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Statistical properties of Corporate Board and Director Networks

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The boards of directors of the largest corporations of a country together with the directors form a dense bipartite network. The board network consist of boards connected through common directors. The director network is obtained taking the directors as nodes, and a membership in the same board as a link. These networks are involved in the decision making processes relevant for the macro-economy of a country. We present an extensive and comparative analysis of the statistical properties of the board network and the director network for the US Fortune 1000 corporations and the Italian Stock Market corporations. Some statistical properties are found to be specific to the director networks and the same in all the different cases of study. Some other statistical properties are instead found to be specific to the board networks but again the same in all the different cases of study. In particular the connectivity degree distribution of the director network has always a power law tail with similar exponent. On the contrary, the connectivity degree distribution of the board network is always rapidly decreasing. All the considered networks are Small World networks, assortative, highly clustered and dominated by a giant component. The presence of lobbies in boards turns out to be a macroscopic phenomenon in all cases of study. These results suggest a common underlying mechanism shaping the corporate control network over time and over different countries and should be taken into account in models of macroeconomic dynamics.

INTRODUCTION

The boards of directors of the corporations of a country form together with the directors a bipartite network. The board network consist of boards connected through common directors. The director network is the network obtained taking the directors as nodes, and a membership in the same board as a link. It is well known that the director network of the largest companies in the US and in other countries has a high degree of interlock, meaning the fact that some directors serve on several boards at the same time so that many boards are connected by shared directors. Interlock convey information and power (i.e. banks lending money to a firm can use interlocked directors in firms of the same industrial sector to get information about the real risk of the loan).

It has been argued that in a capitalistic economy, as a consequence of economic power concentration, "a special social type emerges spontaneously, a cohesive group of multiple directors tied together by shared background, friendship networks, and economic interest, who sit on bank boards as representative of capital in general" [1]. Now, while part of the public opinion has been since long ago concerned about the fact that the corporate elite would represent a sort of "financial oligarchy controlling the business of the country" [2], stockholders are more concerned about the effectiveness of boards in overseeing management.

Board's directors should in fact monitor managers's strategies and decisions to the interest of stockholders. Recently, after several cases of bankruptcy in the western countries, the role of boards in the decision making process is under examination and more sophisticated forms of corporate control are often advocated in the public opinion.

Two issues raise very naturally about directors interlock networks: the first is the characterization of the topological properties of the board network and the director network. Because large corporations' boards are organized in a network leading the economy of a country, the second issue is of course how the structure of these networks influences the decision making process in which directors are involved.

Davis and collaborators have shown [3] that the director network and the board network of the Fortune 1000 corporations has Small World properties in the sense of Watts and Strogatz [4].

Newman et al. [5] have applied on the same data set a random graph model showing that using the generating function method, it is possible to reproduce very accurately the degree distribution of the director network. On the contrary, their model fails in predicting the degree distribution of the board network. In fact the director network turns out to be *assortative* as observed commonly in social networks, meaning that directors with high (low) degree tend to be connected to directors with high (low) degree. As a consequence even if the random graph model predicts the right degree distribution for the director network it underestimate the number of boards with high number of interlocks and with small number of interlocks.

As a general empirical finding, social networks are characterized by assortativity and high *clustering coefficient cc* (the latter measuring the average fraction of connection between the first neighbors of a node out of all the possible connections among them).

Newman et al. [7] have recently argued that the presence of groups or communities in a social network is able to produce alone both assortativity and clustering. They develop a model in which nodes belong to one or more groups and have probability p to be connected to another node of the same group. Instead they are never connected to nodes of groups they do not belong to. If groups have heterogenous size, than nodes who belong to a small group tend to have low degree and are connected to others in the same group, who also have low degree. This model explains about 40 p.c. of the observed assortativity in the Fortune 1000 network. This means that some additional sociological mechanism is at work, probably the fact that new board members are more likely to be recruited among those who are already connected to some of the current board member.

Some recent works have focussed on the influence of the structure of the interlock network on the decisions made by boards. There are essentially two kinds of decisions a board is faced to. *Local* decisions regard topics specific to the board, such as the appointment of a vice president, for which boards can be assumed not to influence each other. Battiston et al. [9] investigate by means of a decision making process model how a minority of well connected directors can influence significantly the decision of the majority.

