Strong ties in a small world

van der Leij, M.; Goyal, S.

Published in:
Review of Network Economics

DOI:
10.2202/1446-9022.1278

Review of Network Economics

Volume 10, *Issue* 2 2011 *Article* 1

Strong Ties in a Small World

Marco van der Leij, *University of Cambridge*
Sanjeev Goyal, *University of Cambridge*

Recommended Citation:

van der Leij, Marco and Goyal, Sanjeev (2011) "Strong Ties in a Small World," *Review of Network Economics*: Vol. 10: Iss. 2, Article 1.
DOI: 10.2202/1446-9022.1278

Strong Ties in a Small World

Marco van der Leij and Sanjeev Goyal

Abstract

This paper examines the celebrated "strength of weak ties" theory of Granovetter (1973). We examine two hypotheses implied by the theory: one, for any three players with two links present, the probability of a third link being present is increasing in the strength of the two ties, and two, the removal of a weak tie breaks more shortest paths than the removal of a strong tie. This paper tests these hypotheses using data on co-authorship among economists. Our data supports the hypothesis of transitivity of strong ties, but it rejects the hypothesis that weak ties are more crucial than strong ties. We then propose an explanation for the strength of strong ties which builds on two properties of the network: one, significant inequality in the distribution of connections across individuals, and two, stronger ties among highly connected individuals.

KEYWORDS: strong ties, small world, social networks

Author Notes: We thank the editor, two anonymous referees, Francis Bloch, Vincent Buskens, Antoni Calv'o-Armengol, Dennis Fok, Matthew Jackson, Willemien Kets, Marcel Fafchamps, Alan Kirman, Michael Kosfeld, Richard Paap, Werner Raub and seminar participants at NAKE Research Day 2004, Erasmus University, Marseille, Utrecht, Mannheim and ICTP (Trieste), for helpful discussions and comments. Marco van der Leij thanks the Spanish Ministry of Science and Innovation (Project grant SEJ2007-62656) for financial support. We are grateful to the Instituto Valenciano de Investigaciones Económicas for publishing the companion working paper and for financial support.

1 Introduction

In a seminal paper, Granovetter (1973) argued that weak ties in a social network (one's acquaintances) are more important for information dissemination than strong ties (one's close friends). Consequently, individuals and societies with few weak ties are disadvantaged. Granovetter's argument proceeds as follows: strong ties are *transitive*; this means that if two individuals have a common close friend, then it is unlikely that they are not related at all. Therefore, strong ties cover densely knitted networks, where a 'friend of my friend is also my friend'. On the other hand, weak ties are much less transitive, and so they are more likely to be *bridges*: crucial ties that interconnect different subgroups in the social network. This implies that information from a strong tie is likely to be very similar to the information one already has. On the other hand, weak ties are more likely to open up information sources very different from one's own. Moreover, a social network with few weak links is likely to be scattered into separate cliques with little communication between cliques. Granovetter's arguments are one aspect of a general theory of social structure: the social world consists of groups which are internally densely connected via strong links and there are a few weak links across the groups.

We find it useful to distinguish between two related and important dimensions in Granovetter's theory. The first dimension is purely structural and describes how the weak and strong links in a social network are organized. The second dimension is about the functioning and usefulness of different types of links in the network. The present paper is concerned with the first dimension of the theory. We develop two testable hypotheses from the arguments in Granovetter (1973): one, that strong ties are transitive; and, two, that weak ties are more important in reducing shortest path lengths between actors.

We now outline the empirical setting and then present our main findings. We study co-authorship relations of economists publishing in scientific journals. This data set contains about 150,000 articles from 120,000 economists collected over a 30 year period. This data set is appropriate for our purposes as it allows us to define and measure the strength of a tie unambiguously: we shall say that the strength of a tie between two authors is given by the number of papers which they publish together.

Our data provides support for the hypothesis that strong ties are more likely to be transitive. However, our second finding is that *strong ties* are more important in reducing distances (as they lie on more shortest paths), which contradicts Granovetter's theory.

The paper then proposes a possible explanation for this surprising finding. We observe that there exists a small set of highly connected hub nodes which constitute the core of the network. We then establish that ties between hub nodes are

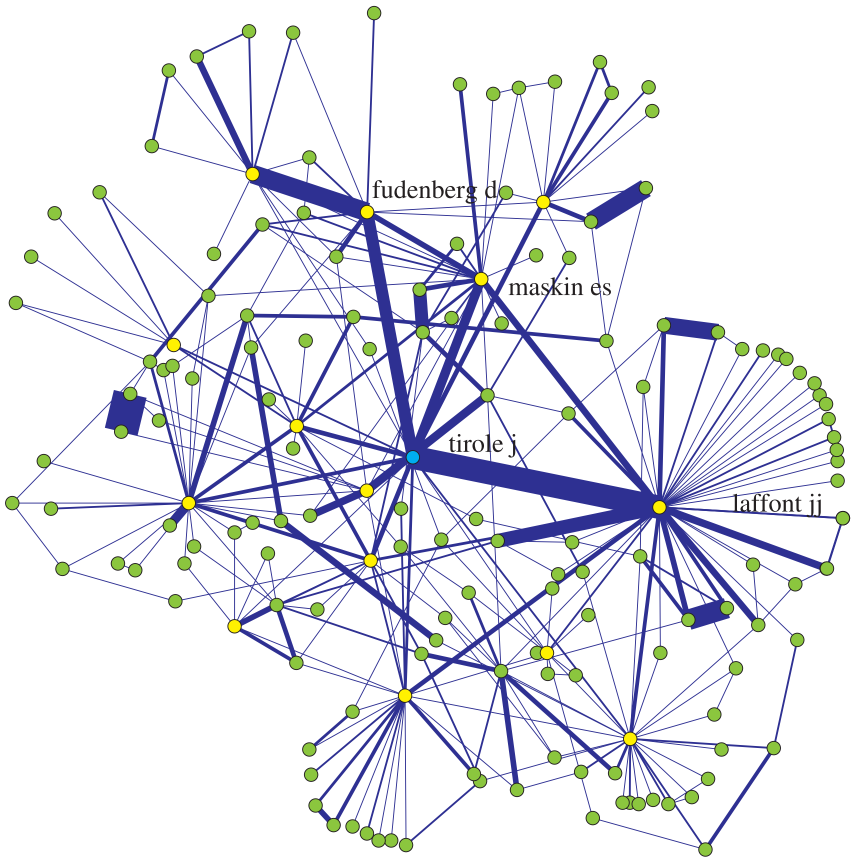


Figure 1: The local network of Jean Tirole.

stronger than the average tie. These two properties taken together help us understand how strong ties are more transitive – as they connect the small set of hub nodes – and also how they can be more important for reducing distances in the network – as they form bridges for a large set of peripheral poorly linked authors. Figure 1 presents the local network around one prominent economist, Jean Tirole, and illustrates that strong ties often lie in the center of the co-author network.

