Economics: An Emerging Small World?

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Summary

The structures of social interaction affect individual behavior and economic performance in important ways. This leads us to ask: does the architecture of social interaction exhibit particular patterns and are these patterns stable over time? We examine interaction among economists by looking at the evolution of co-authorship relations over a thirty year period. We find that in the 1970's this world was quite fragmented with the largest interconnected group { the giant component { covering only 15% of the population. However, by the 1990's economics was much more integrated, with the giant component covering over 40% of the population. The average distance between individuals was small and declined over the period, leading us to conclude that economics is an emerging small world. A crucial stable feature of the network over this period is the existence of several stars (economists with many co-authors each of whom have few collaborators and rarely work among themselves). The world of economics is thus a collection of inter-linked stars. We also find that a growth in the average number of co-authors is the main reason behind the growth in the giant component and the fall in average distances within it. The second part of the paper develops a simple theoretical model of collaboration in economics. We find that an unequal distribution of collaborations and inter- linked stars arise naturally in this environment. Falling costs of communication and increasing credit for joint research lead to greater co-authorship and this supports a larger giant component.

Keywords: Small worlds, Networks, Global village

JEL Classification: C7, A11

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1 Introduction

The structures of social interaction affect individual behavior and economic performance in important ways.[1] This leads us to ask: does the architecture of social interaction exhibit particular patterns and are these patterns stable over time? The first part of this paper empirically examines interaction among economists over a thirty year period from 1970 to 2000 while the second part of the paper presents a theoretical model of co-authorship to account for the empirical findings.

Our empirical work looks at the world of economists who publish in journals and we examine the evolution of co-authorship relations from 1970 to 2000. We split this period into three ten year intervals, 1970-1979, 1980-1989, and 1990-1999. Every publishing author is a node in the network, and two nodes are linked if they have published a paper or more together in the period under study.

We first summarize our findings on the aggregate properties of the network. We find that the number of economists has grown sharply (140 %) in numbers and has more than doubled in the period from 1970 to 2000. This finding is consistent with the growth in the number of fields/specializations and in the corresponding set of field journals during this period and it leads us to expect that the world has probably become more fragmented. However, we find that in the 1990's economics is actually a much more integrated world than it was in the 1970's: in the 1970's the largest group of interconnected economists comprised only about 15% of the population, and there was a large number of small groups. By contrast, in the 1990's there was one huge group of interconnected economists with about 40% of the total population and all the other groups had shrunk in size sharply. The numbers are worth mentioning here: in the 1970's the largest group of economists contained about 5,200 economists while in the 1990's the largest group contained more than 33,000 members. We next consider the level of connectedness within the largest interconnected group. We note that the average number of co-authors is very low; for instance, in the 1990's, a member of the giant group worked with 3 other economists on average. Given the size of the giant group this leads us to expect that the average distance between economists must be large. However, we find that average distance between economists in this giant group is small (only 9.47 in the 1990's) and has fallen significantly over time (despite the growth of the group). These findings put together lead us to the view that economics is *an emerging small world*.[2]

[1]There is now a vast literature on the role of interaction structures. A variety of terms such as local interaction, network effects, peer group effects, have been used. See e.g., Bala and Goyal (1998, 2001), Ellison and Fudenberg (1993) on social learning, Goyal (1996) and Morris (2000) on norms of coordination, Eshel, Samuelson and Shaked (1998) on norms of cooperation, Allen and Gale (2000) on financial fragility of different inter-bank loan networks, Burt (1994) on social networks and individual performance, Glaeser, Sacerdote and Scheinkman (1996) on local interaction and crime, Hagerstrand (1969) and Coleman (1966) on technological diffusion, Munshi (2003) on migration, Watkins (1991) on spread of norms in fertility and marriage and Young (1998) on spread of norms on driving.

[2]The network terminology used here is formally defined in section 2.

What is it about the distribution and arrangement of links in the network that makes this world small? Our first finding is that the distribution of links is very unequal in the three periods under study; there exists a fat tail in the distribution, with a significant number of authors having a very large number of links. In the 1990's, for example, the average number of collaborators (in the whole network) was 1.672 while the maximally connected economist had more than 50 collaborators. Moreover, the clustering, which measures the overlap among co-authors, was .157 in the 1990's network while the clustering for the most connected economist was only .02. This shows that the most connected author had many more links than his cohorts and also that he had very low overlaps among their co-authors as compared to the average person in the network. These numbers lead us to use the term 'stars' for the most connected economists. Our *second* finding is about the role of these well connected nodes in integrating the network. In the 1990's over 40% of the nodes were in the giant component but a deletion of the 5% most connected nodes leaves less than 1% of the nodes in the giant component, thus completely destroying the network. These findings lead us to conclude that *the economics network is spanned by a set of inter-linked stars* and that this is a stable feature of the economics collaboration network.

