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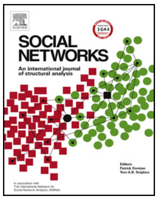

The influence of structural balance and homophily/heterophobia on the adjustment of random complete signed networks

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ABSTRACT

Inconsistencies in the empirical support for balance theory are often explained by recourse to competing mechanisms that reduce the total degree of balance in the network. These mechanisms (such as differential popularity and subgroup hostility) may depend on exogenous properties of the nodes. This paper offers an alternative explanation for the departure of networks from global balance, according to which the myopic nature of sign adjustment in accordance with a pressure for local balance may reduce the global degree of balance and impede the formation of groups, whereas competing mechanisms that rely on exogenous node properties (e.g., homophily) facilitate these processes. The paper describes a set of simulations designed to study the evolution of complete signed networks under a local sign-change regime, induced by structural balance, homophily and heterophobia. Tolerance for local violation of balance and homophily is allowed to vary with a consequent impact upon the global degree of balance and group formation processes. We find the conditions under which the pressure towards local homophily and balance operate against each other culminating in a (locally) dynamic yet (globally) stationary state in which homophily adjusts towards group formation and balance undermines this process.

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1. Introduction

Social structures, which may conveniently be depicted as signed graphs or di-graphs with positive (P) and negative (N) edges on n labelled nodes, may experience the joint impact of both structural balance (Cartwright and Harary, 1956) and homophily/heterophobia (McPherson et al., 2001; Wimmer and Lewis, 2010). These are just two amongst other mechanisms influencing the adjustment dynamics and eventual disposition. This paper is concerned with such an impact in the context of an ongoing search for a parsimonious model of group formation. It builds upon several previous papers, which analyse the role of balance in the adjustment of randomly generated complete and incomplete structures under the auspices of both sign change and link deletion processes (Abell and Ludwig, 2008; Deng and Abell, 2010; Deng et al., 2012).

The general conclusions which may be drawn from these papers are first, that the local adjustment[1] of links in accordance with balance does not necessarily increase the overall degree of balance[2] in the network, this result anticipated by Doreian and Mrvar (1996) when they note that under the auspices of the balance mechanism, “as each actor is involved in many triads, changes towards balance in one triad may move other triads into imbalance”. More generally, Hummon and Doreian (2003) show how uncoordinated sign changes aimed to reduce local imbalances do not necessarily increase the global balance of the system. However, these authors claim that under the auspices of the balance theorem micro-changes should eventually lead to increasing balance in the system. The studies described above (and indeed those described in this paper) do not support this result.

A second conclusion is that the degree of balance is not materially altered by: (1) whether the initial structure is generated randomly or rather by preferential attachment, (2) the size of the

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[1] By local adjustment we imply that links change sign (or, in the case of deletion dynamics, are severed) in particular imbalanced 3-cycles without taking account of the role of the link in any of the, up to $n-2$, other 3-cycles in a complete structure. We will argue that local adjustment is probably more realistic than global adjustment. We also concentrate upon 3-cycles as our evidence suggests that larger cycles are not unstable. However, computing balance in terms of 3-cycles only and cycles of all lengths are identical procedures in complete structures.

[2] The degree of balance is given by the ratio balanced 3-cycles (triangles) to total 3-cycles in a structure. Balanced 3-cycles contain either one or three positive links.

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network ($n > 20$), (3) the degree of completion (density) when above about 20%.

The theory of balance leaves open the conditions under which balance will surrender either a single or two plus-sets (Cartwright and Harary, 1956; Davis, 1967). In addition though balance theory has largely been treated as deterministic, the issue arises as to how tolerant near-balance is to a small number of imbalanced 3-cycles. A theorem due to Easley and Kleinberg (2010) addresses this issue and the theory of generalised balance, formulated within the framework of block modelling (Doreian and Mrvar, 2009, 2014) allows for departures from balance under the auspices of other mechanisms (see below). Davis (1967) proposed that all negative 3-cycles may well be relatively stable and if so then a completely balanced network can consist of more than two plus-sets ($k > 2$). Incomplete structures will allow for null relations internal to and between plus-sets and usually models unreciprocated (i.e. non symmetric) positive and negative links as equivalent to symmetrically related pairs.

The universal instability of one negative link 3-cycles has also been questioned (Doreian and Mrvar, 2009) permitting groups consisting of either mutual positive and negative related “mediators” with positive links to other groups which are themselves predominately negative linked to each other. This licences “relaxed balance” which in the framework of the cluster minimisation algorithm produces generalised block modelling where positive blocks can appear off and negative blocks on the main diagonal of the associate matrix. Extending this line of analysis, Doreian and Mrvar (2014) offer an explanation of relaxed balance called “Structural Balance with Differential Popularity and Mutual Dislike Block Model” (SB-DP-MD Model). They found empirical support, even with limited Newcomb (1961) and Sampson (1968) data, for differential popularity (positive related mediators) and mutual hostility (negatively related mediators). This brings into prominence the issue of multiple mechanisms in the evolution of signed structures which in a rather restrictive framework of the interaction of balance and homophily is the subject matter of this paper. Indeed, Doreian and Mrvar (2014) remark, “Increasing concentration of receiving both positive and negative ties could rest on clearer perceptions of actor attributes...”, i.e., mechanisms which depend on properties that are exogenous to the network structure, just like homophily and heterophobia which we study below.