Granovetter's theory may be seen as an expression of a more general theory of social structure: social networks consist of groups with strong within-group ties and weak cross-group ties.[1] Our paper provides evidence for the existence of social networks in which the strong ties are located in the core. In such networks, strong

[1]These ideas also find expression in a variety of spheres ranging from the study of personal identity in social philosophy (see e.g., Avineri and De Shalit, 1992; Taylor, 1989) to the diffusion of innovations via social communication (see e.g., Rogers, 1995).

DOI: 10.2202/1446-9022.1278

ties are more important for bridging the network than weak ties. We believe that our findings describe a *general* aspect of social structure in many professions and organizations.[2] This social structure arises out of the fundamental time dimension in the creation of links. Individuals create links and strengthen them over time. At any point in time, there will exist a demographic profile of young and old individuals. The young are likely to have relatively fewer ties and these ties are likely to have lower strength, compared to the old. In particular, older individuals will on average be better connected, their links will be with other well connected older individuals, and these links will be (relatively) stronger. Given the key role of highly linked individuals in the social structure, it follows that the strong ties will be more important for connecting up the network than weak ties. Hence, the strength of strong ties in a small world.

Empirical research on the strength of weak ties goes back a long way; recently, the availability of large network data sets has inspired a number of new papers. A comprehensive discussion of this body of work is outside the scope of this paper; here we focus on the research which studies the graph theoretic implications of Granovetter's theory.[3] We first discuss two early studies, Friedkin (1980) and Borgatti and Feld (1994). Friedkin's research is based on a survey of 136 faculty members in seven biological science departments of a single university. He defines a tie between A and B to be strong if A and B have discussed both their current research together, while a tie is weak if only either A or B's research has been discussed by the two. Friedkin confirms the strength of weak ties theory. Borgatti and Feld examine the hypothesis for Zachary's (1977) Karate club data. They find a positive correlation between neighborhood overlap and strength of a tie, which contradicts the strength of weak ties theory. Thus, these early papers arrive at different conclusions with regard to strength of weak ties.

We now turn to more recent papers. Onnela et al. (2007) study a large network of mobile phone conversations. They find support for the strength of weak ties theory.[4] We believe that the difference from our results reflects the presence of a hierarchy in academics, which is present in our data but is missing in the mobile telephony data set. Senior academics have more links than their younger

[2]A core-periphery structure has been suggested for other networks, see Borgatti and Everett (2000) for an overview and for a formalization. One of the suggested variants in Borgatti and Everett (2000) considers weighted networks, with strong ties in the core, intermediate ties between core and periphery, and weak or absent ties between peripheral nodes.

[3]For a discussion on the role of weak and strong ties in conveying job information, see the original discussion in Granovetter (1973) and the extended discussion in Granovetter (1983) and Granovetter (1995). A number of authors have examined this issue; see e.g., Centola and Macy (2007), Lin (2002), and Yakubovich (2005).

[4]For a popular account of the role of weak ties in the stability and functioning of networks, see Csermely (2006).

colleagues. Moreover, ties among senior colleagues are stronger than ties among young academics or between young and old academics. This creates a positive correlation between degree and strength of ties.[5]

The correlation between the degree of two nodes and the strength of the tie between them has also been explored by a number of other authors recently, see e.g., Opsahl et al. (2008), Ramasco and Gonçalves (2007), and Ramasco (2007). These papers find that the relation between degrees of nodes and the strength of ties varies across networks. In particular, Opsahl et al. study the coauthor network among condensed matter physicists. They suppose that the weight of a paper in a link between two authors is declining in the number of collaborators in that paper. Under this assumption, they find that the strength of a tie bears little relation to the degree of the connected nodes. They believe that this neutrality reflects a feature of collaboration among prominent scientists: when they work together, they often work in large teams. In economics, a great proportion of coauthored papers involves 2 or 3 authors only. Consequently, weighting papers by the number of co-authors does not dampen the strength of ties among hubs significantly. So a positive relation between strength of a tie and the degree of the nodes is robust to alternative ways of measuring the strength of ties. This explains the difference of our findings from these recent papers.

Our paper is also related to a strand in the literature on evolving weighted networks, building on the scale free network model of Barabási and Albert (1999) and the fitness model of Bianconi and Barabási (2001). Barrat et al. (2004) and Yook et al. (2001) study the distribution of weights in a network and the distribution of weighted links in a network. In an evolving weighted network, under the familiar assumptions of preferential attachment, networks exhibit fat tails in the distribution of weights. Moreover, older links with high degree also have high weight links. Our paper builds on these ideas and the contribution of our paper is to trace the implications of these strong links between highly connected nodes for Granovetter's strength of weak ties theory.

Finally, we discuss the relation of our paper to an older literature on the institutions of research and bibliometric networks (Merton, 1973; Willis and McNamee, 1990; and Schott, 1998). Merton's early work on the *Matthew Effect* highlighted increasing returns in the ways scientists and researchers credit each other. Willis and McNamee explore the intellectual and institutional ties which connect leading academics, the boards of prestigious journals and prominent universities. In related work, Schott, outlines a core-periphery architecture of global research. These in-

[5]Due to restrictions on the use of data, we have been unable to test this hypothesis on the mobile phone network. However, in personal communication, Dr. J-P Onnela has said that there is *no* positive correlation between degree and strength of ties in the mobile telephone data set.

sights are echoed in our work. In particular, our paper builds on two ideas in this work, one, increasing returns (leading to high degree inequality) and two, the presence of strong ties at the core of networks. Combining it with the observation that ties between high degree nodes are stronger, we propose a possible explanation of the strength of strong ties.