We next examine the role of the different micro variables in explaining the main aggregate changes noted above. We are specially interested in understanding the role of changes in average number of collaborators versus changes in link patterns. Our main finding is that the increase in average number of collaborators is the crucial factor in explaining the growth in the giant component and the fall in average distances. This conclusion seems to contradict a widely held view that the world is becoming smaller because people are forming 'distant' links more often.[3]

These empirical findings are fascinating and we would like to develop a theory to account for them. There is a large literature on the small world phenomenon in physics and mathematics. This work takes as a given that the world is small; our empirical work, however, shows that average distances and size of giant component in our network change greatly over time. We therefore need a theoretical approach which can explain the stable architectural features of the network (the inter-linked stars) as well as the changes in the network (such as growing giant component).

In the second part of this paper we develop a simple incentives based model with the following features. Research papers contain ideas and involve routine work; the quality of a paper depends on the quality of the ideas contained in it. Individuals have ideas and can do routine work; however, some people are better at generating high quality ideas than others. Institutions reward individuals on their research output; this reward specifies

[3]In particular, our finding appears to be in conflict with the conclusion of a recent paper by Rosenblat and Mobius (2003). Their paper studies economists publishing in 8 economics journals and focus on average distances within the giant component. They argue that it is the change in link patterns that accounts for lower average distance between economists. We discuss the reasons for the different findings in detail after presenting our results in section 3 below.

a threshold level of output quality that is considered for evaluation and also specifies a certain credit to single authored work and co-authored work. There are costs to writing papers which increase in the number of papers written in a research area. Similarly there are costs to meeting and working with others which are increasing in the number of co-authors. Analysis of this model tells us that stars – which embody unequal distribution of links and links between well connected and poorly connected players – arise naturally in an academic environment with productivity differentials and the possibility of collaboration. We show that equilibrium networks will contain inter-linked stars and hence will exhibit short average distances. We also show that a decline in costs of communication and an increase in credit to co-authored papers will both lead to an increase in the number of collaborators and therefore an equilibrium network with a higher degree, something which helps explain the growth in the size of the giant component.

We now place the paper in the context of on-going research in economics and physics. There is a large body of research which argues that social interaction structure affects individual behavior and economic performance (see the literature cited in footnote 1). Then there is a pressing need for an empiricial study that investigates what the interaction structure of *real world* social groups is, and how it is evolving over time. This is the primary motivation behind the present paper. To the best of our knowledge our paper is the first attempt in economics at empirically studying the structure of large evolving social networks. Our analysis identifies stable features of a real world network as well as clarifies the nature of basic changes over time. The findings should form the starting point for a systematic empirical and theoretical study of the economic effects of particular structures.

Our paper is also related to the recent literature on network formation.[4] The distinctive aspect of this literature is the use of individual incentives to derive predictions on network architectures. Our paper contributes to this literature by developing a simple model of co-author network formation to explain the patterns we observe in our empirical work.

Our paper may be seen as contributing to the literature on economics research. Recent work on this subject includes Ellison (2002a, 2000b) and Laband and Tollison (2000), among others. Our findings on the relative role of increased co-authoring and distant co-authoring, respectively are related to themes discussed by other authors. In particular, the increase in co-authorship has been noted and the reasons for it have been explored in Hudson (1996), while the role of substantial and increasing informal intellectual collaboration is explored in Laband and Tollison (2000). A variety of arguments – such as increasing specialization and the falling costs of communication among others – have been proposed to explain increasing co-authorship among economists. Hamermesh and Oster (2002) present evidence which suggests that collaboration among distant authors has increased over the years.

[4]See Bala and Goyal (200), Jackson and Wolinsky (1996) and Kranton and Minehart (2001) for early work and Goyal (2003) and Jackson (2003) for surveys of recent developments.

The empirical properties of large social and economic networks have been investigated extensively by physicists in recent years. For comprehensive surveys of the work in physics see Albert and Barabási (2002) and Dorogovtsev and Mendes (2002). This work focuses on the statistical properties of large networks, and uses a variety of techniques ranging from random graph theory to mean field analysis to elaborate on different features of observed networks. We briefly discuss two ways in which our paper contributes to this body of work. The first contribution is the incentives based approach we develop. We believe that networks of scientific collaboration are an outcome of deliberate decisions by individual scientists. This means that the observed networks reflect the technology of production of knowledge and the incentives faced by individuals. We are thus interested in developing a model where technology and incentive schemes are modelled explicitly and we can study their effects on collaboration networks systematically. The second contribution is our empirical work. To the best of our knowledge our paper is the first to study the properties of a network over an extended period of time (thirty years) with a view to understanding the stable and changing features of the network; earlier studies have focused on short periods of time (the maximum period of time covered seems to be 8 years, see Albert and Barabási (2002)). This difference in time horizon allows us to study the emergence of the small world property. The present paper also appears to be the first study of economics collaboration networks; existing work focuses on the natural sciences, medical sciences and mathematics. This is interesting since networks in other subjects exhibit different properties. For example, the relative size of the largest interconnected group of authors and the average number of co-authors seem to be very different in economics as compared to physics or medical sciences.

