The network grew to having 111 states with 607 dyadic ties. Despite the increase in the size of the overall system, there is only one more position than for 1955-58 window. There was a single Middle East position instead of two. The next part of the structure with Oceania/Asia, South America, the Western Bloc, Great Britain, and the USA is essentially the same. There is a second European position containing secondary nations. Czechoslovakia is now a singleton in a position with negative ties to states in the Eastern Bloc. Some small African positions were identified also. Their appearance reflects the formation of some local regional African IGOs. The Asian positions remain present. The nations in these small African positions each have different connections to the rest of the network.

There was a dramatic drop in the number of negative ties within South America compared to 1955-1958. In contrast, the number of negative ties within the Islamic position did not drop. The non-aligned position split into two parts, one with internal positive ties and the other with internal negative ties. This was a critical development in the non-aligned movement of nations. Non-alignment regarding the East-West split need not imply broader agreements regarding national interests.
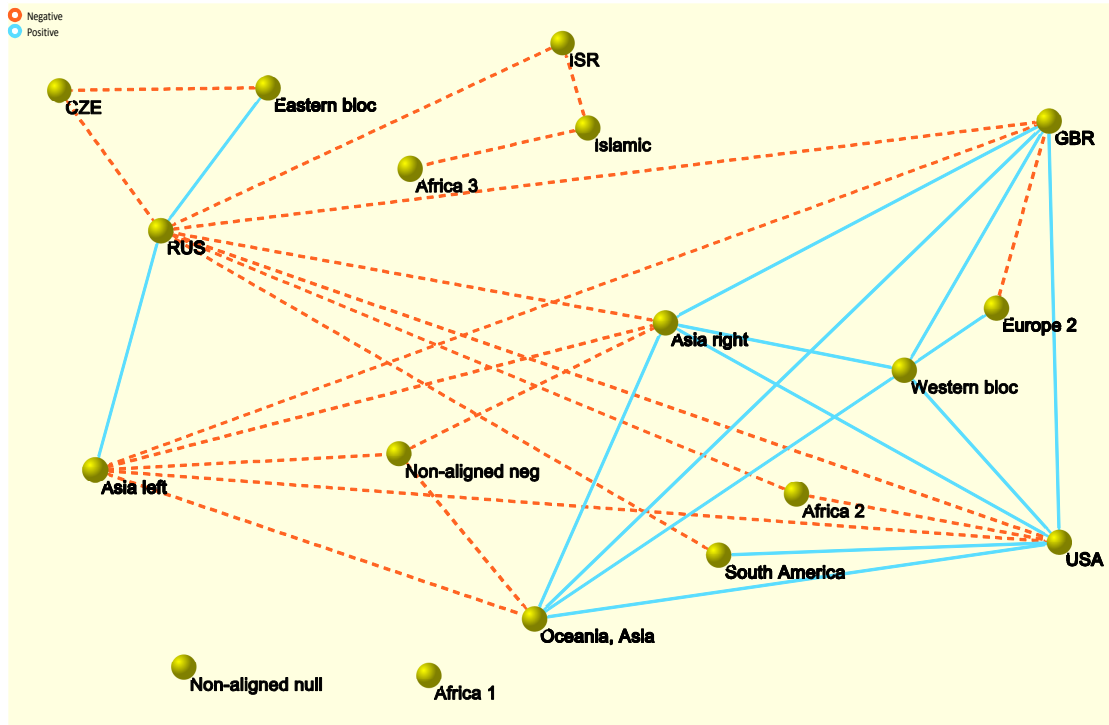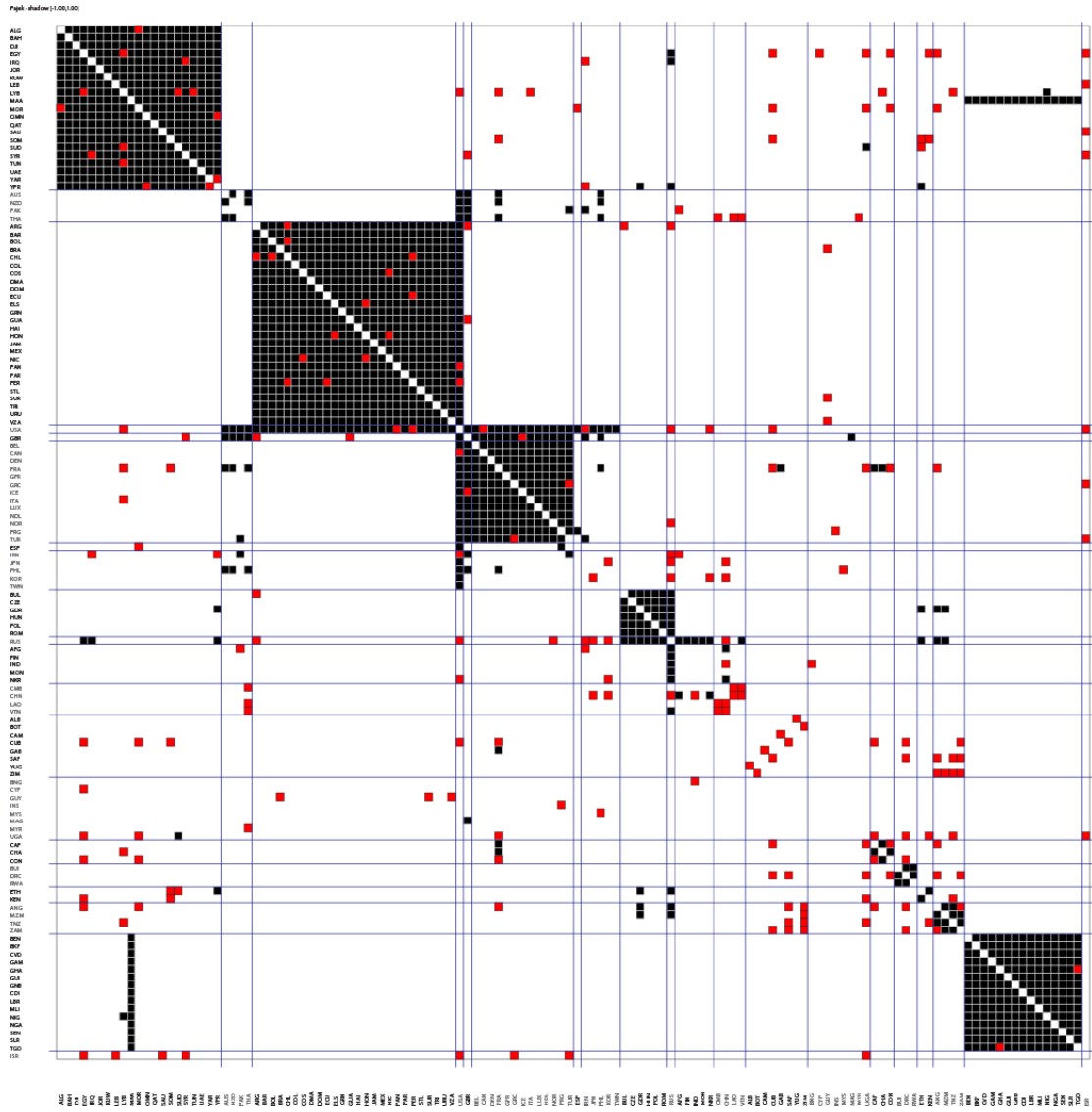
Figure 10. The pre-specified partition of the signed network for 1966-69
Positive ties are shown in black, negative ties in red and null ties in white.

Without surprise, the signed network was not balanced. The SB line index is 48 and the RSB index at 40. The pruned network is shown in Figure 11.

Figure 11. The pruned image for the 1966-69 blockmodel

1976-1979

One decade later, there were 132 nations in the network with 968 dyadic ties. While the period was selected solely as a decade after the previously shown network, trouble was brewing. It came with the Soviet Union's invasion of Afghanistan in 1979 and the response of this invasion by Western Bloc nations, especially the USA. The number of positions shown in Figure 12 is 18, one more than for a decade earlier. The Middle East position is now larger. The essential structure remained the same but with a new large African position of states that are located in the northwest of this continent but below the Maghreb. Mauritania is in a larger Islamic position but has positive ties to all states in the large African position.

One of the African positions has a positive tie to the USSR and four of the African positions have ties to the Islamic position. The SB line index for this network is 70 with 58 the corresponding value using RSB. Both values were the highest thus far, although higher values were reached subsequently. The pruned image is shown in Figure 13.