By contrast, *global* decisions concern topics of general interest to the economy such as whether to increase or decrease investments in development or in advertisement, which depend on the belief in economical growth or recession. In these cases, decisions previously made in some boards might influence other boards, through the presence of shared directors.

In a recent model, Battiston et al. [10] investigate the conditions under which a large majority of boards making a same decision can emerge in the network. In their model board directors are engaged in a decision making dynamics based on "herd behavior" and boards influence each other through shared directors. They find that imitation of colleagues and opinion bias due to the interlock do not trigger an avalanche of identical decisions over the board network, whereas the information about interlocked boards' decisions does. There is no need to invoke global public information, nor external driving forces. This model provides a simple endogenous mechanism to explain the fact that boards of the largest corporations of a country can, in the span of a few months, take the same decisions about general topics, despite the a priori uncertainty of the economic trend.

The results of this model find some support in previous studies carried on in sociology. Haunschild [11] demonstrates the role of inter-organizational imitation of managers in US corporate acquisition activity in the 80'. Davis and Greve [12] have studied the diffusion of governance practices such as the so called 'poison pill' and 'golden parachute', throughout the board network of the US largest corporations in the 80' (The poison pill is a counter measure against hostile takeover allowing "target shareholders to acquire shares at a 50 % discount if an hostile shareholder passes a certain ownership threshold").

Similar issues concern of course not only the boards of large corporations, but many governance structure in social institutions. Boards and directors networks have the advantage to be a relatively well defined framework for which data are publicly available.

In this paper we adopt a complex networks approach, thus going far beyond the analysis of the average quantities involved in the definition of a Small World (average clustering coefficient and average shortest path).

We report an extensive and comparative analysis of the topological properties of the board network and the director network of two cases of study: the corporations of Fortune 1000 for the year 1999 and the companies quoted in the Milan Stock Exchange Market for the years 1986 and 2002. We show that several statistical properties are common to the different data sets despite the fact that they refer to different years and countries. These facts suggest that some universal formation mechanism is at work for this kind of networks, which is not captured in a satisfactory way by the existent models of network formation.

Our analysis indicates that: all the considered networks are Small World networks assortative highly clustered. They are all above the percolation threshold in the sense that they have a strongly connected giant component. The connectivity degree distribution of the director network has always a power law tail with similar exponent. On the contrary, the connectivity degree distribution of the board network is always rapidly decreasing. The director networks have common properties in the different cases of study. The board networks have different properties with respect to the director networks, but these properties are essentially the same in the different cases of study. The presence of a *lobby* [9] in a board, turns out to be a macroscopic phenomenon in all cases of study.

DATA ANALYSIS

The data sets we consider span over different countries and over time. We analysed the composition of the boards of the Fortune 1000 corporations in 1999 (1000 companies) and the boards of the quoted companies in the Milan Stock Market in two temporal snapshots: 1986 (220 companies) and 2002 (240 companies). Data are taken from technical publications used by stock market operators [13–15].

In this paper we map the set of corporate boards into a bipartite graph and we perform a thorough statistical analysis: we analyse the average quantities, the statistical distributions and the degree-degree correlations. Finally, we focus on the econophysical significance of such an analysis, exploring the picture of the market emerging from it.

The bipartite graph structure

A bipartite graph is composed by nodes belonging to two separate classes, and one edge connects always a node of one class to one of the other. An example is reported in **figure 1**. This is a suitable structure to represent our systems, since each node represents either a director or a company, and we put one link between them, if the first sits in the board of the second. We call an *interlock* a link between a director of one company to another company. In other words, we have an interlock when the same director sits in the boards of two companies. If two directors of a given board, serve together as well in another board, we then have a *multiple interlock.* we call *lobby* the subset of directors of a boards who serve on an outside board together with a director of the present board (after [9]). In fact, the members of such a sub-group will be more strongly connected to each other than with the other members of the board, and they will have common interests outside the company under consideration.