The rest of this paper is organized as follows. Section 2 presents basic notation and definitions. Section 3 contains our empirical analysis. Section 4 develops an incentives based model to explain these network patterns while Section 5 concludes.

2 Networks

We start by setting down some basic notation which is useful to discuss network features precisely. Let $N = \{1, 2, .., n\}$ be the set of nodes in a network. We shall refer to n as the *order* of the network. We shall be looking at undirected links in this paper, and for two persons/nodes $i, j \in N$, we shall define $g_{i,j} \in \{0, 1\}$ as a link between them, with $g_{i,j} = 1$ signifying a link and $g_{i,j} = 0$ signifying the absence of a link. If two persons have published a paper together then they are said to have a link between them; if they have published no papers together then they have no link. Thus the information on authors and papers allows us to construct a network of collaboration. We shall say that there is a path between i and j either if $g_{i,j} = 1$ or if there is a set of distinct intermediate co-authors $j_1, j_2 ... j_n$, such that $g_{i,j_1} = g_{j_1,j_2} = ... = g_{j_n,j} = 1$. The collection of all links will be denoted by g. The set of nodes and the links between them will be referred to as a network and denoted by $G(N, g)$. Let $\mathcal{N}_i(G) = \{j \in N : g_{i,j} = 1\}$, be the set of nodes with whom i has a link in network G. Let $\eta_i(G) = |\mathcal{N}_i(G)|$ be the degree of node i in network G, and define $eta(g) = \sum_{i \in N} \eta_i(G)/n$ as the average degree in a network G.

In case $\eta_1 = \ldots = \eta_n = \eta$ we will refer to η as the degree of the network. In general the degree is not constant across nodes/individuals and we are interested in the inequality in the distribution of degree across nodes. To measure this inequality we will compute Lorenz curves of the degree distribution. Suppose the set of nodes $S \subset N$ is ordered, such that $i < j$ if and only if $\eta_i < \eta_j$ for $i, j \in S$, and denote $n_s = |S|$ as the number of nodes in S and $L_S(h) = \sum_{i=1}^{h} \eta_i$ as the number of links in possession of the h least linked nodes. Then the Lorenz curve for S is given by connecting the points

$$(h/n_s, L_S(h)/L_S(n_s)) \in [0, 1]^2.$$

for $h = 0, \ldots, n_s$. The Lorenz curve measures the fraction of links that are in possession of the $x\%$ least linked nodes. Note that perfect equality, that is a constant degree across nodes in S, implies that the Lorenz curve follows the 45 degree diagonal.

Two persons belong to the same component if and only if there exists a path between them. The path relation therefore defines a partition of the network into components. For a network G the partition will be denoted as $P(G) = \{C_1, ..., C_m\}$ with $m \geq 1$. In case $m = 1$ we have a connected network and in case $m = n$ we have the empty network. The components can be ordered in terms of their size, and we shall say that the network has a *giant component* if the largest component fills a relatively large part of the graph and all other components are small, typically of order $\mathcal{O}(\log n)$. We denote the size of the giant component as $n_g c(G)$.

The geodesic distance between two nodes i and j in network G is the length of the shortest path between them, and will be denoted by $d(i, j; G)$. If there is no path between i and j in a network G then we shall set $d(i, j; G) = \infty$. In case G is connected, the average distance between nodes of a network G is given by

$$d(G) = \frac{\sum_{i \in N} \sum_{j \in N} d(i, j; G)}{n(n-1)}$$

If G is not connected then the average distance is formally speaking infinite. In our data the network is not connected and so to study distances we shall use the average distance in the giant component as a proxy for the average distance in the network. The maximum distance between any pair of nodes in a network G is referred to as the diameter of the network and it is given by

$$D(G) = \max_{i,j \in N} d(i, j; G)$$

The clustering coefficient of a network G is a measure of the correlation between links of different individuals. The level of clustering in an individual i's neighborhood is given by

$$C_i(G) = \frac{\sum_{l \in N_i(G)} \sum_{k \in N_i(G)} g_{l,k}}{\eta_i(\eta_i - 1)}$$

for all $i \in N' \equiv \{i \in N : \ \eta_i \geq 2\}$, This ratio tells us what percentage of a person's co-authors who are co-authors of each other. The clustering coefficient for the network G can be obtained by averaging across all persons in a network. We shall use an averaging scheme which gives more weight to authors with a higher degree. This leads us to the following definition for the clustering coefficient:

$$C(G) = \frac{\sum_{i \in N'} \sum_{l \in N_i} \sum_{k \in N_i} g_{l,k}}{\sum_{i \in N'} \eta_i(\eta_i - 1)}$$

A star network is a network where one node, referred to as the center node, is linked to all other nodes in the graph while all these other nodes are only linked to the center node. In some networks, there is no single center of the network, but there is a small number of extremely well connected nodes and the partners of each of these nodes have almost no other connections. We shall, somewhat informally, refer to these well connected nodes as 'stars'.