The rest of the paper is outlined as follows. In Section 2 we develop two testable hypotheses arising out of Granovetter's paper. Section 3 tests these hypotheses, while Section 4 develops a possible explanation for our empirical findings. Section 5 concludes.

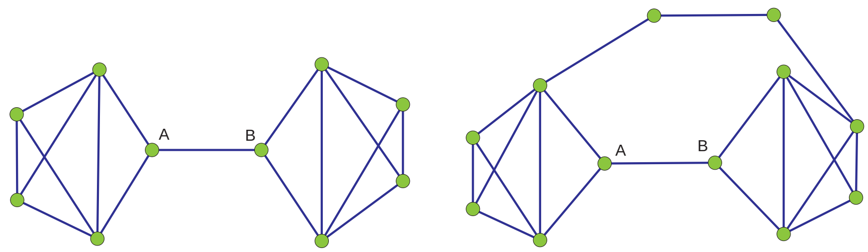
2 Strength of weak ties: hypotheses

We first recapitulate the arguments of Granovetter's 'strength of weak ties' theory. The strength of a social tie is a "(...) combination of the amount of time, the emotional intensity, the intimacy (mutual confiding), and the reciprocal services which characterize the tie." (Granovetter, 1973, p. 1361). This leads to the following thought experiment: consider a triad of three individuals A, B and C in a social network in which AB and AC are tied. Let us refer to such a triad as a connected triple. Now, consider the likelihood that there is also a tie between B and C. In that case, the triad is complete, and the connected triple is called transitive. Granovetter argues that triad completion is more likely if AB and AC are *strong*, because "(...) if C and B have no relationship, common strong ties to A will probably bring them into interaction and generate one" (Granovetter, 1973, p. 1362). Further, since AB and AC have a strong tie, B and C are likely to be similar to A and therefore similar to each other, and this facilitates the formation of a tie between B and C.

Indeed we may say that "... the triad which is most *unlikely* to occur, (...) is that in which A and B are strongly linked, A has a strong tie to some friend C, but the tie between C and B is absent" (Granovetter, 1973, p. 1363). These considerations motivates the first hypothesis:

Hypothesis 1: *For a set of three individuals with two links present, the probability of triad completion is much higher if the links are strong as compared to the case where the links are weak.*

The second step in the theory relates Hypothesis 1 to the presence of shortest paths in the network. A *path* between i and j is a sequence of distinct actors $i = i_0, i_1, \ldots, i_{z-1}, i_z = j$ for which i_{k-1} and i_k, $k = 1, \ldots, z$ are tied. Here z is the path length; recall that the distance between two nodes i and j in network g refers to the shortest path length between these nodes in network g. Following Granovetter (1973, pp. 1364–65), a *bridge* is a tie in a network which provides the only path



(a) The tie between *A* and *B* is a bridge. (b) The tie between *A* and *B* is a local bridge of range 6.

Figure 2: Two networks with a bridge and a local bridge.

between some actors *i* and *j*; a *local bridge* is a tie between *i* and *j* in which the length of the shortest path between *i* and *j* (other than the tie itself) is larger than 2. Figure 2 illustrates a bridge and local bridge.

Granovetter says, "The significance of weak ties, then, would be that those which are local bridges create more, and shorter, paths. Any given tie may, hypothetically, be removed from a network; the number of path broken and the changes in average path length resulting between arbitrary pairs of points (with some limitation on length of path considered) can then be computed" (Granovetter, 1973, p. 1366). Thus the removal of a weak tie would, on average, break more paths and increase average path length more than the removal of a strong tie. For computational reasons we concentrate on shortest paths, leading to the following hypothesis.

Hypothesis 2: *The removal of a weak tie at random from the network would break more shortest paths between actors than the removal of a strong tie.*

3 Testing the hypotheses

We test the hypotheses using data on co-authorship networks of economists publishing in scientific journals. The data is derived from EconLit, a bibliography covering economic journals from 1970 to 1999. Each node is an economist.[6] Two economists are linked whenever they wrote an article together either as the only two authors, or together with a third author. Note that an article with three co-authors automatically results in a closed triad. EconLit does not provide full information on

[6]Author names appear in different forms, often without middle names or with only initials mentioned. A cleaning procedure is used to match the different names to the correct author as best as possible; see Van der Leij (2006, p. 53) for details on the procedure.

author names of articles with 4 or more authors, hence these articles are excluded from the analysis.[7]

We measure the strength of a tie between two economists in terms of the number of articles of which these two economists were co-authors. Our measure of strength has the merit that it does not rely on subjective interpretations of respondents. It is objective and easily and directly measurable. Furthermore, ties based on this measure are symmetric and positive.[8] Granovetter's theory is expressed in terms of symmetric positive ties (Granovetter, 1973, footnote 2), and our measure is therefore appropriate for the theory.

The concept of strength of ties is central to our analysis and so it is important to examine whether our findings are sensitive to the specific measure – number of papers – we use. Keeping this in mind, we have carried out two alternative robustness checks. One, we consider a network of coauthors in which only two-author papers are considered. Two, we have used Newman's (2001) weighting scheme, assigning weight 1 to two-authored paper, and $1/2$ weight to a three authored paper. Our findings on lower betweenness of strong ties, and the key role of strong ties between hubs also obtain under these alternative approaches. We present the 2-author network analysis in the paper; we omit the details of the computations with Newman's weighting scheme due to space constraints.

We now provide some descriptive statistics about the network we are studying in Table 1. There are 129003 economists in all. The average degree – 1.65 – is small but there is significant variation in degrees across economists (standard deviation is 2.74 and the maximum degree is 65). The average strength of a link is 1.403: so that a pair of authors writes less than two papers together, on average. However, here again the standard deviation is large – 1.24 – and the maximum strength is 50! The distribution of degrees and strength of links is presented in Figures 3 and 4.

Around 40% of the total population of economists is part of a large cluster of connected nodes which is referred to as the 'giant component'. This cluster covers all major fields in economics, and the majority of actively participating economists. About 35% of the population never collaborated, and the remaining 25% is part of tiny components of at most 40 economists (0.03% of the total population). Despite the small number of average connections and the large number of economists, the average distance between economists in the giant component is small – 8.66.