As it is well known, two one-mode networks can be extracted from a bipartite graph. Each of these is composed by all the nodes belonging to one class only, conveniently connected. In particular, we will join two companies (directors) if they have at least one director (company) in common. It is worth highlighting that, the existence of interlocks in the bipartite graphs is a necessary condition for the connectedness of the one-mode projections. For example, if there weren't directors administrating more than one company, the projections would be split up into small clusters completely connected inside themselves, but without any connections between each other, each corresponding to a company. It is worth noticing, as well, that a concept of weight naturally arises from the procedure of projection. Indeed, we have very different situations if -for instance- two companies are connected by only one director, or if they have two or more common directors. Such a difference can be included in a weight attached to each edge, whose value reflects the strength of the interaction between the two nodes it connects.

A bipartite graph can be represented in a compact way by means of its adjacency matrix:

$$C_{\alpha i} = \begin{cases} 1 & \text{if } \alpha \text{ sits in board } i \\ 0 & \text{otherwise} \end{cases} \tag{1}$$

This is an $M \times N$ matrix, M being the number of directors, and N being the number of companies. This is a binary matrix, and in general it is neither square, nor symmetric. For the one-mode projection relative to the companies, we should take into account that the number of directors sitting in each of the boards of companies i and j, is equivalent to the number of paths of length 2 connecting i and j in the bipartite graph. Therefore, this number, that gives the weight of the connection between i and j, can be expressed in terms of the adjacency matrix. In the end, if we define the adjacency matrix of the projection as

$$B_{ij} = \begin{cases} w_{ij} & \text{if } i \text{ and } j \text{ are connected with weight } w_{ij} \\ 0 & \text{if } i \text{ and } j \text{ are not connected} \end{cases} \tag{2}$$

then, we obtain that its entries are:

$$B_{ij} = \sum_{\alpha} C_{\alpha i} C_{\alpha j}. \tag{3}$$

It is easy to derive a general relationship between the adjacency matrix of the bipartite graph and that of the one-mode projection.

$$B = C^T C. \tag{4}$$

With the same reasoning we derive the corresponding result for the directors' projection.

$$D_{\alpha\beta} = \sum_i C_{\alpha i} C_{\beta i}. \tag{5}$$

And,

$$D = C^T C. \tag{6}$$

This representation stores most of the information regarding the networks into a compact matrix. It will be used in our further studies on bipartite graphs. For the moment, we notice that the matrix elements have a straightforward interpretation. While the off-diagonal entries are essentially the weights of the edges, the diagonal entries, are, respectively, the size B_{ii} of the board of the company i, and the number $D_{\alpha\alpha}$ of boards director α serves on.

Average quantities

In **table I** some of the global and average values describing the two projections are reported. For sake of comparison, we reported in the same table and in the next, the values corresponding to two well studied networks: cond-mat [17] and A.S.Internet 1999 [16]. The first one is the network of authors of the papers of condensed matter physics archived at Los Alamos Laboratories. The second, is the Internet map, as it appeared in 1999, considered at the autonomous systems level. While the first network is a social one, and we expect to observe some similarity with the ones of the directors we are studying, the second one is a technological network.

Observing the projections from a global point of view, the first thing to notice is the presence of a maximal connected component. The fraction N_c/N of nodes belonging to it is over the value of 0.8 for all the projections. Since the connectedness derives from the interlock, we can conclude that the phenomenon of the interlock is strong enough to bring the projected networks above the percolation threshold.

Another interesting aspect to be noticed, is that both the projections are much less sparse than the comparison networks. A measure of the sparsity of a network is the value of its average degree k compared with the one it would have if it were completely connected k_c (equal to $N-1$, where N is the number of nodes). The value of k/k_c for the boards projection is bigger than that for the directors projection, which is anyway one order of magnitude higher than that of cond-mat and Internet.

Finally, the network displays small-world property. The average distance between two nodes of the maximal connected component is always of the order of few units, thus of the order of $log(N)$, N being the total number of nodes. Moreover, the clustering coefficient is exceptionally high, reaching values around 90% in the directors network and around 35% in the boards one. This indicates a remarkable tendency towards clicquishness in both of them.