Figure 12. The pre-specified partition of the signed network for 1976-79
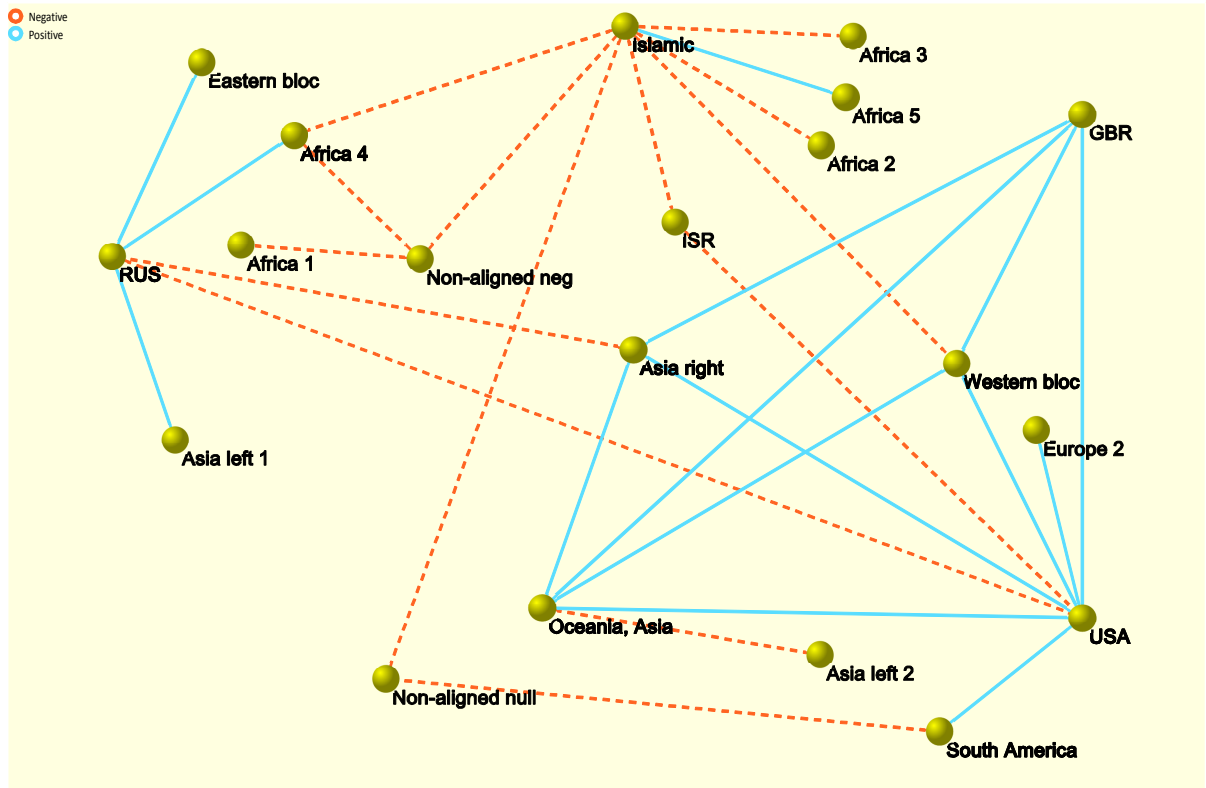*Positive ties are shown in black, negative ties in red and null ties in white.*

Figure 13. The pruned image for the 1976-79 blockmodel

1990-1993

The final partition we show corresponds to a period of profound change in the international system of nations. The USSR collapsed in 1989 followed by the demise of the former Yugoslavia in the early 1990s. Both of these endings of former 'nations' were preceded by great turmoil, especially in the former Yugoslavia when it was destroyed by both nationality and ethnicity based warfare, the worst and most savage in Europe since WWII. Slovenia was the first new nation to establish its independence. Other new nations were formed but only after far greater bloodshed. Many new nations were formed following the collapse of the Soviet Union. There were now 155 nations in the world order with 1288 dyadic ties between pairs of them. The partitioned structure is shown in Figure 14.

The Middle East position is much expanded but with many negative ties centered on Iraq. The eight-year war between Iraq and Iran had ended in 1988 but Iraq launched its invasion of Kuwait in 1990. The South American block had expanded even further as had the Western Bloc which absorbed other European nations including some from the former Soviet Union. This position is labeled simply as Europe rather than the Western bloc (even though Canada is in it). Other former states from that union were located in another less obviously aligned position but negatively tied to Russia. Similarly, new states from the remainder of Yugoslavia had negative ties with what remained, in essence, Serbia. The number of positions increased only to 19 in response to these dramatic changes. Even so, much of the earlier structure remained in place. The pruned image is shown in Figure 15.
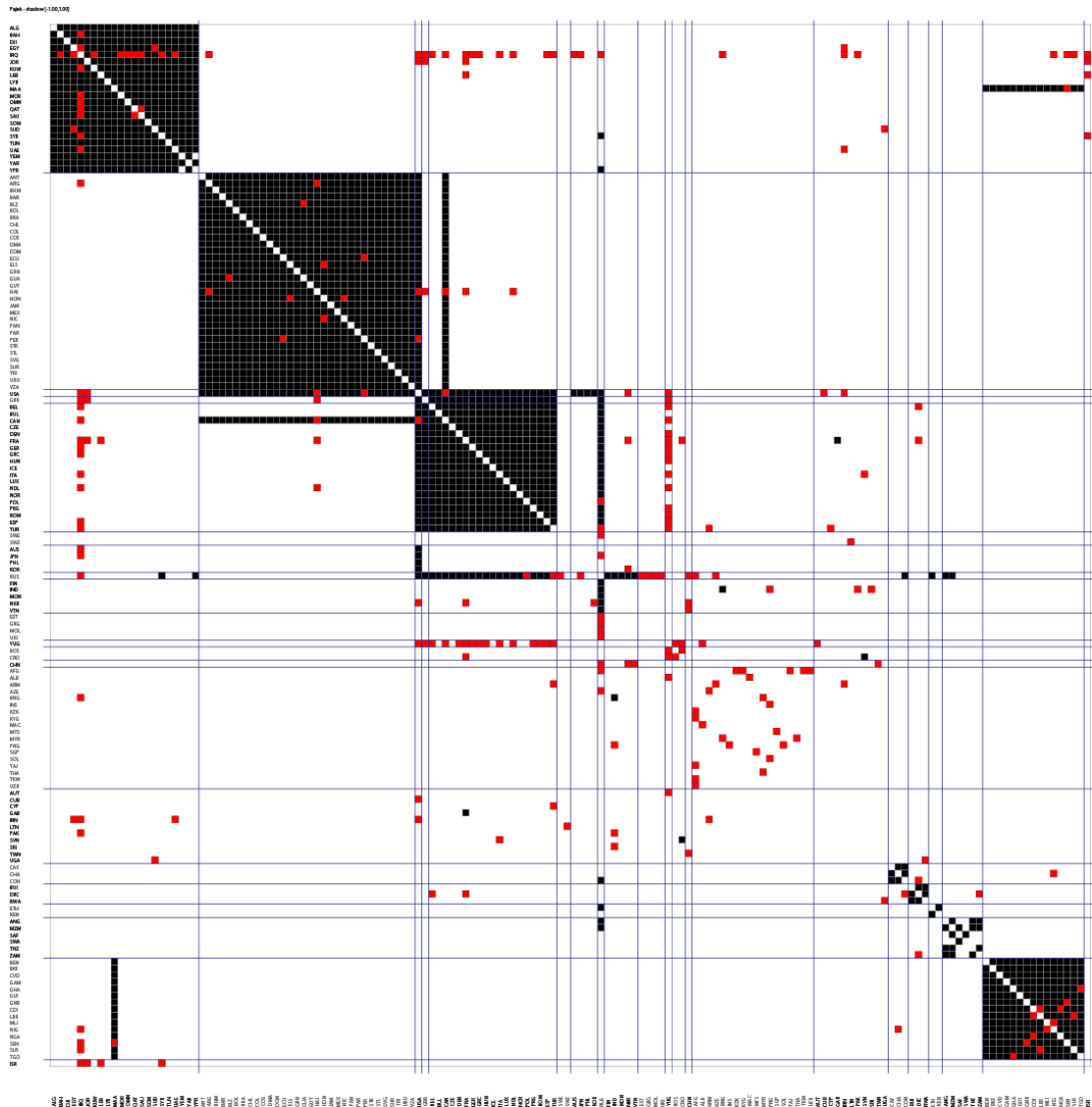
Figure 14. The pre-specified partition of the signed network for 1990-93
Positive ties are shown in black, negative ties in red and null ties in white.

This level of imbalance was the highest among these 51 windows: the SB line index was 82 with the RSB measure at 76. Clearly, dramatic changes such as the collapse of both the Soviet Union and Yugoslavia plus the aggressive behavior of Iraq under Saddam Hussein affected the level of imbalance of the international system greatly.
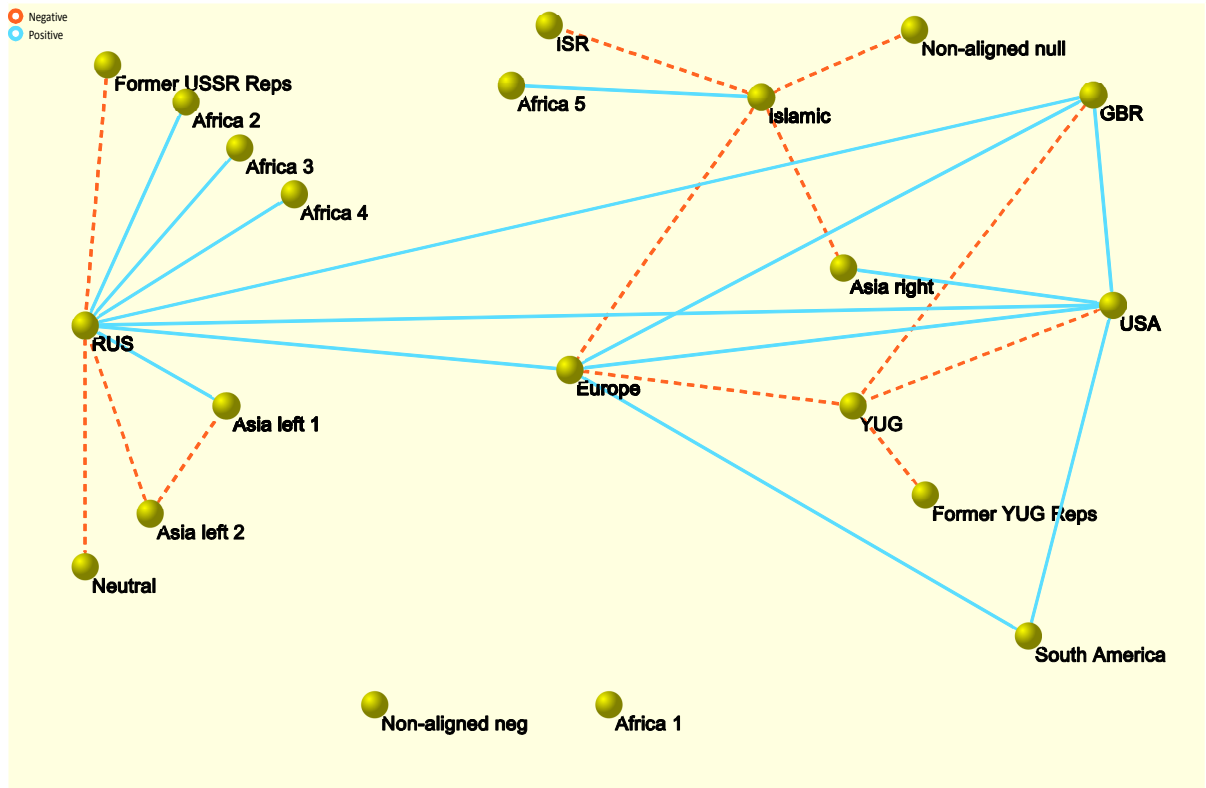
Figure 15. The pruned image for the 1990-93 blockmodel

The reported results, especially for 1990-93, raise an additional issue. The system of nations can be viewed as an endogenous system as it is the only international system on the planet. This makes it difficult to think in terms of 'exogenous' shocks, often a useful conception when thinking of the dynamics of systems located within a larger system. Yet such events constitute major local and global shocks to the system. The 'local' aggression of Iraq when it invaded Kuwait, most likely, is not solely local as it was driven by the quest to control more oil in an international oil market. Also, a coalition of nations was formed to drive the Iraqi forces out of Kuwait.