We shall say that a network G exhibits small world properties if it satisfies the following properties:

1. The number of nodes is very large as compared to the average number of links, $n >> \eta(G)$.

2. The network is integrated; the giant component exists and covers a large share of the population.

3. Clustering is high, $C(G) >> \eta(G)/n$.

4. The average distance between nodes in the giant component is small, $d(G)$ is of order $\ln n$.

This definition is a modified version of the notion of small world presented in Watts (1999).

3 Empirical Patterns

We study the world of economists who published in journals which are included in the list of EconLit. We cover all journal papers that appear in a 10 year window and we look at three such windows: 1970-1979, 1980-1989 and 1990-1999. The list of journal articles includes all papers in conference proceedings, as well as short papers and notes. We do not cover working papers and work published in books. The main reason for not covering working papers is that this can potentially lead us into double counting. The main reason for restricting attention to journal articles is that the EconLit database starts covering books from the 1980's only and this would sharply restrict the time frame of our study. Table 1 provides an overview of the coverage of our data. Tables 2 and 3 give us data on the number of EconLit journals and the number of articles published in these journals over this period. The number of journals has grown from 196 in 1970 to 687 in 1999 while the number of journal articles in EconLit has grown from 62,569 in the 1970's to 156,454 in the 1990's. In Table 3 we can also see that the number of pages per article has increased from 12.85 to 16.49 and that less and less papers have a single author. This trend was highlighted in Ellison (2002a).

The coverage of the Econlit data set is clearly partial and, to check the robustness of our findings, we also consider an alternative set of data. We use the list of the Tinbergen Institute Amsterdam-Rotterdam (hereafter TI list) to do this. This list of journals is used by the Tinbergen Institute to assess the research output of faculty members at 3 Dutch Universities (University of Amsterdam, Erasmus University Rotterdam and Free University Amsterdam). The Institute currently lists 133 journals in economics and related fields (econometrics, accounting, marketing, and operations research), of which 113 are covered by EconLit in 2000. The appendix presents the list of these journals and Table 2 shows the growth of this set over the 1970-2000 period. We observe that out of the 113 journals in 2000, only 46 were covered by EconLit in 1970! While some of the new journals are general interest journals, it is fair to say that most of the increase comes from the expansion in the number of field journals. We interpret this as evidence of a broadening as well as a deepening in the subject matter that is covered by economics. Table 3 also shows summary statistics for the TI list data set. Not surprisingly we see an increase in the number of papers, the number of pages per paper and the number of coauthored papers.

We thus have six data sets: 3 for the set of all journals covered in EconLit and 3 for the set of TI journals, and we construct a network for each data set. We first find the nodes in the network by extracting the different author names that appear in the data. As in Newman (2001) we distinguish different authors by their last name and the initials of all their first names. Consequently, authors with the same last name and different initials are considered different nodes. We note that a single author may sometimes be represented by two nodes because of misspellings in the data or because of non-consistent use of middle names. On the other hand, two different authors might appear as one node in the network if their surname and initials are identical.[5] Further, for papers with more than three authors EconLit reports only the first author and the extension *et alia*, and, hence, the other authors are not known. We therefore exclude articles with four or more authors from our network analysis. We then construct the whole co-authorship network by adding links between those authors that have coauthored a paper. We note that we do not weight the links, that is, we do not distinguish between more or less prolific relationships.[6]

[5] We also considered networks in which separate authors are distinguished by their last name and the first initial only. The conclusions are not affected by this extraction rule.

[6] We also analyzed weighted networks, see Newman (2001). Results are only slightly different.

3.1 Aggregate patterns

We now discuss four aggregate statistics to examine the small world feature of the network, namely: the order of the network, the existence and size of a giant component, the average distance between the nodes in the giant component, and the clustering coefficient.