[7] In the EconLit database 77% of all the co-authored articles had 2 authors, 19% had 3 authors, and 4% had 4 or more authors. Results presented in Van der Leij (2006, pp. 53–56) show that the structure of the co-author network is qualitatively unaffected when (for a subset of the data) articles with 4 or more authors are included.

[8] Let s_{ij} be the strength of a tie between actors i and j. The tie is symmetric if $s_{ij} = s_{ji}$. A tie is positive if $s_{ij} \geq 0$.

Table 1: Network statistics for coauthorship networks in economics.

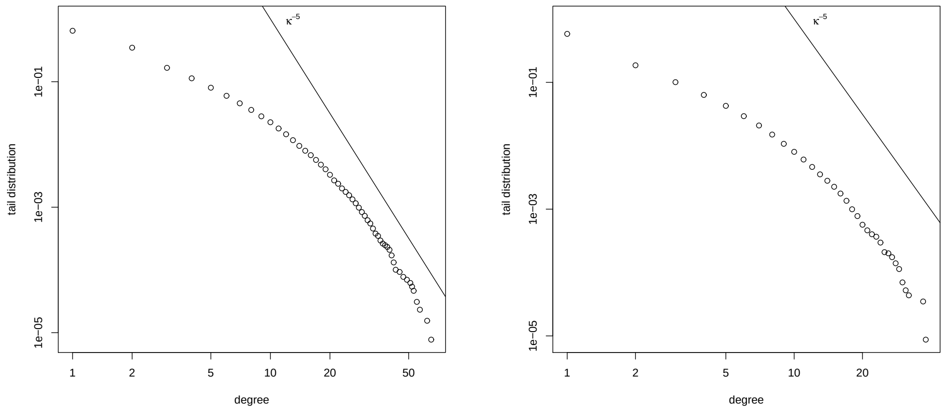
articles	All	Only with 2 authors
number of nodes	129003	114584
average degree	1.65	1.09
std.dev. degree	(2.72)	(1.80)
max degree	65	38
average strength	1.40	1.38
std.dev. strength	(1.24)	(1.12)
max strength	50	33
size of giant component	51600	34600
as percentage	.40	.30
second largest component	40	62
isolated	45340	47934
as percentage	.35	.42
clustering coefficient	.12	.02
degree correlation	.13	.12
average distance	8.66	10.03
std.dev. distance	(2.10)	(2.53)
maximum distance (diameter)	30	32

Link degree of a node: number of links attached to the node. Strength of a link: number of papers coauthored by the two authors of a link. Size of giant component: size of the largest component, a subset of nodes for which there is a path between each pair of node in the subset. Second largest component: size of the largest component except the giant component. Isolated: number of nodes without any links. Clustering coefficient: fraction of connected triples that are transitive. Degree correlation: correlation coefficient between the link degrees of two neighbouring nodes. Distance of a pair of nodes: shortest path length between the pair of nodes.

Finally, observe that the clustering coefficient is high (relative to what we would expect in a random network). [9]

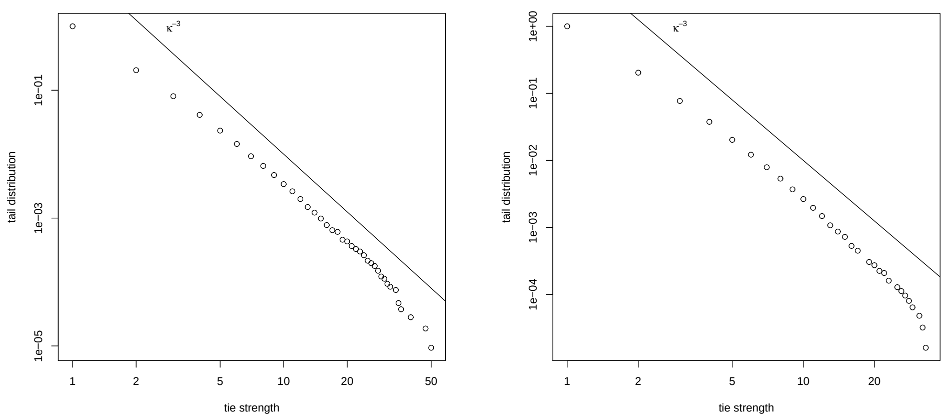
[9]The clustering coefficient is much lower when we exclude 3-authored articles, as 3-authored articles automatically create closed triads. However, even for the network of 2-authored articles only, the clustering coefficient is still a factor 1000 higher than what would be expected in an Erdős-Rényi random network. For a further discussion of the statistical properties of the coauthor network of economists, see Goyal et al. (2006) and Van der Leij (2006).

DOI: 10.2202/1446-9022.1278



(a) Network of all articles (b) Network of articles with 2 authors

Figure 3: Pareto plot of the degree distribution. The *x*-axis gives the degree and the *y*-axis gives the fraction of nodes with a degree greater or equal to *x*. The straight line represents a scale free distribution with exponent -5.



(a) Network of all articles (b) Network of articles with 2 authors

Figure 4: Pareto plot of the tie strength distribution. The *x*-axis gives the strength of a tie and the *y*-axis gives the fraction of ties with a strength greater or equal to *x*. The straight line represents a scale free distribution with exponent -3.

We first examine the transitivity of ties.[10] Let us say that a tie between A and B is a *weak tie* if the strength of the tie is smaller than some threshold, $c_S\ in\{2,3,5\}$, and a *strong tie* otherwise. We gather the set of ordered triples with actors A, B and C for which there is a tie between A and B and between A and C. We partition this set of triples ABC into three subsets in which:

1. both AB and AC are *weak* ties (weak-weak);
2. AB is a weak tie and AC a strong tie, or vice versa AB is strong and AC weak (weak-strong);
3. both AB and AC are *strong* ties (strong-strong).

For these three subsets we compute the fraction of triples that are completed, that is, for which there is also a tie between B and C. Table 2 shows the results for the two data sets and strength thresholds of 2, 3 and 5.[11]

Table 2 offers strong support for hypothesis 1. Suppose a link between two authors i and j is strong if there are 5 or more papers involved. The Table then tells us that triad completion occurs in (approximately) 11% of the cases where a weak-weak triple exists, while it occurs in almost 33% of the cases where a strong-strong triple exists. Thus triples with two strong links are more likely to be transitive. Similar patterns also hold when we define strength with threshold at 2 and 3 papers, respectively.