The collapse of the Soviet Union was not a simple local event. It occurred in a global context defined by an acute rivalry between two super powers. The collapse of Yugoslavia can be viewed as a consequence of long suppressed Balkan rivalries and the lure of potential memberships in the EU. In short, such seemingly local conflicts are not purely local. We return to this topic after considering temporal levels of imbalance in the overall world system.

http://mrvar.fdv.uni-lj.si/pajek/SVG/CoW/

Movie 2. The sequence of the pruned RSB blockmodel images over time

As is the case for the negative ties movie, clicking on the link takes viewers to a web page containing the movies. Clicking 'pruned images' leads to the pruned image for the first window. Below the image is the word 'next' which, when clicked, takes the viewer to the second window. These windows are labeled by their last year rather than the first. Clicking on the red negative dot removes the negative ties. The positive ties can be removed by clicking on the blue dot. If used, they do not have to be restored before moving to the next window. For all windows other than the first one, clicking on 'previous' takes viewers to the pruned image of the previous window.

5. Levels of Balance and Imbalance through Time

We divide our discussion of balance and imbalance into two parts although the line indexes and cycle-based indexes have a strong connection with each other. Section 5.1 presents the results for the line indexes, Section 5.2 does the same for the cycle based measures and Section 5.3 discusses some methodological implications for measuring imbalance for signed networks.

5.1 Line indexes of imbalance

Figure 16 shows the plot of the structural balance (SB) index across the 51 periods. It shows great variation in the level of imbalance across these networks. At a minimum, it provides *decisive* evidence against the fundamental balance theoretic hypothesis of signed networks evolving towards a balanced state. This does *not imply* balance theoretic approaches are without value. Balance is an important property of the international system. However, too many global and local processes and events preclude a smooth unidirectional evolution regarding imbalance in the system as a whole.
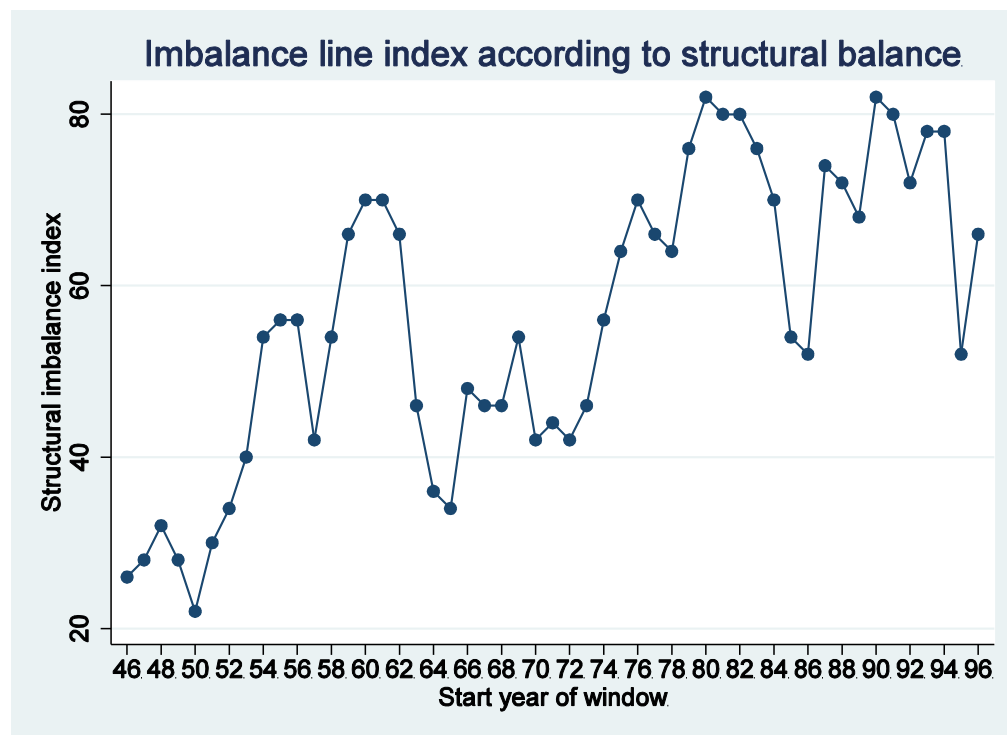

Figure 16. The line index of imbalance under structural balance (SB)

The changes in this imbalance measure can be summarized in a straightforward fashion. Imbalance was low for 1946 through 1953. Within this period there was some variation, with an increase through 1948 followed by a decrease to the lowest value for the series in 1950. Starting with the transition to the 1951 window, there was a steady increase to a modestly high level of imbalance in 1954. There was a plateau for imbalance for 1954-56 before another sharp drop in 1957. This was followed by another steady increase to the highest level of imbalance thus far for 1960-61. A steady decline in imbalance followed. The low level in 1965 was last seen in the early

1950s. Next came a jump in imbalance for 1966 to a level that held roughly for three windows before spiking in 1969 and dropping in 1970. The level of imbalance held quite steady for three years.

Starting in 1971 there was another steady increase in imbalance to a high in 1976 equaling one seen in the early 1960s during the Cuban missile crisis. There were small drops through 1978 before some larger increases occurred leading to a new high in 1980 which held for the next two windows before a steady decrease through 1986 to a (local) low followed by a sharp increase in 1987. This was followed by some modest instability with two increases followed by a decline at 1989. Then came a jump to a new highest level of imbalance in 1990 which held (with some variation) through 1994 before a sharp drop in 1995 and a modest increase for 1996-1999. Overall, the period after 1972-74 had higher levels of imbalance than in earlier times.
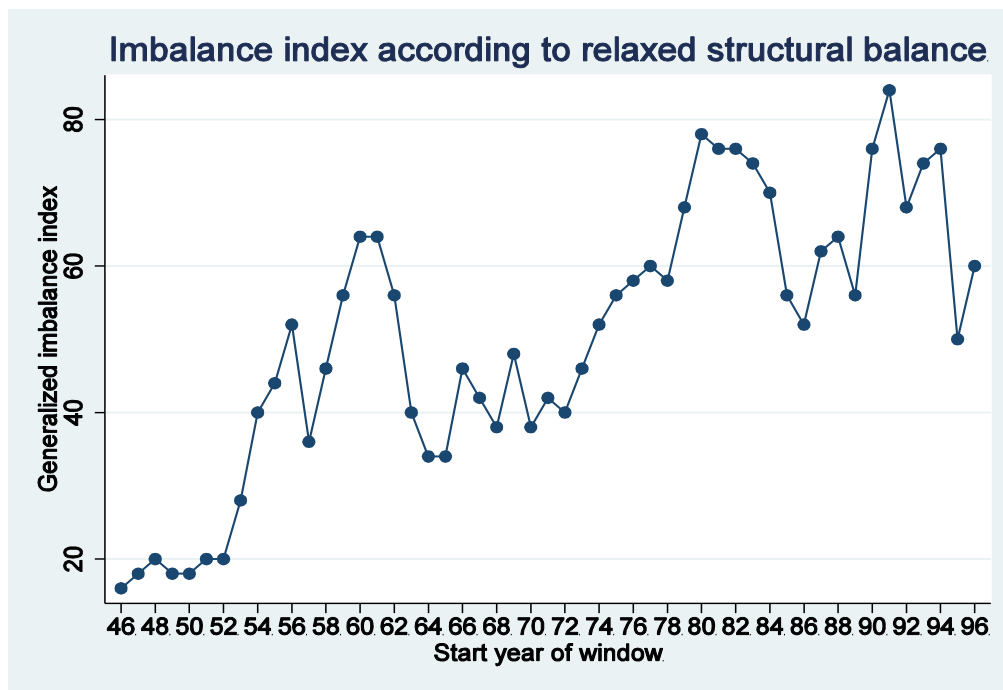

Figure 17. The line index of imbalance under relaxed structural balance (RSB)

We consider next the corresponding trajectory of the line index of imbalance from the pre-specified RSB model shown in Figure 17. The plots in Figures 16 and 17 have great similarity: they tell the same story. Throughout, the RSB line index was lower, consistent with it allowing some departures from the rigidity of the classic SB approach. Overall, the conclusions using the two measures are the same. The changes with this index may be slightly less extreme than for RSB. There may be some key differences between them meriting further attention regarding the presence of all negative 3-cycles. However, the product moment correlation between the two series (0.973) confirms their close agreement.