Fluctuations in the average quantities can be observed both in space and time. Such a behaviour can be essentially reduced to the fluctuations in the dimensions and number of links of the networks. As far as the Italian market is concerned, it should be taken into account that an element of noise was introduced when collecting data. Indeed, the 1986 data include the so called *restricted market*, i.e. that composed by companies listed only in certain cities (for example, only Milan or Rome, and not in the whole national market). This slice of the market is absent in 2002 data, and this accounts for most of the fluctuations in the global quantities describing the two Italian networks. Nevertheless fluctuations do not affect the statistical properties.

Distributions

Let us now move from the average quantities describing the networks toward their statistical distributions.

In figures 2, 3, the weight distributions are displayed. Weights correspond to the off-diagonal elements of the adjacency matrixes. A broad distribution can be observed in both the projections, but, significantly enough, the Italian market show a lower slope, as well as a higher maximum weight than those displayed by the American one (two boards with six common directors and two directors with eight common companies). This suggests a stronger interlock and lobbying phenomena in the first one.

The number of companies administrated by each director and the distribution of the size of the boards (the corresponding quantity in the other projection) show very different distributions (figure 4,5). These are exactly the distributions of the diagonal matrix elements. The first one is broad, suggesting a heterogeneous hierarchy in the power of directors (if we take as a measure of power the number of boards a director sits in). Peaks of influence are reached by directors that sit simultaneously in a number of boards of the order of 10. The board size distribution, on the contrary, displays a characteristic scale around the value of 10, and a maximum size around the value of 30.

Again we find radically different behaviours of the degree distribution for the two projections (figures 6, 7). While the boards show a rapidly decaying trend, the directors display a power law tail with slope 2.5. It is necessary to observe that, on the contrary of what happens for cond-mat, such behaviour appear only above a threshold of around 10 directors: it is very unlikely to find a director connected with less than 10 colleagues, essentially because this is the characteristic size of a board. Interestingly enough, the power law tail stretches much further than the maximal size of the boards. Whenever a director has more than 10 links in general this is the result of the interlock between different boards.

A similar behaviour between the two projections and between them and cond-mat can be observed when the site-betweenness distribution is plotted (figure 9 and 8), since a rapidly decaying trend is always displayed. A positive correlation between site betweenness and degree is displayed in figure 11.10, where the trends are increasing power-laws with slopes 2.2 for the directors and 1.5 for the boards.

Degree degree correlation

As observed in many recent studies[6], a feature that seems to be characteristic of social network is the assortativity. In other words, the presence of positive degree correlations. In particular, social networks tend to be assortative, in the sense that nodes with a certain degree tend to connect with nodes of similar degree. This tendency can be measured by means of the distribution $Knn(k)$ (the average nearest neighbour degree of a node of degree k), and by the assortativity coefficient. The first distribution is given by

$$Knn(k) = \sum_{k'} k' P(k'|k) \tag{7}$$

where $P(k'|k)$ gives the probability that a nearest neighbour of a node of degree k has degree k'. This distribution is increasing, flat or decreasing if, respectively, the network is assortative un-assortative or disassortative (terms corresponding to positive, null or negative degree correlation). A complete definition of the assortativty coefficient can be found in ref. [6]. For the purpose of this work, by the way, it is enough to say that it is proportional to the correlation coefficient of the degrees i and j of the nodes at the end of an edge. The plots of $Knn(k)$ for the networks under study display a slight increase, but the values of the assortativity coefficient, are definetely positive (see table II).

CONCLUSIONS: THE EMERGING PICTURE OF THE CORPORATE CONTROL NETWORK

Before summarizing our main results, one further quantity needs to be added to give the magnitude of the multiple interlock. We have computed the percentage of companies whose board contains a lobby of size at least two (we call lobby the subset of directors of a boards who serve on an outside board together with a director of the present board. Thus a lobby of size 2 consists of two directors co-administrating another company). It turns out that 35% of US companies and 44% (1986) and 63% (2002) of Italian companies have a lobby of size at least 2. This is a macroscopical phenomenon, and it has been shown [9] that it can affect the decision making process of boards, making possible that minorities manage to drive the board decision against the interest of the majority.