Our analysis of the collaboration network starts with an examination of the order of the network, i.e., the number of publishing economists. Table 4 tells us that the profession has grown substantially in this period: the number of authors has grown from 33,770 in the 1970's to 81,217 in the 1990's. The data based on the TI list is consistent with this trend: the number of authors has increased from 14,051 in the 1970's to 28,736 in the 1990's. Our first finding is therefore the following: *the number of journal publishing economists has grown substantially – more than doubling – over the period 1970 to 2000.*

We next discuss the existence and size of the giant component. Table 4 tells us that in the 1970's the largest component contained 5,253 nodes, which constituted about 15.6% of the population. This largest component has expanded substantially over time and in the 1990's it contains 33,027 nodes, which is roughly 40% of all nodes. Correspondingly, there has been a sharp fall in the proportion of isolated nodes from almost 50% in the 1970's to about 30% in the 1990's. At the same time the second largest component has also declined in size: it had 122 members in the 1970's and only 30 members in the 1990's. This trend is consistent with evidence in the data on the TI list. These observations lead to our next finding: *There has been a significant increase in the level of integration of the network over the period 1970 to 2000. In particular, the giant component has grown substantially; it covered 15% of the nodes in the 1970's and covers over 40% of the nodes in the 1990's.*

We now turn to the distance between the nodes in the network. As is the norm we set the distance between nodes in the different components to infinity and we use the average distance between nodes in the giant component as a proxy for our measure of average distance in the network. We find that this average distance has declined from 12.86 in the 1970's to 9.47 in the 1990's. We also note that this fall in average distance has been accompanied with a significant fall in the standard deviation in the distances between nodes from 4.03 in the 1970's to 2.23 in the 1990's. This pattern is consistent with the trends observed in the data on journals in the TI list. This leads to our next finding: *The giant component has become significantly "smaller" in terms of distances.*

We turn next to the level of overlap between co-authorship, which is measured by the clustering coefficient in the network. Table 4 shows that clustering coefficient for the network as a whole was .193 in the 1970's, .182 in the 1980's and .157 in the 1990's for the network of all EconLit journal articles, and .188 in the 1970's, .180 in the 1980's and .167 in the 1990's when we consider articles in TI list journals only. These clustering levels are very high. To make this concrete, let us consider the figures from the 1990's. There are 81,217 authors and on average a person has 1.672 co-authors; we can interpret this as saying that the probability of a link being formed is approximately .000025. In a random graph, since the probability of link formation is independent, the clustering coefficient should be approximately equal to this probability of a link. However, the actual clustering coefficient is given by .157, which is more than 6,000 times the level predicted by the random model of link generation. These observations lead us to our next finding: *the clustering coefficient for the network is very high throughout the period under study.*[7]

When we set these findings against the criteria for a network to display small world properties, we find that throughout the period 1970-2000 the collaboration networks satisfy (1), (3) and (4), i.e. the average degree of the networks under consideration is tiny relative to the number of nodes,[8] clustering is high, and distance within the giant component is small. As to criterion 2, we note that the coverage of the giant component was relatively modest in the 1970's but in the 1990's it covered over 40% of the nodes. That is, a giant component has emerged and thus in the 1990's the collaboration network satisfies all four criteria. Furthermore, we see a decline of average distances within the giant component. This leads us to conclude that *economics is an emerging small world.*

3.2 Micro-level statistics

What is it about the number and arrangement of links in the network that generates these aggregate features. Our approach to this question is founded on the idea that individual economists have a choice between writing papers by themselves or in collaboration with others, and that the network of collaboration we observe arises out of the decisions they make in this regard. Thus the crucial micro level data in this approach are the number of collaboration links that an individual forms and the patterns of linking across economists.

We start with the behavior of the average number of links. In all the data we have assembled we observe the following: the average degree of the networks is very low but it has grown significantly in the period 1970 to 2000. For the set of all journals in EconLit, Table 4 tells us that there is almost a doubling in the per capita number of links/collaborators from .894 in the 1970's to 1.672 in the 1990's. This figure covers all publishing economists and it is useful to also examine the per capita number of collaborators among people who are in the giant component. Table 4 shows us that the per capita number of collaborators increased from 2.48 in the 1970's to 3.06 in the 1990's. This trend is also visible and clear cut in the TI list of Journals. This yields us our first finding on the micro statistics of the network: *the number of collaborators has been increasing consistently through the 1970-2000.*

[7]Papers with three co-authors increase the clustering coefficient. However, when we compute the clustering coefficient only considering papers with two co-authors, we find that the clustering coefficient is around .015, still more than 600 times the level predicted by a random link model.

[8]For instance, from Table 4 we see that in the 1990's the average degree was 1.68 while the number of publishing economists was well over 80,000.