5.2 Cycle-based measures of imbalance

We consider first the *number* of imbalanced triples through the 51 windows. These are shown in Figure 18. Visually, the number of unbalanced triples when the all-negative triple is treated as balanced (Davis, 1967) is extremely close to that shown in Figure 18. It is not duplicated here.
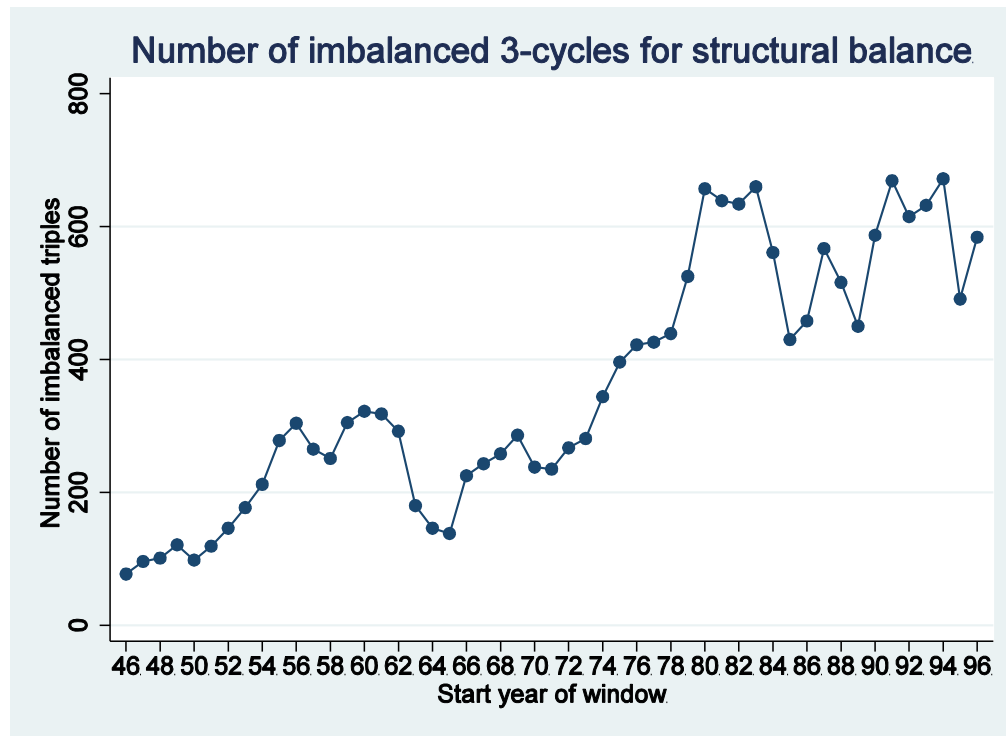

Figure 18. The number of SB imbalanced 3-cycles over time

Visually, the trajectories in Figure 16 through 18 look very similar despite their different metrics. This impression is confirmed by the correlations in Table 3. All are highly significant ($\alpha = 0.001$). It does not matter whether the number of imbalanced Heider or Davis 3-cycles are used (as r=0.999 for this pair) for 3-cycles nor whether the SB or RSB measures are used (r=0.973 for this pair). Yet there is some slippage between the two types of measures. The correlations of the RSB line index of imbalance with the numbers of imbalanced 3-cycles for both Heider and Davis are lower at about 0.931. Even so, they agree overall about the temporal changes in imbalance.

	Number of Heider Imbalanced 3-cycles	Number of Davis Imbalanced 3-cycles	Imbalance (SB)	Imbalance (RSB)
# imbalanced triples (H)	1.0			
# imbalanced triples (D)	0.9995	1.0		
Imbalance (SB)	0.9069	0.9064	1.0	
Imbalance (RSB)	0.9309	0.9310	0.9733	1.0

Table 3. Correlations between four indices measuring imbalance over time

We turn to consider the *proportions* of imbalanced triples as they have been the usual measure of imbalance hitherto. Consider the proportions of imbalanced triples under SB shown in Figure 19.
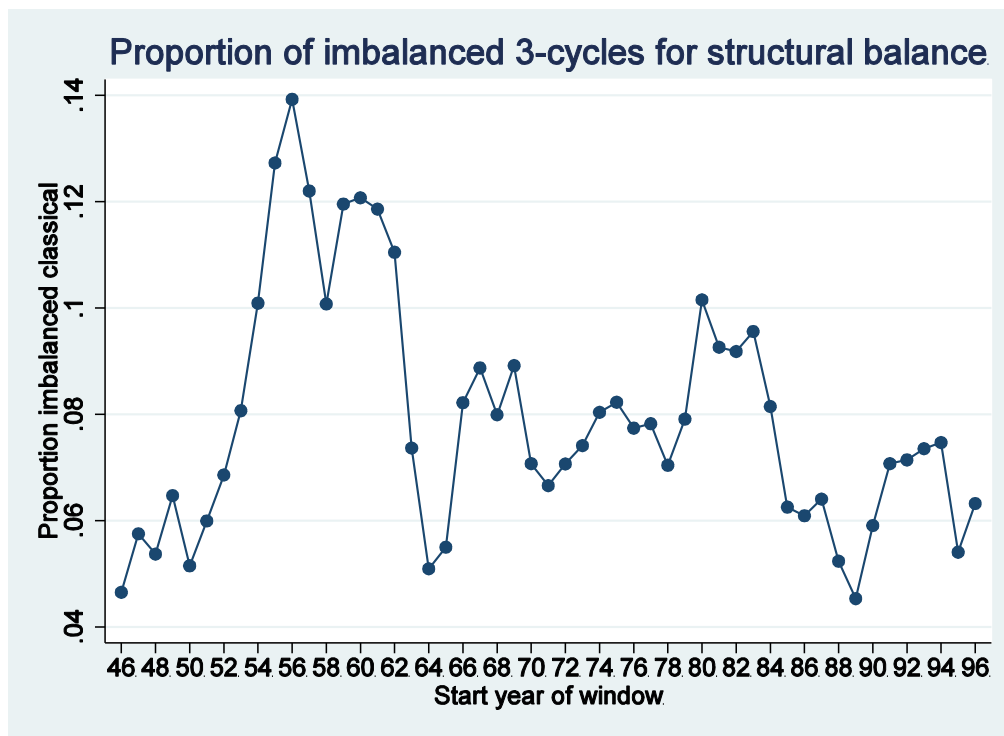

Figure 19. The proportion of SB imbalanced 3-cycles over time

If the trajectory shown in Figure 19 is taken at face value, two possible implications emerge. One implies a very different story regarding imbalance. While there is considerable variation over time in the values of these proportions, their values in the earlier years are all higher than over the later years. While the variation is too large to claim some simple, but seemingly strong, support for the general 'tendency towards balance' hypothesis, the trajectory appears suggestive. Essentially, the same trajectory is present under the Davis reformulation, as the correlation between the two trajectories is about 0.994. So the same potential conclusion follows regardless of how the imbalanced triples are counted before computing their proportions.

Alternatively, there may be a methodological problem when using the proportion of imbalanced 3-cycles as a measure of imbalance. Figure 20 shows the distribution of the four possible types of 3-cycles over time. The obvious feature of this display is the *huge* number of all positive 3-cycles compared to the numbers of the three other types of 3-cycles involving a least one negative tie. As noted in Section 3.1, the growth in the number of IGOs continued throughout the 50 years we consider (Pevehouse *et al.*, 2004; Ingram *et al.*, 2005).
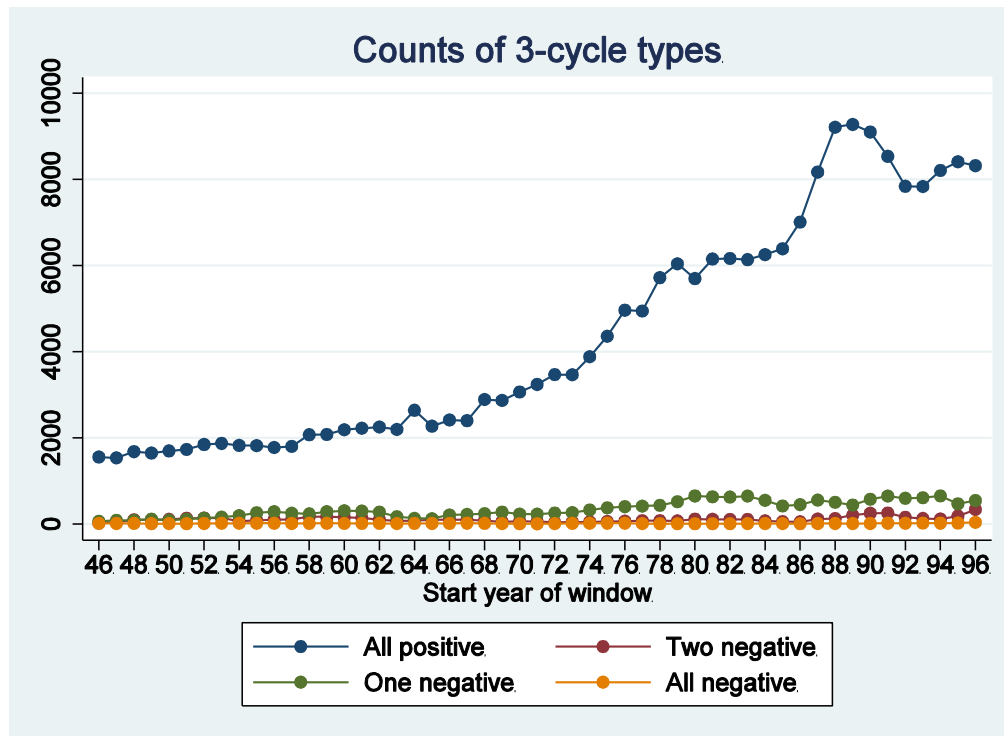
Figure 20. The distribution of the four types of 3-cycles over time

These results introduce some methodological issues not considered within the balance theoretic literature hitherto. Most of the early data sets for which balance theory was considered had either the same number of positive and negative ties (through the data collection designs used) or very similar numbers of them. In human groups, time is invested in creating and maintaining both positive and negative ties. It could be that the relative costs of maintaining positive and negative ties by states merits further attention. We pursue this next.

The costs entailed by joining an IGO are relatively small beyond establishing one and paying dues for its maintenance. When one exists, joining it is less costly than being involved in creating it. In contrast, the costs of engaging in active conflicts are much larger, especially in the form of border disputes and warfare. We argued that negative ties are interesting given their potential for disrupting the status quo. Yet they are dwarfed in number due to the explosive growth in the creation IGOs as well as NGOs. In short, having a very large number of all positive 3-cycles implies that the proportion of imbalanced 3-cycles distorts the measure of imbalance in the system regardless of conflictual disputes.