From the analysis we have performed, a number of global features seems to characterize the network of the entities who control the major corporation of a country: all the considered networks are Small World networks, assortative and highly clustered. They are all above the percolation threshold in the sense that they have a giant component. The connectivity degree distribution of the director network has always a power law tail with similar exponent. On the contrary, the connectivity degree distribution of the board network is always rapidly decreasing. The director networks have the same common properties in the different cases of study. The board networks have different properties with respect to the director networks, but these properties are essentially the same in the different cases of study. The presence of a lobby in a board, turns out to be a macroscopic phenomenon in all cases of study. These results seem stable over different countries (Italy and US) and over time (Italy 1986 and 2002).

Because economies depend so much on the choice of the corporate elite, it is clear that the observed features should be taken into account in modelling macro-economical dynamics.

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TABLE I: Average and global quantities for The boars' projections, marked with B, the directors' projections, marked with D, cond-mat and Internet. N=number of nodes, E= number of edges, N_c/N=fraction of nodes belonging to the maximal connected component, k/k_c=average degree over $N-1$, b=average site betweenness, Cc=average clustering coefficient, d=average distance.

	$B, 86$	$B, 02$	B, US	$D, 86$	$D, 02$	D, US	$C-M$	$AS, 99$
N	221	240	916	2378	1906	7680	16725	5287
E	1295	636	3321	23603	12815	55437	47594	10100
N_c/N	0.97	0.82	0.87	0.92	0.84	0.89	0.83	–
$k/k_c(\%)$	5.29	2.22	1.57	0.84	0.71	0.79	0.03	0.07
b/N	0.736	0.875	1.080	1.116	1.206	1.384	1.932	2.21
Cc	0.356	0.318	0.376	0.899	0.915	0.884	0.327	0.241
d	3.6	4.4	4.6	2.7	3.6	3.7	6.4	3.7

TABLE II: Assortativity coefficients

	$B, 86$	$B, 02$	B, US	$D, 86$	$D, 02$	D, US	$C-M$	$AS, 99$
r	0.12	0.32	0.27	0.13	0.25	0.27	–	–

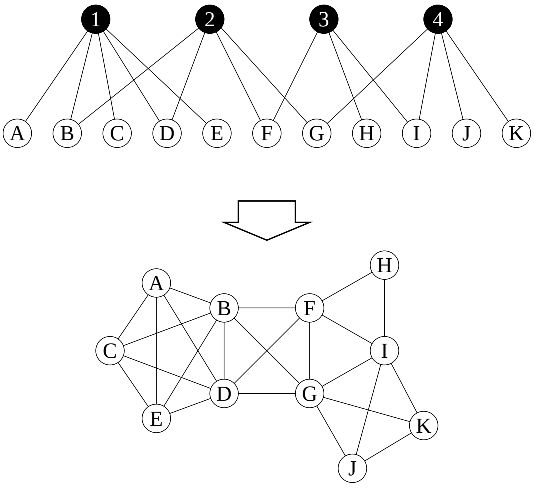

FIG. 1: A bipartite graph and its one-mode projection. After Newman et al. 2001

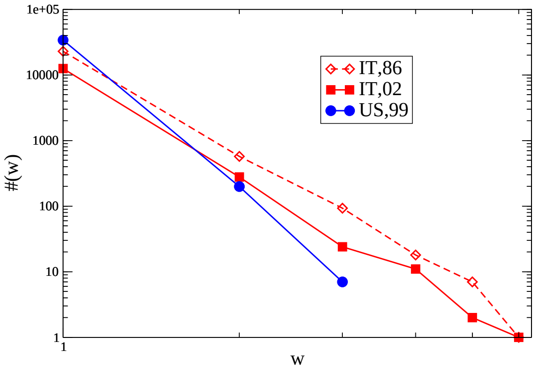

FIG. 2: Weight distribution of the directors' projection: broad distribution, with differences visible between the American and the Italian market.

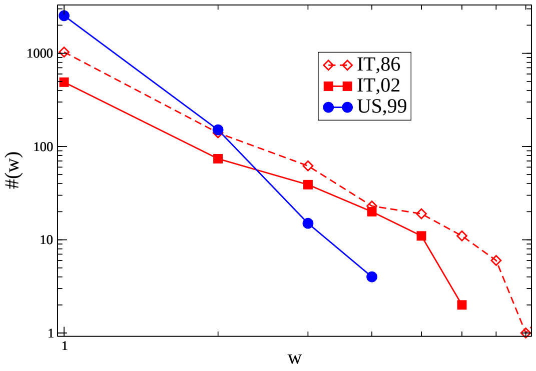

FIG. 3: Weight distribution of the companies' projection.

