Loss of structural balance in the cross-correlation networks of financial market signals the onset of major crisis

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Financial markets are complex systems comprising a large number of interacting agents who are subjected to intermittent shocks of external information, and as such provide scientists with a rich source of data for the purpose of identifying possible universal patterns characterizing self-organizing collective phenomena in economics [1]. Following the crisis and Great Recession of 2007-2008, there has been increasing interest in understanding possible phenomena that can give rise to systemic risk in financial networks and in uncovering patterns that may be used as signatures for alerting us to impending large-scale collapse of the system [2]. Here we present our analysis of the long-term dynamical features of a financial market, viz., price movements of several hundreds of equities listed in the New York Stock Exchange (NYSE) for a period of nearly nine decades (1925-2012), with the aim of determining whether robust empirical indicators of impending economic crisis can be extracted from the data. We split the data into 85 overlapping periods of 1001 days - and in each of these periods we focused on the 300 stocks having the highest average price in that interval among all the stocks. Following earlier studies [3, 4] we have used the cross-correlations in the fluctuations of the daily closing price of different stocks (measured by daily log-returns) to construct a network which characterizes the structure of interactions in the market for each of the 85 intervals. The cross-correlation matrix $\mathbf{C}$ for each interval is subjected to spectral analysis [1, 3, 4] splitting it into three components corresponding to (i) the overall market mode $\mathbf{C}^{global}$, (ii) industrial sector or community modes $\mathbf{C}^{group}$ that correspond to significant interactions between related stocks and (iii) idiosyncratic modes $\mathbf{C}^{random}$ that are indistinguishable from stochastic fluctuations. Next, we exclusively use the cross-correlation components that are contributed by intra-group interactions to construct a network of statistically significant interactions among the stocks. We construct the adjacency matrix for each period by connecting two equities i and j with a positive (negative) link if the corresponding matrix entry $C_{ij}^{group} > 3\sigma_r$ ($< 3\sigma_r$, respectively), where σ_r is the standard deviation for the distribution of matrix entries. The resulting signed, undirected networks representing the market for each of the 85 periods were then analyzed using a number of graph metrics, and in particular, tested for the occurrence of *structural balance*.

The concept of structurally balanced networks was originally introduced in the context of social interactions [5] and refers to systems having positive or negative links arranged such that they do not give rise to inconsistent relations within cycles in the network. An example of arranging such links so that they give rise to an inconsistency (resulting in loss of balance or *frustration*) occurs when 3 nodes A, B and C are connected to each other such that the links between A,B and B,C are positive, but that between A,C is negative. If the node states can be in one of two states (e.g., "up" or "down"), it is easy to see that no possible assignment of states exist that satisfy all the given relations between the nodes. In general, a system loses balance if triads of connected nodes possess an odd number of negative relations. It is also known that a balanced network can be always mapped to a system comprising two subnetworks, with only positive interactions existing within each subnetwork, while links between the two are exclusively negative [6]. The possibility of loss of balance in complex networks being correlated with catastrophic events have earlier been explored in the context of international relations and the outbreak of war [7].

Our analysis of the networks for the 85 successive periods reveal significant temporal variation in the frequency of negative relations between various equities that often appear to increase immediately before or during intervals identified with major recessions in the US economy [Fig. 1 (a)]. The number of connected triads (linked by statistically significant cross-correlations) that are observed also vary over a large range spanning 5 orders of magnitude but become particularly large only during the period preceding (and following) the two particularly catastrophic events that occurred during the period

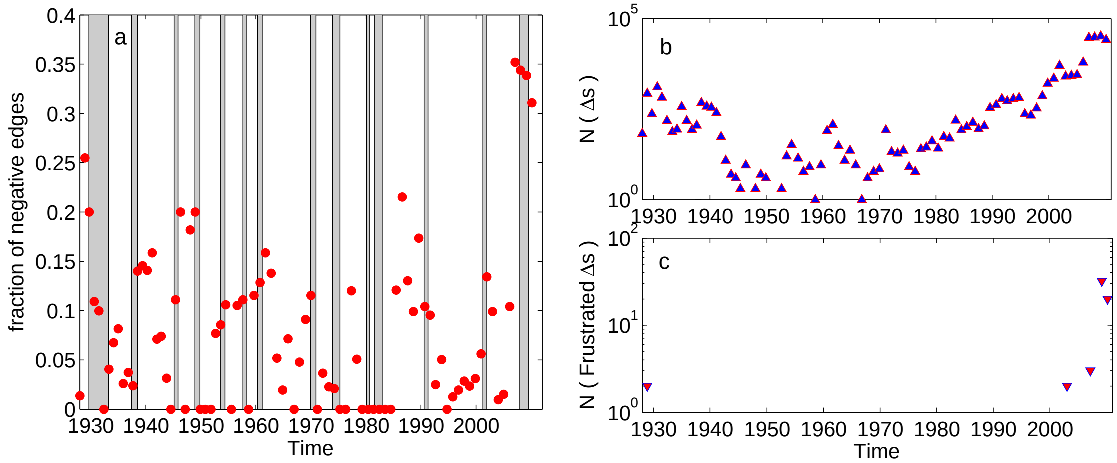

Figure1: (a) The ratio of the number of negative links to the total number of links corresponding to statistically significant cross-correlations between 300 stocks of the NYSE shown for 85 different time-intervals spanning the period between December 31, 1925 to February 1, 2012. The shaded boxes mark periods identified as corresponding to recessions of the US economy by the National Bureau of Economic Research (NBER). (b) The total number of triangles and (c) that of frustrated ones (i.e., structurally unbalanced triads comprising an odd number of negative links) formed by the links corresponding to statistically significant cross-correlations shown for the same period as in (a). Note that while the number of negative links as well as the total number of triangles show high values for many eras (the former usually peaking prior or during periods of recession), frustrated triangles occur in the period under study only around the onset of major economic crises, viz., the 1929 Great Crash and the 2007-2009 Crisis.

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under study, viz., the Great Depression of the 1930s and the 2000s Crisis [Fig. 1 (b)]. However, most strikingly, the number of frustrated triads which measures the extent of the loss of structural balance in the network of interactions only show non-zero values in the periods just prior to the 1929 crash and the 2008-09 financial meltdown [Fig. 1 (c)]. It is tempting to conclude that structural balance (or more appropriately, the lack of it) can act as a very robust indicator for signaling the onset of major economic crises. Our results suggest that investigating measures of structural balance in networks characterizing interactions between various dynamical components of the economy and, in particular, those arising in the context of systemic risk may lead to significant insights for understanding how local perturbations propagating through complex networks can occasionally trigger global catastrophes.

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