Some of the IGOs are large. For example, the Organization of American States (OAS) is the world's oldest regional organization[15] formed in 1948. When founded, it had 21 members with another 14 joining later. This accounts for the increasing size of the diagonal block for South America shown in the formatted blockmodel arrays. NATO is another large IGO, one whose size is exceeded by the 57 members of the Organization of Islamic Cooperation (OIC) founded in 1969 with 36 members.[16] All IGOs generate dyadic ties between the members in them, with the large

[15] See http://www.oas.org/en/default.asp for details.
[16] See http://www.oic-oci.org/oicv2/home/?lan=en# for details on origins, memberships and concerns. Eleven members were added following the demise of the Soviet Union.

ones contributing many all positive 3-cycles to the signed network. This distorted the proportion of imbalanced 3-cycles as a measure of imbalance. However, this relative difference and implied distortion may apply only to this network or others with a wide disparity between the numbers of negative and positive ties. As a result, the conclusions we reach below need not apply to all signed networks. It may be useful to track the differences between the number of imbalanced triples and their proportions when studying signed networks.

5.3 Some methodological implications regarding balance in signed networks

There are at least three implications stemming from the empirical results provided in the previous two sections. First, using pre-specification for fitting signed blockmodels is critical. Both the simple SB partitions and the community detection methods failed in their simple forms. More generally, we regard pre-specification of blockmodels as critically important in many substantive contexts. As noted above, we often know more about a social network than is implied by switching on an automatic procedure and simply accepting the results. Regardless of whether this knowledge is empirically driven or substantively based, it is sensible to use it through pre-specifying blockmodels, partially or completely, that can then be fitted as then tested.

Second, great care is needed in selecting which imbalanced measure to use. For the CoW signed networks, the number of imbalanced 3-cycles and the proportion of imbalanced 3-cycles behaved very differently. Our diagnosis of this suggested that having a huge number of positive 3-cycles distorted the proportion of imbalanced 3-cycles. This merits additional attention for the study of international relations. The early Cartwright and Harary (1956) theorem was for complete signed networks. In practice, few such networks are studied. Historically, the studied networks were sparse. In the main, this was due to using a fixed choice design for data collection where the number of ties for an actor was restricted, usually to the same very small number for both positive and negative ties (Wasserman and Faust, 1994: Chapter 4). In such restricted networks it was reasonable to opt for using proportions of imbalanced cycles for a cycle-based measure of imbalance. When the number of ties at vertices can be much larger and unequally distributed, this is no longer the case. Hence our earlier suggestion to track both measures. While the number of imbalanced 3-cycles is more appropriate for this network, it may not apply to all signed networks.

Third, for the networks considered here the nature of the negative ties varied considerably. This corresponded to the differences between local, regional and global conflicts in the overall system of nations. There are local, regional and global processes in play. Even though we think they cannot be separated cleanly in their operation, these distinctions need to be born in mind when considering balance theoretic outcomes, especially when interpreting them. A partial attempt at doing this is presented in Section 7. While the presence of processes operating at different levels was obvious for international relations, it seems reasonable to think in terms of such processes operating at the individual level in many human social groups. *Multiple* components for models of change in signed (and unsigned) networks have to be included in an overall model rather than assuming a *single* process operates across a whole system. Doing this will not be an easy task, one complicated by a distinction between regional and global levels for the international system.

Also relevant is the presence of 'contentious' states or states becoming contentious through their links to other states. Most of the positions identified in the blockmodels are regional. The presence of negative ties in positive blocks was noted earlier as a source of overall imbalance.

Figure 21 displays the counts of negative ties within diagonal blocks over time. The correlation between this series and the number of imbalanced triples is 0.903. In general, these counts increase over time with notable local peaks in the early 1960s (corresponding to the Cuban Missile Crisis), the late 1960s (corresponding the Warsaw Pact invasion of Czechoslovakia), through the 1970s, the early 1980s (which included the Soviet invasion of Afghanistan and disputes between the USA and the USSR), and in the early 1990s (following the collapse of the Soviet Union and the breakup of Yugoslavia). There also local lows in the early 1950s the mid-1960s and the mid-to-late 1980s.
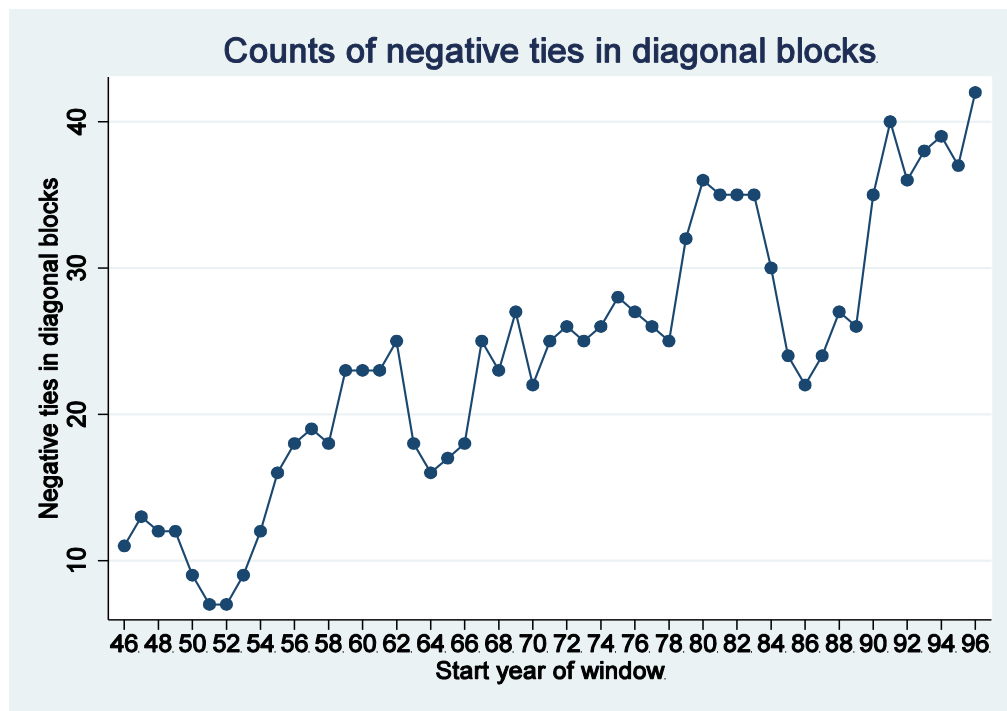

Figure 21. The distribution of negative ties in diagonal blocks over time

Even though the local peaks appear to coincide with global events, it does not follow that they are driven only by them. They may feature also local issues and conflicts. We explore this briefly using Figures 22 and 23 which show the number of negative ties in the large South American block and the block(s) for the Islamic Middle East.
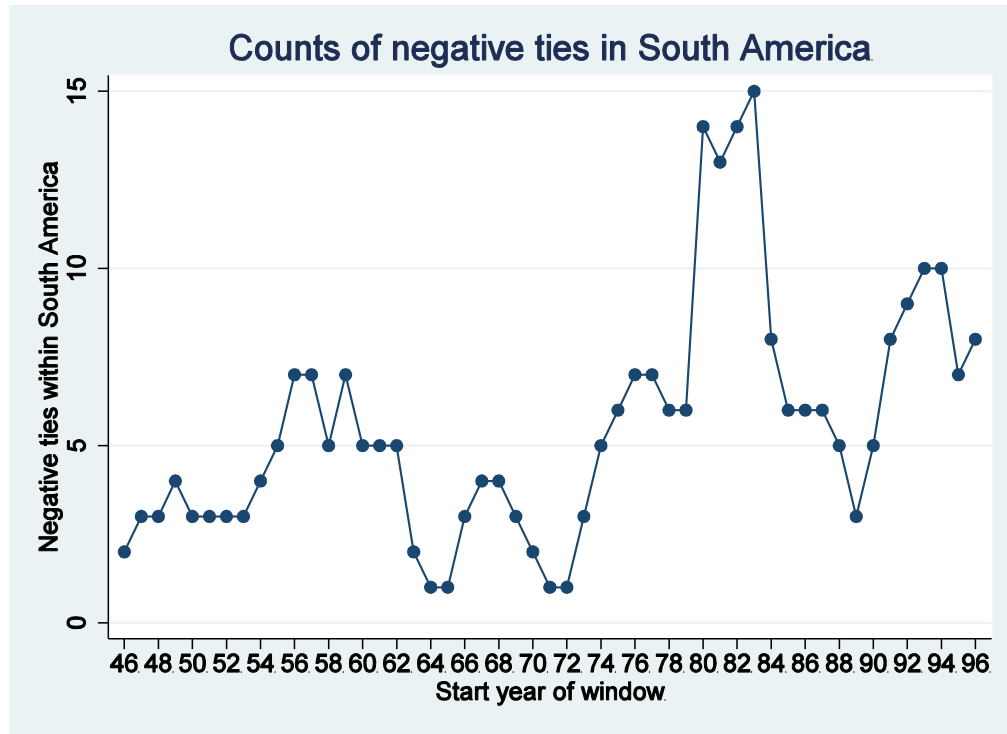
Figure 22. The distribution of negative ties in the South American block

In Figure 22, we focus primarily on the spikes of the mid-1950s, the early 1980s and the early 1990s. The majority of the negative ties for these periods involve pairs of neighboring countries, including maritime borders as well as land borders. Indeed, this holds for all of the windows. The large spike in the early 1980s is more complicated. Grenada was involved in a considerable number of these negative ties. In 1979, a pro-Marxist, Maurice Bishop, took control of the island country through a bloodless coup. Apparently, this did not sit well with other states in the surrounding areas. Certainly, it was not well received by the US Administration. A concerted effort was made to undermine the Bishop regime, culminating in the 1983 US invasion of Grenada. Complicating matters, albeit in a balance theoretic sense, Cuba was an ally of the Grenada under the Bishop regime. A seemingly restricted regime change became a wide regional conflict through the involvement of the USA. Subsequently, the negative ties within South America involved border disputes over rival claims, a recurring feature of this region, that are local rather than global.