We now turn to the distribution of the degree across nodes. We start by noting that the Pareto plot of the degree distribution appears to converge to a straight line for high degree k. This suggests that at high quantiles the distribution converges to a Pareto or power-law distribution.[9] An important characteristic of such a distribution is the existence of a fat tail. Indeed, extreme degree values appear more frequently in the real data than in a binomial distribution fitted on the 1990's data set. While under the fitted binomial distribution it is unlikely that any author has more than 10 links, in reality we see that more than 1% of the authors have more than 10 links and some of them have 40 to 50 links. We explore the inequality in the degree distribution further by looking at the Lorenz curves. Figure 2 suggests that the 20% most-linked authors account for about 60% of all the links.[10] These observations lead us to the following finding: *The distribution of links in the population of economists is very unequal and exhibits a fat tail.*

We now examine more closely the link pattern of the individuals who have very large degree in the network of collaboration. Table 5 tells us that in the 1970's the maximally connected person had 25 links and the 100 most linked persons had 12 links on average. Looking more closely at the most connected individual we see three very striking features: one, this person published 44 papers out of which 42 (i.e. 95% of them) were co-authored; two, he had 25 collaborators while the average number of collaborations per capita was less than 1; and three, the clustering coefficient for this person was only .05, which is much smaller than .193, the clustering coefficient of the network at large. Similarly, in the 1990's the most connected individual published 66 papers, of which 64 were co-authored (i.e. 97% of the total), had 54 collaborators (while the per capita number of collaborators was under 2) and a clustering coefficient of .02 (while the clustering coefficient of the network as a whole was .157). Thus the most connected individuals collaborated extensively and most of their co-authors did not collaborate with each other. These individuals can be viewed as 'stars' from the perspective of the network architecture. A closer inspection of Table 5 reveals that these three patterns are quite general and hold for the average of the 100 most linked individuals in the 1970's, 1980's and 1990's. This leads us to state: *There is a large number of 'stars' in the world of economics.*

We next examine the role of the stars in connecting different parts of the network. For this purpose we compared the consequences of randomly deleting 2% or 5% of the nodes on network connectivity and clustering with the consequences of deleting star nodes. We did this for the network based on all EconLit journals. Table 6 shows the results. We can see that a removal of 5% of the authors at random has almost no effect on the network connectivity and clustering. For the 1990's, we find that the size of the giant component goes down from .407 to .389, while the average distance within the giant component

[9] A power-law distribution would take the form $f(k) = \alpha k^{-\beta}$, with $\alpha > 0$ and $\beta > 0$.

[10] From Figure 2 it appears that inequality has substantially diminished. However, this observation is somewhat misleading since it appears to stem from a decrease in the number of isolated authors. If we considered non-isolated authors only, we would observe a marginal increase in equality. In our working paper version we provide Gini coefficients to quantify inequality in the distribution of links.

increases marginally from 9.47 to 9.68. By contrast, a removal of the 5% most connected nodes has a devastating effect on the network. The giant component breaks down almost completely. Moreover, the impact on clustering is very substantial: it increases from 0.157 to .344. This suggests that stars play the role of connectors and sharply reduce distance between different highly clustered parts of the world of economics. We therefore conclude that *the economics world is spanned by a collection of inter-linked stars.*

We would like to plot the networks for the periods of 1970's, 1980's and 1990's to get an overall picture of the networks. This has proven to be very difficult due to the large numbers of nodes involved. We have therefore tried to plot the local network around some prominent well connected economists (Figures 3-4). These plots are fascinating and suggest a number of ideas; we would like to draw attention in particular to one striking feature of the networks: hierarchy. For instance, in the plot for Joseph Stiglitz (Figure 3) we find that he is linked to several persons who are themselves 'stars' in the sense discussed above. Furthermore, we observe that these star co-authors of Mr. Stiglitz typically do not work with each other and also that the co-authors of these persons typically do not work with each other, nor they do work with Mr. Stiglitz. Thus there seems to be a hierarchy of well connected persons. We find this structure remarkable as this hierarchy is mostly self-organizing. A similar structure can be observed in the plot for Jean Tirole (see Figure 4).

The discussion on micro-variables allows us to make two general points. The *first* point is about a stable feature of the network: inter-linked stars span the network of collaboration throughout the period under study. The *second* point is about an important change: there has been a significant increase in the average degree of the network.

3.3 Explaining the emerging small world

There are two principal macro level changes in the structure of the economics network from which we conclude that a small world is emerging: one, the giant component is growing, and two, average distance within the expanding giant component is falling. Further, we observe one principal micro level change, namely, the average degree is increasing. We would like to examine the relative importance of this increase in average degree in explaining the macro level changes.

We first point out that one would expect the increase in average degree to be related to the changes in the macro level variables. A higher average degree means that there are more links in the network, and these extra links bring economists together. These economists would otherwise not be connected, or only indirectly connected. Thus, everything else constant, a higher average degree increases the size of the giant component and decreases the average distance within the giant component.[11]

[11] In a uniformly random graph the expected size of the giant component increases with average degree. Further, in a uniformly random graph average distance converges to $\ln n / \ln \eta$ for large n whenever $\eta > 1$ (see, e.g., Albert and Barabási, 2002).