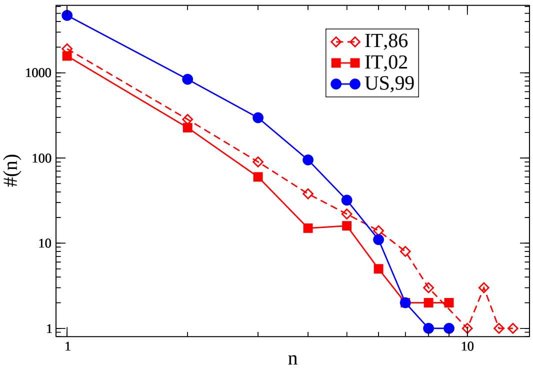

FIG. 4: Distribution of the number of boards per director: broad distribution.

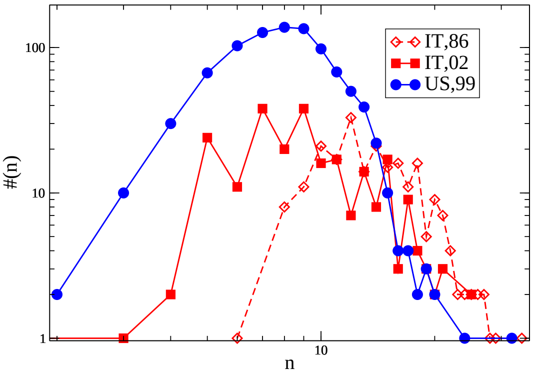

FIG. 5: Distribution of the size of the boards: characteristic scale around 10.

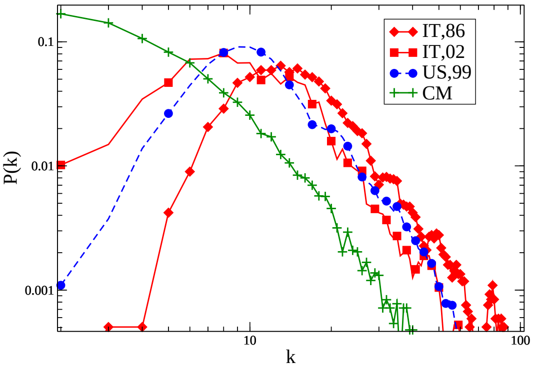

FIG. 6: Degree distribution of the directors' projection: power law tail.

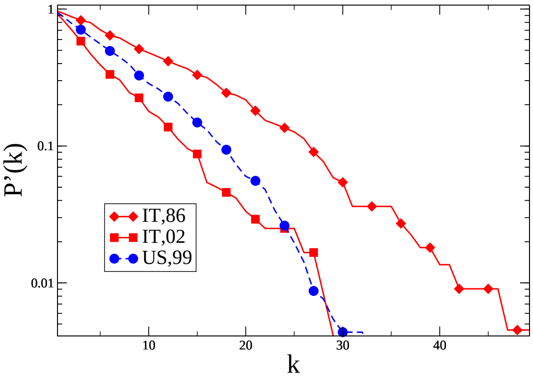

FIG. 7: Rapidly decreasing degree distribution of the companies' projection.

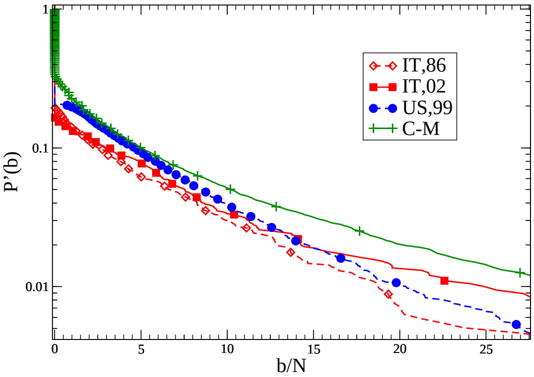

FIG. 8: Rapidly decreasing Site betweenness distribution of the directors' projection.