Figure 23 provides the same kind of display for the Islamic Middle East. We focus briefly on the spikes in the early 1960s, 1971 and 1988-91. During these periods, as with others, the majority of the negative ties feature pairs of bordering states. During the early 1960s, the majority involve Egypt and Iraq. In 1971, almost half of the ties involve Libya under Gaddafi. Similarly, the overwhelming number of negative ties for 1988-91 featured Iraq.
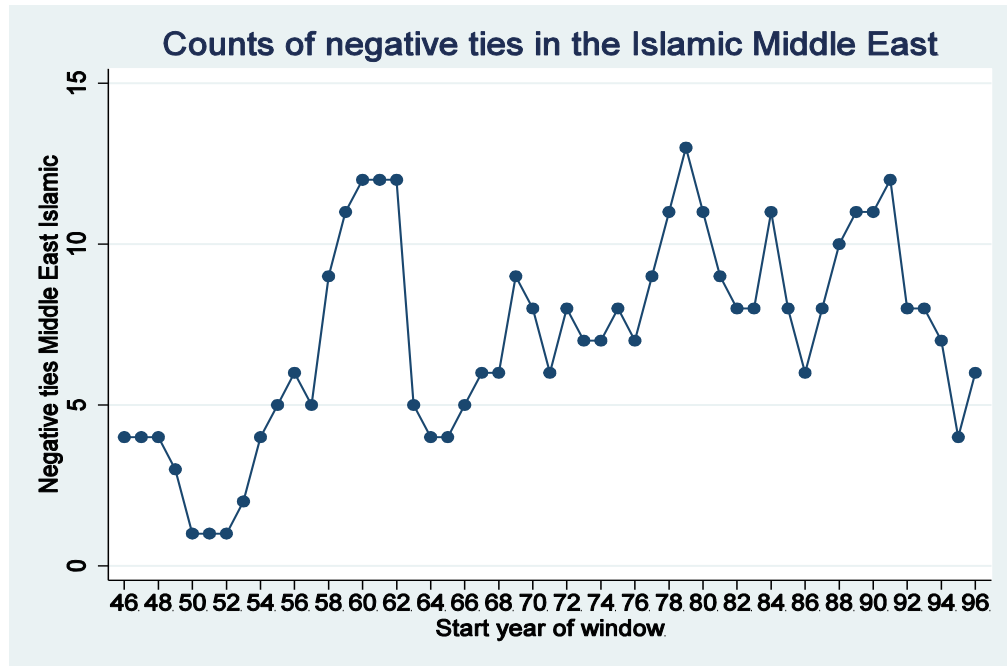
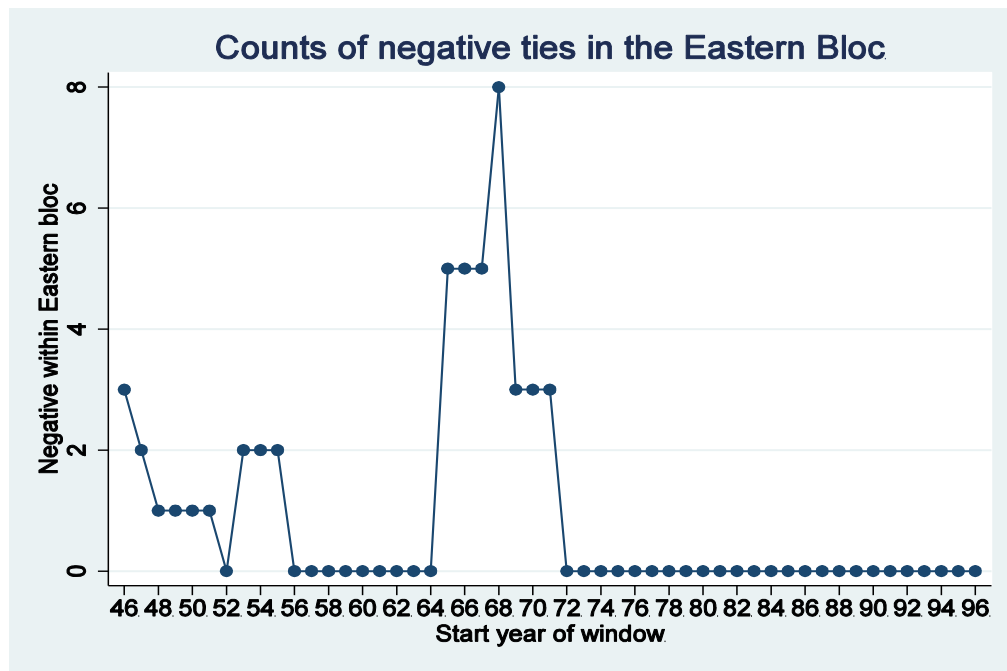Figure 23. The distribution of negative ties in the Middle East block(s)

Figure 24. The distribution of negative ties in the Eastern Bloc

In the main, the number of negative ties in the diagonal blocks for the Eastern and Western Blocs was quite small. One exception, see Figure 24, for the Eastern Bloc came in 1968 with the Warsaw Pact invasion of Czechoslovakia and the time two short periods before and after this event.

The distributions in the Figures 22 and 23, together with the long-running Cold War, suggests the presence of 'contentious' states having an unusually high number of negative ties. Figure 25 shows the distribution of negative ties for the USA and the USSR, the two most contentious states in the era under consideration here. The correlation between these two series is 0.56 suggesting some, but not complete, correspondence between them. Some of their negative ties have to do with attempts to exert greater control in their own geographic spheres and influence states elsewhere.

Figure 26 provides the same distributions for China and Taiwan. The correlation between these two series is 0.69 suggesting a stronger correspondence than for the USA and the USSR. In the period immediately following WWII, China was a particularly contentious state with the number of negative ties being far above those for the primary Cold War protagonists. Of course, China was another major player in the conflict between the East and the West. In contrast, Taiwan, a state over which China sought, and continues to seek control, had a lower profile. Even so, it was elevated following immediately WWII.
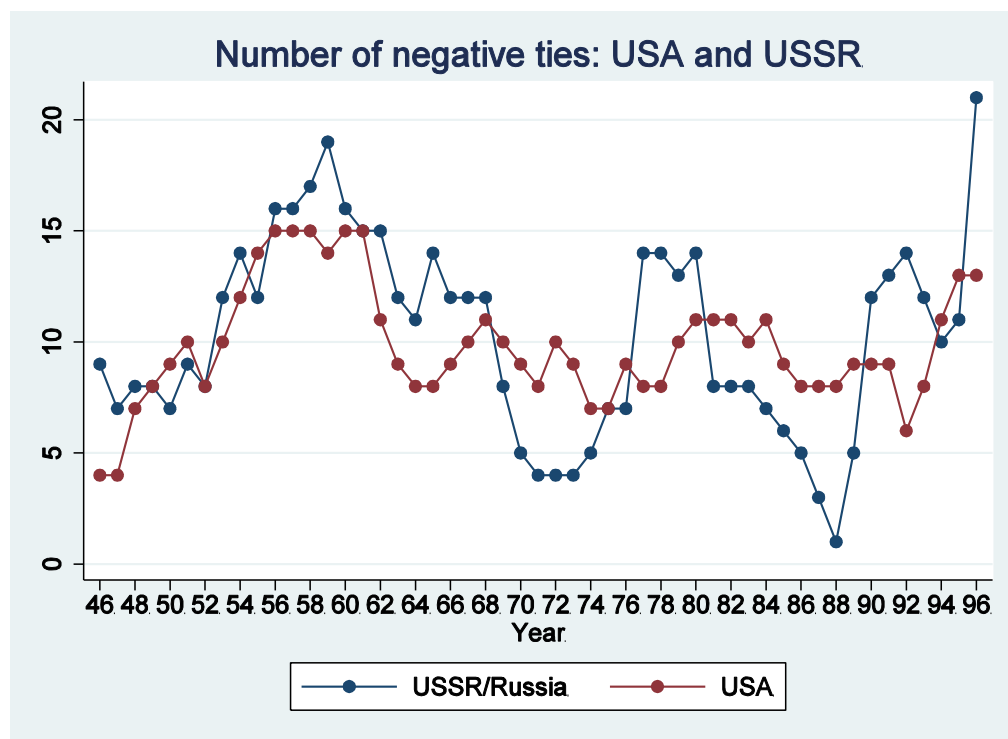

Figure 25. The distribution of negative ties for the primary Cold War protagonists
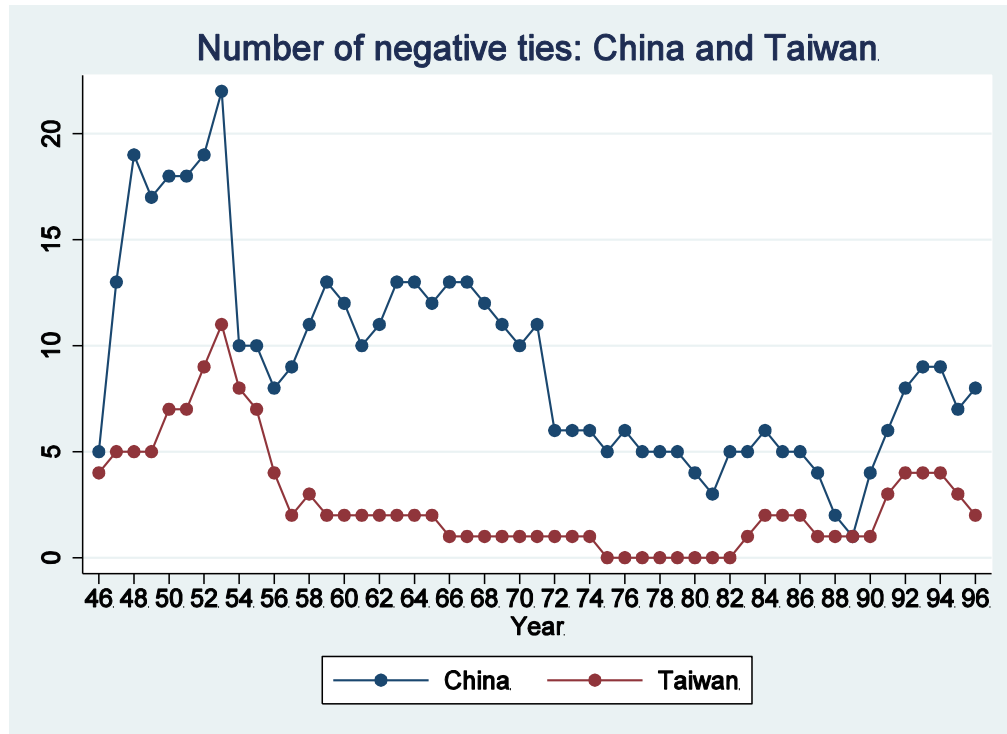
Figure 26. The distribution of negative ties for the China and Taiwan