Figure 5 presents a plot relating average strength of the ties AB and AC versus the probability that the tie BC is closed, together with a fit from a logistic regression. These figures again suggest support for the hypothesis that strong-strong ties triad completion more likely.

We next examine the relationship between tie strength and betweenness. We shall use the concept of link betweenness to measure presence of a link on shortest paths. This concept was introduced by Girvan and Newman (2002) and is defined as follows; let n be the number of nodes in the network, g the set of ties in the network, $\mathscr{L}_{ij}$ is the set of shortest paths between i and j and L a typical shortest path. Then the betweenness of a link AB is

$$B_{AB} = \frac{2}{n(n-1)} \sum_{ij} \frac{1}{|\mathscr{L}_{ij}|} \sum_{L\in\mathscr{L}_{ij}} I_{AB\in L},$$

where $I_{AB\in L}$ is an indicator variable, which takes value 1 if $AB \in L$ and takes value 0 otherwise.

[10] We use clustering and transitivity as synonyms.

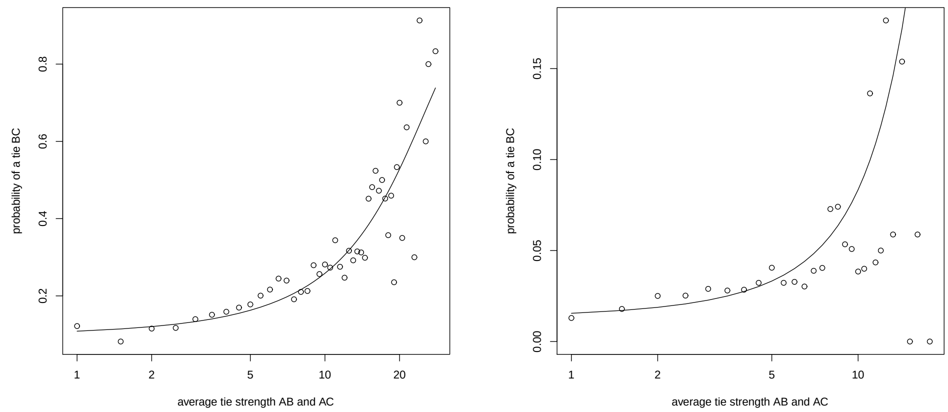
[11] The use of a dichotomic measure of tie strength is only for explanatory purposes. In the companion working paper (Van der Leij and Goyal, 2010), we provide additional evidence in the form of logit regressions on connected triples, in which a continuous measure of tie strength is used.

DOI: 10.2202/1446-9022.1278

Table 2: Fraction of subsets of connected triples that are transitive in the co-authorship network for economists.

articles	all	only with 2 authors
observations	548487	190052
	Strong tie: ≥ 2 papers	
weak-weak	.122	.0129
weak-strong	.096	.0205
strong-strong	.182	.0336
	Strong tie: ≥ 3 papers	
weak-weak	.113	.0149
weak-strong	.121	.0259
strong-strong	.236	.0455
	Strong tie: ≥ 5 papers	
weak-weak	.113	.0169
weak-strong	.160	.0292
strong-strong	.332	.0701
all	.118	.0178

Observations are connected triples. The set of connected triples is partitioned into three subsets. Weak-weak: connected triples consisting of two weak ties. Weak-strong: connected triples consisting of one weak and one strong tie. Strong-strong: connected triples consisting of two strong ties. All: all connected triples. χ^2-test: test statistic for χ^2-independence test (2 degrees of freedom).



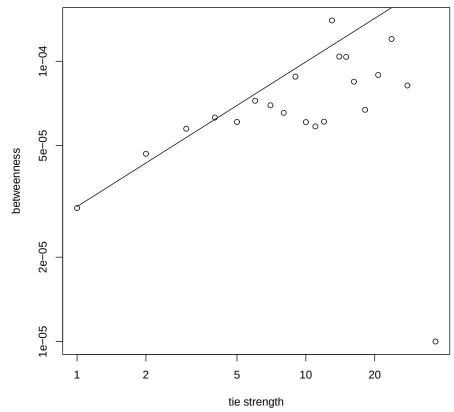
(a) Network of all articles (b) Network of articles with 2 authors

Figure 5: Plot of average tie strength AB and AC versus probability of a tie BC. Each dot gives the fraction of closed triples (closed by a tie BC) for all connected triples with the same average tie strength AB and AC. Dots that represent less than 10 observations are merged. The solid line shows the fitted values from a logit model.

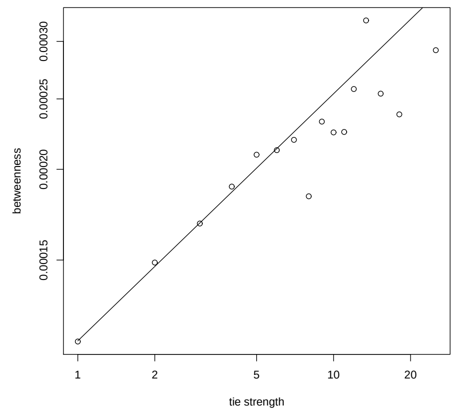
In words, link betweenness of a link *AB* measures the fraction of all pairs of actors *i* and *j* for which the link *AB* lies on a shortest path between *i* and *j*. If there are multiple shortest paths between *i* and *j*, then each shortest path contributes equally to the link betweenness of the links on these paths. Link betweenness is likely to be related to the flow of ideas in a co-authorship network. If each economist would be good for one independent idea, and each idea would flow on the shortest path to the other economists in the network, then link betweenness would exactly measure the fraction of ideas that flows on a particular link.

We extract the giant components from the network, and for each tie in a giant component we compute link betweenness using the algorithm of Newman (2001). Figure 6 presents a plot of the relation between strength of ties and link betweenness and a fit of log-linear regression. This figure reveals that there is a *positive* relation between a tie's link betweenness and its strength.

The positive relation that we find between link betweenness and strength, directly contradicts Hypothesis 2. Hence, we conclude that Hypothesis 1 is supported, but that Hypothesis 2 is rejected. Overall, this suggests that the strength of weak ties theory as posed by Granovetter (1973) is not valid, at least not for the investigated social network of economists.