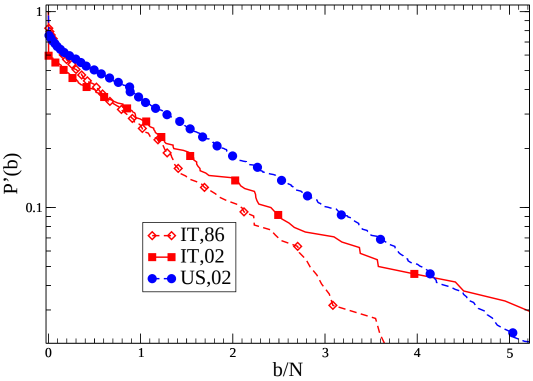

FIG. 9: Rapidly decreasing Site betweenness distribution of the companies' projection.

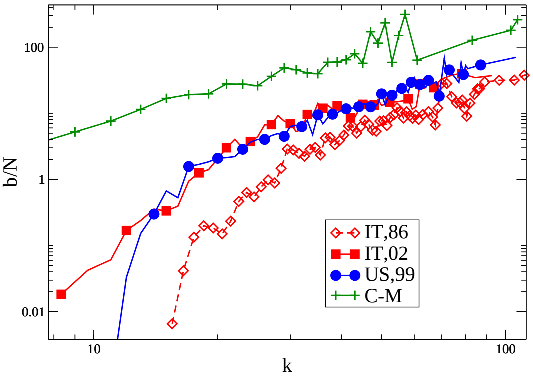

FIG. 10: Site betweenness-degree correlation in the directors' projection: increasing power law trend.

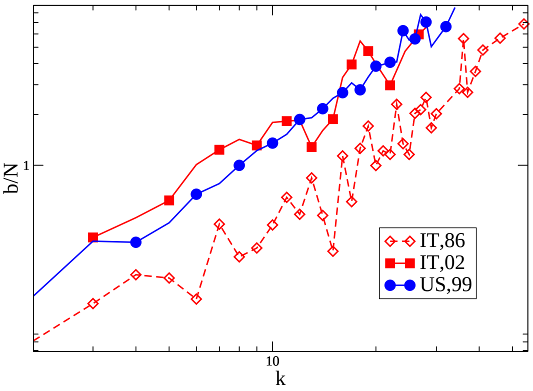

FIG. 11: Site betweenness-degree correlation in the companies' projection: increasing power law trend.

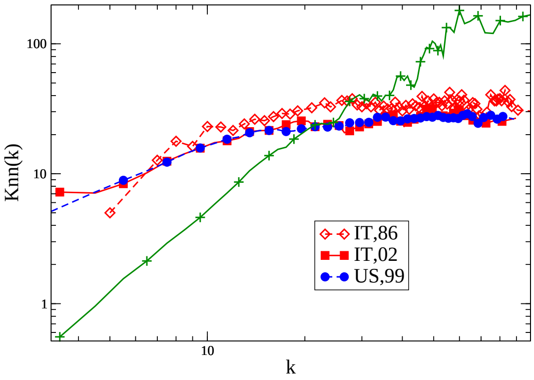

FIG. 12: Increasing average nearest neighbour degree of the nodes of degree k in the directors' projection.

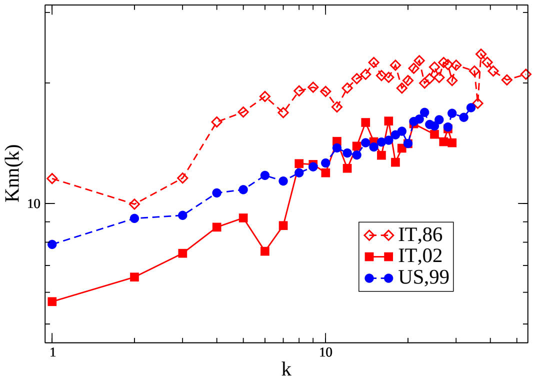

FIG. 13: Increasing average nearest neighbour degree of the nodes of degree k in the directors' projection.