Figure 27 shows the corresponding trajectories for Iran and Iraq. The high level of negative ties for Iraq, under Saddam Hussein, was discussed in the context of many negative ties within the Islamic Middle East position. It had the highest number of negative ties among all the Middle East countries in this period, along with negative ties to other states. The number of negative ties for Iran jumped after the Shah of Iran was overthrown and replaced by the Islamic cleric, Khomeini.
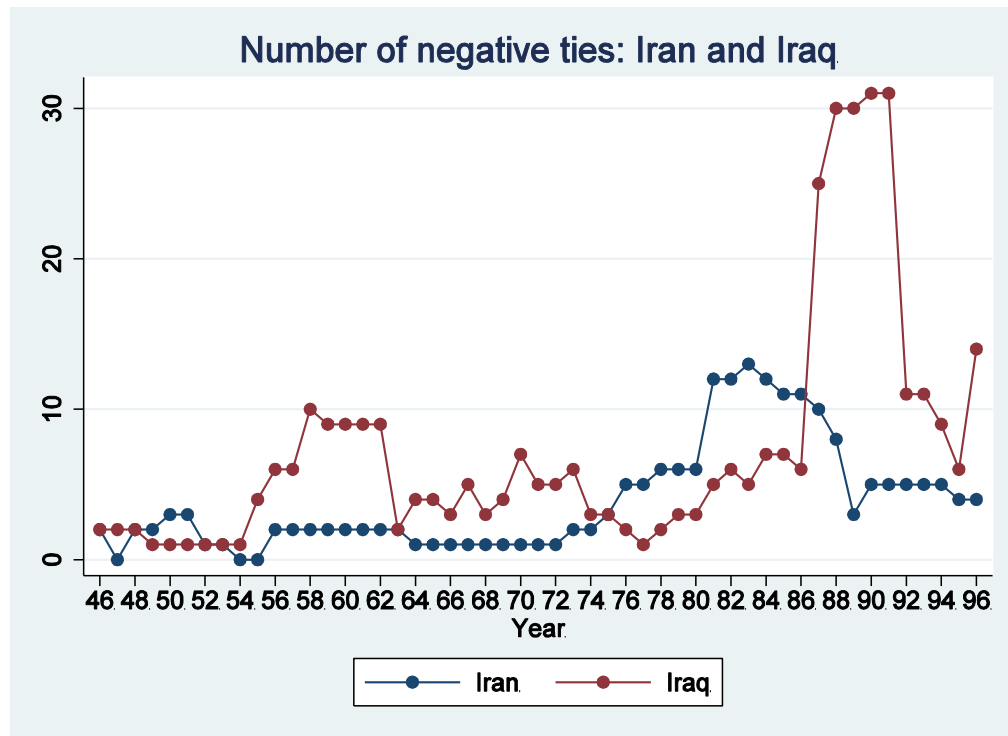
Figure 27. The distribution of negative ties for the Iran and Iraq

The variations in the levels of contentiousness by states over time, along with the dynamics of conflicts, both regional and global, suggest that constructing a general modeling strategy for change in signed networks over time will be very difficult. We turn to considering how changes in negative ties can be interpreted, something done implicitly when we considered contentious states.

6. Interpreting negative ties and changes of imbalance in the international system

As noted in Section 3.3, the early work applying balance theoretic ideas to signed international relations used events as a source for coding the signs of ties between states. Events can be viewed as driven by issues of sufficient importance to national actors. Hensel (2001) joins other scholars in advocating for an issue-based approach to world politics. See, for example, O'Leary (1976) and Diehl (1992) who both lamented the absence of empirical work focusing on issues even though their papers were separated by sixteen years. Datasets have been constructed to address this issue based on the broader CoW database. These datasets focus on specific conflictual events and the issues involved in order to understand the strategies and actions of the actors involved. While this is very useful for understanding *specific* events, we use such event sequences as part of an effort to understand changes in the *overall* pattern of signed international relations. More specifically, we look at local, regional and global events as well as ways they are linked.

Local events

We start with local events and their impacts on imbalance. The negative tie between Argentina and Chile appears frequently in the large positive diagonal blocks of the blockmodel arrays. One reason is their ongoing conflict regarding the Beagle Channel, one of the three waterways between the Atlantic and Pacific Oceans. It has both strategic and symbolic importance for both nations. According the Hensel's (2001) listing, this conflict was a persistent source of conflict from 1904 through 1985, with periodic military confrontations. This negative tie is present in the 1955-58, 1966-69 and 1976-79 windows shown in Figures 8, 10 and 12. It is present also in many other windows. There were clashes in 1967 over the lucrative centolla (southern king crab) industry and fishing rights. The two nations came close to being at war in 1978 regarding rival territorial claims to three islands in this channel. They went to the brink of war again in 1982. Local events can be coupled to regional events. When Great Britain and Argentina were at war over the Falkland (Malvinas) Islands in the South Atlantic, also in 1982, Chile sided with Great Britain.

Ecuador and Peru have had territorial disputes for almost two centuries. Since 1948 there were disputes over their boundary in the Cordillera del Condor, a mountain range in the eastern Andes. Armed conflict in 1981 followed the Peruvian army taking control of three Ecuadorian military outposts. There was a month long war between them over territory claimed by both nations in 1995. The fighting ended with a signed agreement brokered by Argentina, Brazil and Chile with USA involvement. Via third-party involvements, a local conflict became a regional event. A final peace agreement was signed in 1999. Changes in the signs of relations and their impact on imbalance were evident in specific windows.

The Dominican Republic and Haiti divide the Caribbean Island Hispaniola. Conflict between them has lasted for a least a century. Certainly, they do not share the island. At best, they coexist. The dictators controlling these two nations for much of the period we studied used the underlying hostility for their own political ends, with invasions and massacres being ordered and taking place. Many other neighboring pairs of South American states have been involved in repeated territorial disputes, including Colombia and Nicaragua, Guatemala and Honduras, Panama and Colombia, and Honduras and Colombia. See Hensel (2001) for a fuller listing. All are local events creating negative ties in a positive diagonal block and so induced imbalance. When resolved, they lowered imbalance, at least until the next active conflict flared up.

Regional events

Some of the local disputes in South America also involve the USA. Conflicts between Mexico and the USA, especially over the water flow of the Rio Grande, can be viewed as local. However, disputes between the USA and non-bordering South American nations are not strictly local. They stem from the USA attempting to control resources or impose political regimes they support. Among the former efforts are conflicts between Chile and the USA over access to copper and between Panama and the USA over control of the Panama Canal. The latter efforts includes the reaction to the 1954 revolution overthrowing a US-supported dictator and leading to a democratically elected government. This government was ousted by a CIA supported coup to install another dictator, leading to a long civil war. In Cuba, the US supported regime of Batista was ousted by another revolution lead by Fidel Castro. Attempts were made to remove Castro via coups including the failed Bay of Pigs invasion and assassination plots. The CIA supported the overthrow of the dictator ruling the Dominican Republic in 1961. Following the election of Allende as president in Chile in 1970, the USA used covert action to undermine his regime. This resulted in the CIA sponsored violent coup bringing Pinochet to power in 1973. These events

created both positive and negative ties in our data and affected imbalance. There were similar coup attempts, both successful and failed, in Africa and Asia.

Iceland and Great Britain fought three 'cod wars' following unilateral declarations by Iceland extending its territorial waters to 12 miles (1958), then to 50 miles (1972) and to 200 miles (1975). The issue of over-exploiting the cod fisheries by trawlers from Belgium, the Faroe Islands and West Germany, as well as Great Britain, made the conflict a regional one even though there were only two active protagonists in the waters around Iceland. European states acted in concert in an effort to prevent Iceland from protecting its waters and fish stocks. Both the USA and NATO became involved following a threat by Iceland to close an airbase used by their forces.

Conflict over very long contested borders involved the two countries, China and India, having the world's largest populations, with Pakistan also in the mix. The former colonial power, Great Britain, left behind arbitrary borders inviting disputes. Among them, Kashmir has been a persistent flashpoint, one exacerbated by Pakistan's support for its Muslim majority since 1947 after the violent partition creating India and Pakistan. Both nations have been rivals, with each wary of the other. One desolate mountainous area, Aksai Chin, claimed by India and China was one factor in the 1962 Sino-Indian War,[17] the consideration of which continues in the next sub-section.

Global events

The longstanding conflict between China and India expanded as a part of a global conflict when Pakistan leased the Peshawar Air station to the CIA. In 1959, Pakistan's newly installed leader following a coup, permitted U-2 spy plane flights for reconnaissance over the region. When one of these flights was shot down by the USSR and its pilot captured, this triggered another global crisis. Similarly, the conflict between Cuba and the United States in the early 1960s became global over the Cuban missile crisis, with the USA and USSR going to the brink of nuclear war following the discovery of Soviet missiles on Cuba. States within the Eastern and Western blocs mobilized in what appeared to be balance theoretic processes.