In the literature, however, other explanations have been given for the emergence of a small world. The explanation which is most often heard is that the decrease in communication and travelling costs has made collaboration across individuals in different departments and countries easier (see Rosenblat and Mobius, 2004). There is plenty of empirical evidence showing that there has been a substantial increase in 'distant' collaborations in the last years. For example, Hamermesh and Oster (2002) find that in the 1970's only 5.6% of the collaborations were between authors working at different departments throughout the duration of the project. This number increased to 20.3% between 1992 and 1996. Therefore, economists have substituted collaboration projects with colleagues from the same department for projects with collaborators from 'distant' departments. This 'rewiring' of links should in principle make the world smaller (see Watts and Strogatz, 1998). That is, the giant component should grow and distances within the giant component should shrink when there are more 'distant' links.[12]

We would like to compare the importance of the change in average degree on change in the macro level variables, relative to the importance of other effects as the increase in distant collaboration. Here we would like to take into account that the size of the network has increased dramatically, and this tends to increase distances.[13] For this purpose we carry out the following simulation experiment.[14] Starting with the 3 networks based on all articles in EconLit, we first *randomly* delete *nodes* from the networks of the 1980's and the 1990's until the size of these networks is equal to the size of the network in the 1970's (i.e. 33,770 individuals). Next, we randomly delete *links* from all three networks until they all have the same degree of .67. This procedure *controls* for the changes in the size and in the degree of the network, while *preserves* other changes, as changes in the degree distribution or in the arrangement of links. In particular, the proportion of distant links in the networks is not altered by this procedure. The procedure makes a draw from three random networks, random in the sense that every draw of this procedure creates a different network with different macro outcomes. Formally, denote $G_t(N_t, g_t)$ as the coauthorship network in decade t. Then the above procedure draws from a random network $\mathcal{G}_t(m, z)$, assigning positive probability to any network $G(N, g)$ where $N \subset N_t$, $g \subset g_t$, $|N| = m$ and $\eta(G(N, g)) = z$, and zero probability to any other network.

Since we control for the changes in size and degree, we can formulate the following hypotheses. If the increase in degree were the *only* relevant factor leading to the emergence of a small world, we would expect that the networks adjusted by the above procedure are very similar and that their macro level properties are basically the same. Alternatively, if other factors such as the rearrangement of links (rewiring) did matter, then we would

[12] In the model of Rosenblat and Mobius (2004), despite the fact that this substitution effect increases group separation, average distance decreases.

[13] In a uniformly random network, average distance converges to $\ln n / \ln \eta$ for large n, see e.g. Albert and Barabási (2002). Hence, in a random network a larger network results in larger distances.

[14] We could regress the macro level variables on network size, average degree and the fraction of distant links; however, this procedure is not feasible since we only have 6 networks observed.

expect to observe an increase in the size of the giant component and a decrease in average distances as we move from the 1970's to the 1990's adjusted networks. Denoting $\tilde{n}_{gc,t} \equiv \mathrm{E}\{n_{gc}(\mathcal{G}_t(33770, .67))\}$, and $\tilde{d}_t \equiv \mathrm{E}\{d(\mathcal{G}_t(33770, .67))\}$, we thus consider the four following hypotheses:

$$
\begin{array}{llll}
1) & H_0 : \tilde{n}_{gc,1980's} = \tilde{n}_{gc,1970's} & \text{against} & H_1 : \tilde{n}_{gc,1980's} > \tilde{n}_{gc,1970's} \\
2) & H_0 : \tilde{n}_{gc,1990's} = \tilde{n}_{gc,1980's} & \text{against} & H_1 : \tilde{n}_{gc,1990's} > \tilde{n}_{gc,1980's} \\
3) & H_0 : \tilde{d}_{1980's} = \tilde{d}_{1970's} & \text{against} & H_1 : \tilde{d}_{1980's} < \tilde{d}_{1970's} \\
4) & H_0 : \tilde{d}_{1990's} = \tilde{d}_{1980's} & \text{against} & H_1 : \tilde{d}_{1990's} < \tilde{d}_{1980's}
\end{array}
$$

To test the hypotheses we repeat the procedure 200 times and create a sample of 200 observations from the random networks of the 1970's, 1980's and 1990's, and for each network in the sample we compute the relevant statistics. Table 7 shows the means and the standard deviations of the main macro statistics based on this sample (note that the size and the average degree are fixed). Our first observation is that, on average, the giant component comprised 9.0% of the population in the 1970's adjusted network, 11.0% in the 1980's adjusted network, and 11.6% in the 1990's adjusted network. Hence, the size of the giant component slightly increases. This is also confirmed by the test statistics in Table 8. The giant component is (significantly) larger in the 1980's than in the 1970's with a t-statistic of 53.8, and similarly the giant component is (significantly) larger in the 1990's compared to the 1980's.[15] We note, however, that this increase in the size of the giant component is of much smaller magnitude than the increase in the size of the giant component in the actual network: as reported in Table 4, the giant component in the actual networks increased from 15% in the 1970's to 40% in the 1990's!