(a) Network of all articles



(b) Network of articles with 2 authors

Figure 6: Plot of tie strength versus link betweenness. Each dot gives the geometric mean of the link betweenness for all ties in the giant component with the same tie strength x. Dots that represent less than 10 observations are merged. The solid line shows the fitted values from a loglinear regression.

4 Strength of strong ties

Our analysis suggests that, in the social network of coauthorship relations among economists, strong ties are more likely to yield completed triads but strong ties also exhibit greater betweenness. We now propose an explanation of these patterns in terms of two properties of the economists' network. The *first* property is the presence of economists with a high number of links (referred to as hubs in the literature). It is well known that these hubs play a key role in bringing nodes close and in connecting the network (see e.g., Albert et al., 2000, Goyal et al., 2006). Given their crucial role in the network, the hubs have a high betweenness centrality. This property extends in an intuitive way to links between the hubs. The *second* property is that the links between hubs are stronger than other links. Due to the central position of the hubs in the network, this implies that the links with high link betweenness are typically *strong*. These two properties put together suggest that strong links connect individuals who have more links on average and this means that they lie on more shortest paths. This more than compensates for the greater transitivity of strong links noted above and leads to strong links having greater betweenness. The

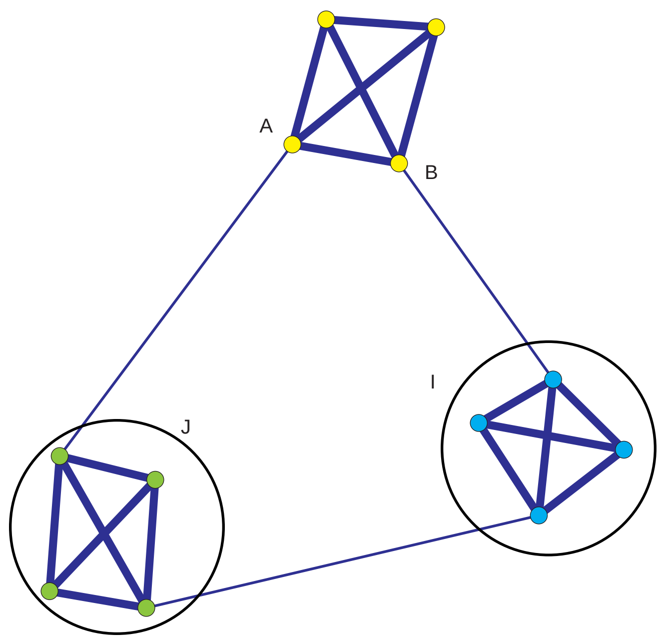


Figure 7: An island network.

working of these two properties can be explained by considering two networks: the island network structure in Figure 7 and the core-periphery network structure in Figure 8.

Consider first the island network. This network represents a view of social networks which often has been put forward when explaining the 'strength of weak ties' theory; see e.g., Figure 2 in Granovetter (1973, p. 1365) or Figure 1 in Friedkin (1980, p. 412). The social world consists of communities with strong internal ties. These communities are connected through trade relations or communication ties which are typically weaker than intra-community ties. Let us briefly examine the status of the two hypotheses in this network. Hypothesis 1 is obviously true as the only connected triples with two strong ties are within an island, while triples with one or two weak ties involve nodes from different islands. As everyone within an island is directly connected, it must be that all connected triples with two strong ties are transitive. Second, observe that weak ties directly connect two separate islands; $4 \times 4 = 16$ shortest paths depend on a weak tie. The strong tie, on the other hand, is only crucial for the connectedness of the actors who have other strong ties. In Figure 7 the strong tie between A and B lies on the shortest path between A and

DOI: 10.2202/1446-9022.1278

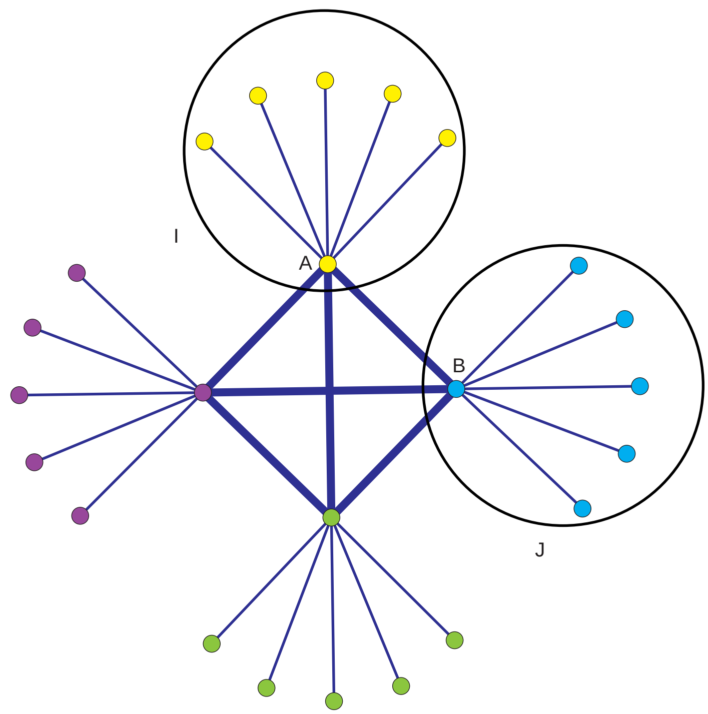


Figure 8: A core-periphery network.

B, between A and the actors of island I, and between B and the actors of island J; a total of $5 + 5 = 10$ shortest paths. Other strong ties have the same or lower link betweenness. Hence, in the island network weak ties have higher link betweenness than strong ties.

Now consider the core-periphery network structure in Figure 8. This network consists of a core of four actors. These actors have a number of ties with peripheral players who each have only one link. Each core actor is connected to five peripheral actors. The peripheral actors themselves have only a weak link to one of the core actors, and no link to other peripheral actors. Thus there is significant inequality in degrees across actors in the network. Let us examine the status of the two hypothesis in this network. First, triples with two strong ties necessarily involve core actors only. Since the core is completely internally connected these triples are transitive. On the other hand, triples with a weak tie involve peripheral players, and these triples are typically not transitive. Hence, the first hypothesis holds. Second, in a core-periphery network a strong tie belongs to the shortest path of the two core actors *and* the peripheral 'clients' attached to the core actors. On the other hand, a weak tie only connects the peripheral player involved. So, in Figure 8 the link between *A* and *B* belongs to the shortest paths of all nodes between *I* and *J*, a total of $6 \times 6 = 36$ paths. A weak tie only belongs to the shortest paths that connect a peripheral player to the rest of the network; this adds up to 23 paths. Hence, strong ties have a higher betweenness than weak ties in a core-periphery network. Thus Hypothesis 2 is rejected.