Mohammad Mosaddegh became prime minister in Iran in 1951 by winning a democratic election. He nationalized its oil industry which incurred the wrath of those global oil countries operating in Iran. Great Britain and the USA became active in protecting their interests. Both of these states were involved in the coup removing him from power in 1953 and the installation of the Shah of Iran who was sympathetic to UK and US interests. This could have been classified as a local dispute internal to one nation but for the impactful outside involvement. We included the 1954 Guatemalan coup as regional but one of the prime drivers was the US multinational corporation, United Fruit, whose corporate interests were threatened by the actions of another democratically elected government. When dominant world powers are involved, such disputes can be viewed as global, emphasizing the difficulty of separating local, regional and global events.

The 1948 break between Albania and Yugoslavia also supports this argument. When the Albanian Liberation army took control of Albania, Yugoslavia was the first nation to recognize their new government. But Stalin, leader of the Soviet Union, was fearful of Tito's growing power in Yugoslavia. This led to Yugoslavia's expulsion from the communist alliance in 1948. Hoxha,

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[17] This terrain made fighting particularly difficult, especially with heavy weaponry which were very inaccurate in the thin mountain atmosphere. The conflict was described as 'two bald men fighting over a comb', a description used also to characterize the Falklands war.

Albania's dictator, was loyal to Stalin and broke with Tito. These negative ties are evident in Figure 5. Half a century later, the break-up of both the Soviet Union and Yugoslavia were events of global proportions. Many positive ties were broken or created. The same was true for negative ties. The result was a more imbalanced international order in the balance theoretic sense. This can be seen clearly in Figures 14 and 15.

While we have no quarrel with studies focused on accounting for specific conflictual events and the actions of the states involved, we think it is useful to consider the events in the global context of the world as a whole. The specific conflicts discussed briefly in this section are indicative of a general strategy for accounting for changes in the level of imbalance in the overall system. This can be done in a more extended fashion, no doubt by coupling such analyses to the other perspectives regarding international relations. As noted at the outset, we did not see the balance theoretic approach as antithetical to these other broader approaches. Rather than dissecting all of the specific events we combined them so as to consider them in a more general context.

7. Summary and Further Topics

We applied structural balance theoretic ideas to study the signed networks for international relations in data produced by the Correlates of War project. The two methods used were signed blockmodeling using pre-specification to delineate the temporal structure of the world order and tracking the level of imbalance over time. Regarding the former, Section 5 provided a series of these blockmodels and the images obtained from them. In broad terms the fundamental structure was remarkably stable with clearly defined positions that persisted while other positions were being formed. The level of imbalance changed dramatically through time with both increases and decreases. There were no uniform movements of these measures, contradicting decisively the balance theoretic claim that signed network systems move toward balance. In general, they do not.

The set of clusters we identified differed from those identified by Neirop (1989) although there were communalities between them. These differences have two sources. One was the pre-specification of the primary Cold War protagonists as singletons in their own positions as well as Israel. The second source was our use of negative ties in addition to positive ties. Neirop considered only positive ties driven by IGO memberships. It seems imperative that, when partitioning nations according to their network ties, both positive and negative ties be included. See also Doreian et al. (2013) regarding voting in the United Nations General Assembly.

In Section 3.1 we argued that the balance theoretic approach was complementary to the general approaches to international relations outlined in that section. In general, we cleave to this position but have to give more credence to the realist and neorealist positions when the presence of negative ties between nations, especially territorial disputes, is involved. Add the long running Cold War between two super powers vying for control of resources and attempting to forge favorable allegiances and it becomes hard to dispute the basic tenets of the realist approach. No doubt, norms can come into play with the mobilization of coalitions as the liberals and neoliberals claim. But it will be hard to distinguish the mobilization of widely accepted norms from norms advocated by different coalitions when one or more prevail. Even so, trying to locate a coherent position between these two approaches may well be impossible even though there are tenets of each approach having merit. Given the presence of many negative ties, it is hard to support the more abstract functionalist and institutionalist approaches because in emphasizing the needs of the overall system, and the operation of its alleged laws, this approach appears to downplay

negative ties and the potential they have for disrupting any status quo even while considering peaceful resolutions of conflict.

We do not claim the balance theoretic approach, by itself, is fully general in contrast to the claims made by advocates of other approaches. However, we think treating signed relations can be coupled fruitfully to these broader approaches by making the negative ties, and the events generating them, more explicit beyond studying conflictual events as a set of *separate* events ignoring wider contexts. Including balance theoretic ideas can made the general approaches more general. This will require a detailed focus on the signs of ties, the ways they change as well as the reasons for their changes. We approached this in Section 7 but a more systematic effort will be required.

The results we have presented can serve as a starting point for a more sustained approach to signed international relations within a balance theoretic perspective. Our analyses made it clear that the hypothesis of signed systems tending towards balance is untenable. A more fruitful approach is to enquire into the conditions under which, and nature of the social forces whereby, signed networks change in ways that increase or decrease the level of balance in the system. Part of this further effort will involve statistical modeling of change which can take many forms including ERGMs, logit regression (see de Nooy, 2008) and the use of differential equations[18].

In studying change in social networks a distinction is made between endogenous and exogenous change (see, for example, McCulloh and Carley, 2011). For many social networks located in wider contexts, this is an important distinction. However, we wonder if this holds for the full international network. Whether the process is endogenous or exogenous for a single world system of nations will be very hard to decide in a satisfactory fashion. We have treated change as an endogenous process. Yet we also write about shocks to the system. Events such as invasions, wars and external interference can be viewed as both exogenous and endogenous. For example, when the USA sponsored/engineered coups in many parts of the world, these can be viewed as exogenous for the states where the coups took place. But they are also intrinsic to the policies of the US over long periods of time and endogenous for the system. We suspect separating endogenous and exogenous components in a clean way will be impossible.

Generating a general model for change in a dynamic system having signed ties will be a challenging task given the arguments outlined in Section 6.3. Certainly, this holds for international relations but we suspect it holds also for small groups given the limited evidence provided by Doreian and Krackhardt (2001) using temporal data. The notion of dealing with both local and global processes is applicable to all signed networks, one largely ignored in the studies of small human groups also.

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[18] Some caution is merited here. Marvel et al. (2011) use a differential equation model, $dx_{ij}/dt = \Sigma_k x_{ij}.x_{jk}$ to study change in signed networks. The term x_{ij} is the value of the tie from i to j with x_{jk} being the corresponding value of the ties from j to k. This equation makes it clear why the signed networks they study have to be complete: if either x_{ij} or x_{jk} is 0, there is no contribution to the forces for change.

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Appendix

As a partial step towards looking more closely at the generation of signed ties we consider the quintessential local ties between states: sharing a common border. Adjacency can be seen as relevant for the generation of positive and negative ties between states. For these analyses, a shared border included both land and maritime boundaries. It was straightforward to construct the adjacency matrix for all states using maps and checking lists of boundaries. For each window, we constructed the adjacency matrix for those states in the network at that time. Separate matrices were constructed for positive and negative ties. Using quadratic assignment regression, QAP, (see Dekker *et al.* 2007) we regressed each signed relational matrix on the corresponding shared border matrix. We used only 26 windows—because adjacent windows have a heavy overlap. In each, the relationship was significant. The variance explained for each window is plotted against the start year of the window in Figure 28.
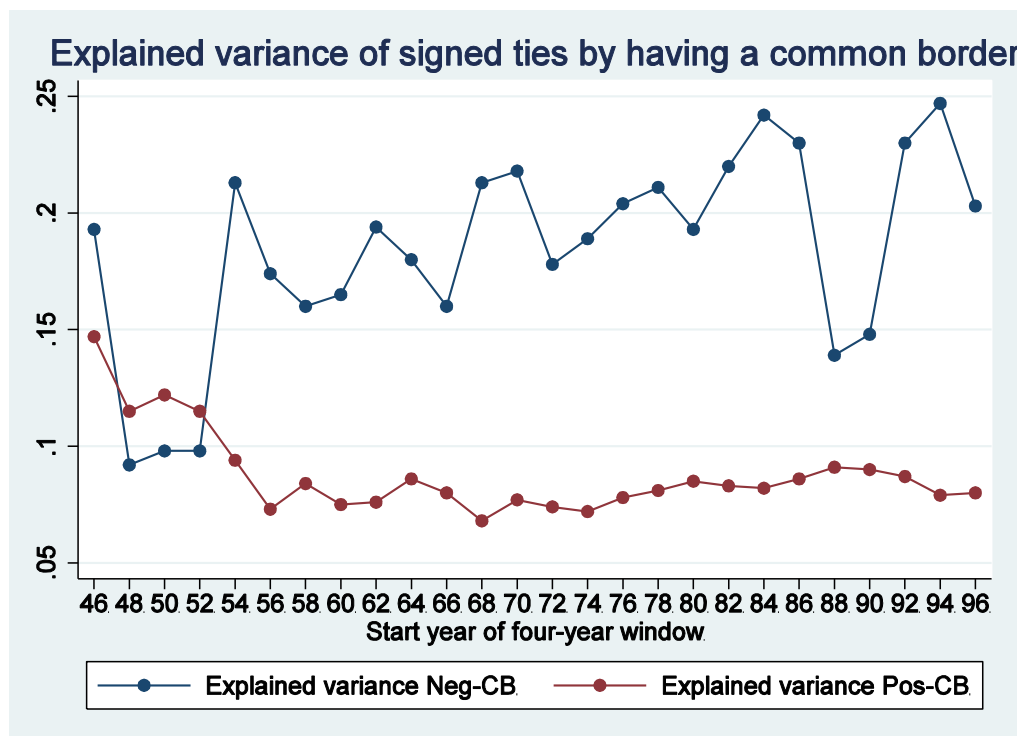

Figure 28. Explained variance of signed ties by sharing a common border

The variance explained differed markedly for the negative and positive ties. This ranged from 9.2% (1948) to 25% (1994) for the negative ties. The range for the positive ties was from 6.8% (1968) to 15% (1946). Further, it varied greatly over time for the negative ties. In the main, the local negative ties are border disputes that can erupt at any time even though they may be dormant for long periods. The lower explained variance for the positive ties may be due to the larger number of these ties that are generated through widely dispersed memberships in IGOs and broad alliances. Even though adjacency remains fixed, it impact on the presence of ties can vary considerably.