Since adjustment to more than one possible stable state is predicted by the interaction of balance theory with other mechanisms (and, indeed, by balance in isolation) the conjoint theory cannot be regarded as complete without a further specification of the adjustment processes (Abell, 2015). The dynamics could be determined by the proportion of positive and negative links formed in the early period of the evolution of the structure when balance would constrain the transitive closure of 3-cycles (Doreian and Krackhardt, 2001). This would, however, require actors to anticipate the stress of imbalanced cycles and consequently to avoid them. It may be useful to conceive this early period as one where the dynamics are solely governed by pair relations progressively giving way to adjustment according to the wider structural precepts of balance. We adopt this viewpoint, and conceive balance as an adjustment mechanism of a structure, evolved for other reasons. The stress is experienced after the links are established. Clearly, dynamics could involve both adjustment and initial constrained transitive closure but in this paper we focus upon “later” adjustment. Separation in this respect is not entirely satisfactory but we attempt to justify it below.

The dynamics of both weighted and binary symmetric positive and negative links have been studied, combining a mixture of simulation and analytical results. Anatal et al. (2005, 2006) have shown that in complete structures with symmetric binary links, the globally constrained adjustment of links can sometimes fail to reach balance, becoming “jammed” whilst still imbalanced. Nevertheless, simulations of a local adjustment rule (globally unconstrained) which allows that a randomly selected imbalanced 3-cycle flips the sign of a constituent link, without regard to the impact on other cycles, can produce a system in a (non-absorbing) stationary state, in which half the 3-cycles are balanced and half of the links are positive, assuming the probability of flipping any link in an unbalanced 3-cycle is constant. Moreover, the system will stay in this unbalanced, stationary state for a period of time that increases with the number of nodes n like e^{n^2}.

Kulakowski et al. (2008) studied weighted links in continuous rather than discrete time under global adjustment and found a sharp transition from two plus-sets to one, with increasing initial proportion of positive links. Using weights and a global adjustment rule, Marvel et al. (2011) developed a closed form solutions over a wide range of initial proportions of positive and negative links, finding that balance is achieved in finite time though unrealistic weightings are required.

Deng and Abell (2010) studied local adjustment as a Markov process with varying transition probabilities between the four types of 3-cycles. The density of links, initial proportion of positive links and network size were allowed to vary. Local adjustment was not found to increase the degree of balance beyond a stationary state in which 50% of the 3-cycles were balanced, unless the transition probabilities reflected a strong bias towards positive links when one plus-set ($k = 1$) is favoured (Anatal et al., 2006). These results are immune to a range of network sizes above $n = 20$ and densities larger than 0.2. However, below these values the size of the fluctuations is relatively large thanks to the discrete nature of the system. Groups are formed according to the structural theorem and the system grinds to a halt upon reaching global balance, which is an absorbing state.

The picture that emerges is one whereby balance is far from an open and shut matter and where it is operative it will likely be attended by other mechanisms. However, many of the empirical studies are cross-sectional in nature with limited over time observations (Newcomb, 1961; Sampson, 1968) and it is somewhat unclear whether, at the point(s) where the structure is studied, it has achieved a steady state or not. Doreian and Mrvar (2009, 2014) demonstrate that the global degree of balance is over time increasingly less dominant over the other structures they trace. Whether in the longer term these trends are monotonic is an unresolved issue.

Although it falls well beyond the ambitions of this paper, the current state of the literature suggests that the interaction of all of, at least, the following mechanisms will eventually need to be incorporated into both the formation and adjustment of signed networks: reciprocity, mutuality, completion (density), preferential attachment, balance homophily/heterophobia, differential popularity/unpopularity and the extent to which groups become cognised by network participants. Only when multiple mechanisms are in place can we hope to achieve in simulations structures similar to those observed in empirical settings. Furthermore, the size of the network and its initial state (e.g., the proportions of positive and negative links) may also be pertinent. Although it is not our intention to re-produce real networks at this initial stage, this preliminary exploration of simulations of balance may allow us to do this in the future.

Homophily (McPherson et al., 2001) disproportionately generates positive links between pairs of identically exogenously and fixed labelled nodes, though the literature rarely designates the sign of the links. In the context of signed structures we may add that heterophobia will generate negative links between exogenously labelled nodes which are differently labelled. The exogeneity could be dropped allowing for the co-evolution of node attributes and links.

A homophilic and heterophobic (where no confusion is caused we shall use the term homophily to cover both tendencies) structure is balanced, though a balanced structure is not necessarily

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