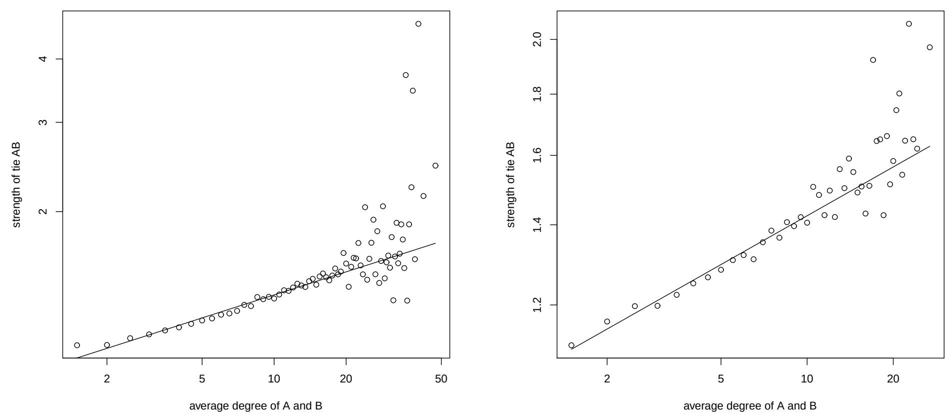
Observe that in both Figure 7 and Figure 8, weak ties form (local) bridges. However, the importance of these bridges is very different in the two network structures. In the island network structure the bridges connect different *communities* to each other, while in the core-periphery network structure the bridges only connect a single peripheral player to the rest of the network. Hence, the bridges are more 'crucial' in the island structure than in the core-periphery network structure.

We now examine these two properties – degree inequality and location of strong ties – in the co-author network of economists. First, we note that there is indeed a considerable inequality in the link degree distribution of the networks. Table 1 shows that the coefficient of variation of the degree distribution is 1.65, which points towards overdispersion relative to an exponential distribution. Next we turn to the correlation between strength and average degree. Figure 9 presents a plot of the average degree of *A* and *B* versus the strength of the tie *AB* for all ties in the giant component. It suggests that there is a significant positive relation between strength of links and average degree of the two co-authors. Hence, if two actors *A* and *B* both have many links, then the link between them is expected to be strong.

Granovetter's theory emphasizes the role of weak ties in forming bridges across communities. By contrast, our work highlights the strength of strong ties as they arise at the core of the social network. We believe that this reflects a fundamental time dimension in the creation of links in a profession. Individuals create links and strengthen them over time. At any point in time, there will exist a demographic profile of young and old individuals. The young are likely to have relatively fewer ties and these ties are likely to have lower strength, as compared to the old, simply because they have had less time. The older individuals will on average be better connected and their links will be with other well connected older individuals. Thus strong ties may be more important for connecting up the network than weak ties.

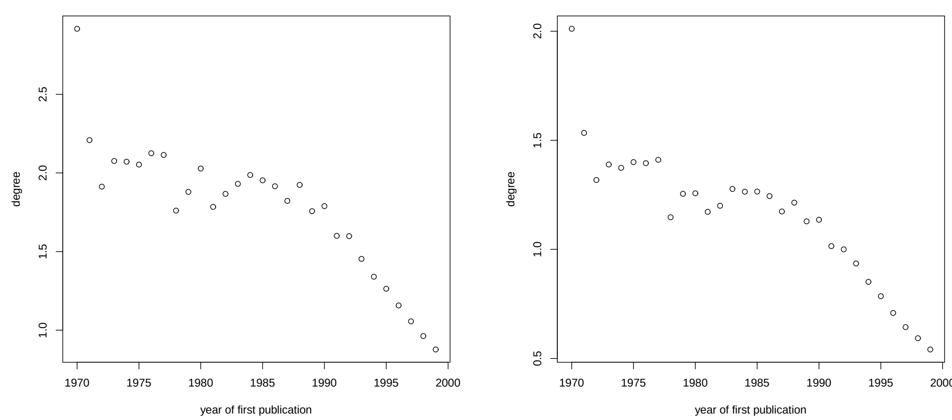
This positive relation between age and degree, and between age and tie strength is indeed observed in the network of economists. In Figures 10 and 11 we show the relevant relations, in which we approximate the entry year of a particular economist by his or her first publication in the database. In Figure 10 we observe that economists that entered the network earlier have a higher degree. Finally, in Figure 11 we observe that ties between older economists are stronger on average.

DOI: 10.2202/1446-9022.1278



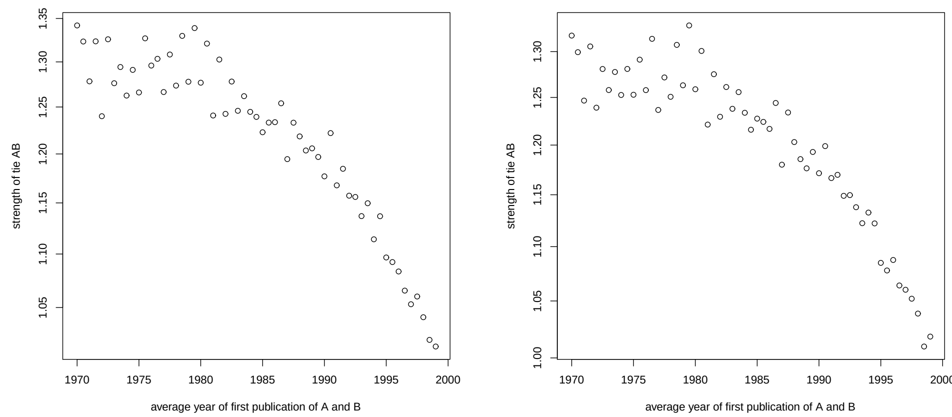
(a) Network of all articles (b) Network of articles with 2 authors

Figure 9: Plot of average degree of A and B versus tie strength AB. Each dot gives the geometric mean of the tie strength for all ties AB in the giant component with the same average degree of nodes A and B. Dots that represent less than 10 observations are merged. The line shows the fitted values from a loglinear regression.



(a) Network of all articles (b) Network of articles with 2 authors

Figure 10: Plot of year of first publication of an author versus degree of the author. Each dot gives the average degree for all authors whose first publication was in the same year. Dots that represent less than 10 observations are merged.



(a) Network of all articles (b) Network of articles with 2 authors

Figure 11: Plot of average first year of publication of A and B versus tie strength AB. Each dot gives the geometric mean of the tie strength for all ties AB in the network with the same average initial year of publication of A and B. Dots that represent less than 10 observations are merged.

5 Concluding remarks

This paper examines the celebrated ‘strength of weak ties’ theory (Granovetter, 1973). We find that in the network of coauthors among economists strong ties exhibit greater triad completion but that they nevertheless have greater betweenness than weak ties. Thus the network of economists exhibits a ‘strength of strong ties’ property.

The second part of the paper develops an explanation for these patterns which rests on two properties of the network: one, significant inequality in the number of co-authors across individuals, and two, a positive relationship between the strength of a tie and the number of co-authors of the involved authors. Together these properties help provide an explanation for the rejection of the ’strength of weak ties’ theory.

These findings are demonstrated for the network of coauthorship among economists, but we believe that our findings are of wider interest. The traditional view has highlighted the role of weak ties in forming bridging across communities. By contrast, our work points to the location of strong ties at the core of a network among highly connected nodes. We believe this reflects a time dimension in the creation of links which may be at work in other organizational and social settings.

DOI: 10.2202/1446-9022.1278

References

Albert, R., H. Jeong, and A. L. Barabási (2000): "Error and attack tolerance of complex networks," *Nature*, 406, 378–382.

Avineri, S. and A. De Shalit (1992): *Communitarianism and individualism*, volume 65, New York, NY: Oxford University Press.

Barabasi, Á. L. and R. Albert (1999): "Emergence of scaling in random networks," *Science*, 286, 509–512.

Barrat, A., M. Barthelemy, R. Pastor-Satorras, and A. Vespignani (2004): "The architecture of complex weighted networks," *Proceedings of the National Academy of Sciences*, 101, 3747–3752.

Bianconi, G. and A. L. Barabasi (2001): "Bose-Einstein condensation in complex networks," *Physical Review Letters*, 86, 5632–5635.

Borgatti, S. P. and M. G. Everett (2000): "Models of core/periphery structures," *Social Networks*, 21, 375–395.

Borgatti, S. P. and S. L. Feld (1994): "How to test the strength of weak ties theory," *Connections*, 17, 45–46.

Centola, D. and M. Macy (2007): "Complex contagions and the weakness of long ties," *American Journal of Sociology*, 113, 702–34.

Csermely, P. (2006): *Weak links: Stabilizers of complex systems from proteins to social networks*, Berlin: Springer Verlag.

Friedkin, N. (1980): "A test of structural features of granovetter's strength of weak ties theory," *Social Networks*, 2, 411–422.

Girvan, M. and M. E. J. Newman (2002): "Community structure in social and biological networks," *Proceedings of the National Academy of Sciences*, 99, 7821–7826.

Goyal, S., M. J. van der Leij, and J. L. Moraga-González (2006): "Economics: An emerging small world," *Journal of Political Economy*, 114, 403–412.

Granovetter, M. S. (1973): "The strength of weak ties," *American Journal of Sociology*, 78, 1360–1380.

Granovetter, M. S. (1983): "The strength of weak ties: A network theory revisited," *Sociological Theory*, 1, 201–233.

Granovetter, M. S. (1995): *Getting a job: A study of contacts and careers*, Chicago, IL: University of Chicago Press, second edition.

Lin, N. (2002): *Social capital: A theory of social structure and action*, New York, NY: Cambridge Univ Press.

Merton, R. K. (1973): *The sociology of science: Theoretical and empirical investigations*, Chicago, IL: University of Chicago Press.

Newman, M. E. J. (2001): "The structure of scientific collaboration networks," *Proceedings of the National Academy of Sciences*, 98, 404–409.

Onnela, J. P., J. Saramäki, J. Hyvönen, G. Szabó, D. Lazer, K. Kaski, J. Kertész, and A. L. Barabási (2007): "Structure and tie strengths in mobile communication networks," *Proceedings of the National Academy of Sciences*, 104, 7332.

Opsahl, T., V. Colizza, P. Panzarasa, and J. J. Ramasco (2008): "Prominence and control: The weighted rich-club effect," *Physical Review Letters*, 101, 168702.

Ramasco, J. J. (2007): "Social inertia and diversity in collaboration networks," *The European Physical Journal-Special Topics*, 143, 47–50.

Ramasco, J. J. and B. Gonçalves (2007): "Transport on weighted networks: When the correlations are independent of the degree," *Physical Review E*, 76, 066106.

Rogers, E. M. (1995): *Diffusion of innovations*, New York, NY, USA: Free Press, fourth edition.

Schott, T. (1998): "Ties between center and periphery in the scientific world-system: accumulation of rewards, dominance and self-reliance in the center," *Journal of World Systems Research*, 4, 112–44.

Taylor, C. (1989): *Sources of the self: The making of the modern identity*, Cambridge, MA: Harvard Univ Press.

van der Leij, M. and S. Goyal (2010): "Strong ties in a small world," Working Paper WP-AD 2010-02, Instituto Valenciano de Investigaciones Económicas.

van der Leij, M. J. (2006): *The economics of networks: Theory and empirics*, Amsterdam: Thela Thesis.

Willis, C. L. and S. J. McNamee (1990): "Social networks of science and patterns of publication in leading sociology journals, 1960 to 1985," *Science Communication*, 11, 363–381.

Yakubovich, V. (2005): "Weak ties, information, and influence: How workers find jobs in a local Russian labor market," *American Sociological Review*, 70, 408–421.

Yook, S. H., H. Jeong, A. L. Barabási, and Y. Tu (2001): "Weighted evolving networks," *Physical Review Letters*, 86, 5835–5838.

Zachary, W. W. (1977): "An information flow model for conflict and fission in small groups," *Journal of Anthropological Research*, 33, 452–473.