Our second observation is that the mean distance is, on average, 14.50 in the 1970's adjusted network, 15.47 in the 1980's adjusted network, and 15.47 in the 1990's adjusted network. Hence, after controlling for size and degree, we see an *increase* in average distance from the 1970's to the 1980's and stable distances from the 1980's to the 1990's! Not surprisingly, the tests in Table 8 confirm that the hypothesis of nondecreasing distance cannot be rejected.

We also performed a similar experiment on the TI list data set. The results are also reported in Tables 7 and 8. These results are very similar to the results based on all articles. These observations imply that changes in the patterns of links only partially account for the growth of the giant component and it *cannot* account for the fall in average distances within the giant component. Our experiment thus leads to the conclusion that *the increase in average degree is the driving force behind the emergence of a small world.*

In a recent paper, Rosenblat and Mobius (2004) argue that it is the change in patterns of links that explains the fall in average distances. Our finding contradicts this argument. We

[15] Since $\tilde{g}_{gc,t}$ and $\tilde{d}_t$ are not normally distributed, we also perform non-parametric Wilcoxon (Mann-Whitney) tests to test for equal median.

shortly examine the approach used by them to understand the reasons for the conflicting conclusions. Rosenblat and Mobius (2004) look at a network of collaboration of authors who published in 8 core economics journals. They compare the collaboration network of 1975-1989 to the network of 1985-1999 and the network of 1970-1989 to the network of 1980-1999. They consider the giant component only, and they observe that average degree in the giant component has increased from 2.52 to 2.72 across the two networks. They control for this change in average degree by deleting links according to the ratio $1 - C_1/C_2$, where C_1 is the average degree in the giant component between 1975-1989 and C_2 is the average degree in the giant component between 1985-1999. They find that average distances are lower in the giant component of the adjusted 1985-1999 network as compared to the actual 1975-1989 network. This leads them to argue that it is the change in the pattern of links that has led to a fall in average distances in the giant component (see Table 6 in their paper).

We note that the procedure of Rosenblat and Mobius (2004) does not correct for the increase in the number of nodes. Further, only a small fraction of the links are removed (at most 11% of the links). Furthermore, they only focus on the giant component of the network, ignoring smaller components of the network. In our procedure, by contrast, we remove a considerable fraction of all nodes and links. One reason for this different approach is a difference in scope of the paper. While Rosenblat and Mobius take the giant component as given, the emergence of a giant component is one of our main findings, and we observe it in all the networks analyzed.[16] We therefore believe that one cannot treat the size of the giant component as given, and one should aim at controlling both for the size and the degree of the whole network. Secondly, a closer look at their table reveals that their procedure does not correct the increase in average degree within the giant component fully. That is, even in the adjusted 1985-1999 network the average degree is higher (2.58) than in the actual 1975-1989 network (2.52). The reason for this discrepancy is that, as links are deleted at random, nodes with few links will drop out of the giant component earlier, leaving nodes with a higher degree in the giant component. On the other hand, Table 7 shows that our procedure, deleting nodes and links in the whole network, results in an average degree in the giant component that hardly changes.[17]

3.4 Data robustness

We now briefly discuss some aspects of the data that we use. A shortcoming of the above data for our purposes is the partial coverage of the EconLit list. We observe that this list has been growing over time and the data discussed above relate to this expanding world. This pattern creates the following possibility: in the 1970's the world of journals

[16] We analyzed a data set similar to that used by Rosenblat and Mobius (2004). We found that fractional size of the giant component in this data set increased from 20% in 1975-1989 to 30% in 1985-1999.

[17] We applied our procedure and the procedure of Rosenblat and Mobius (2004) to a dataset similar to that in their paper. We found that, using our procedure, there is no evidence that average distance decreases. The results are available on request.

was actually very similar to the one we observe today but the EconLit data set does not capture this as it covered a small subset of journals and therefore excluded a large part of the journal publishing world. If this were true then the data above would be about the world of EconLit authors but would not be a good indicator of the world of journal publishing economists per se.

To get around this problem, we carry out two related robustness checks. We study the network of collaboration using only the subset of journals that appear in EconLit for the entire sample period. This is the route taken in Table 9. The number of authors has gone up significantly from 22,960 in the 1970's to 32,773 in the 1990's, about 43%. We now turn to the statistics on the pattern of connections. We note that the largest component has grown from 3,076 nodes in the 1970's, which was about 13% of all nodes, to 10,054 nodes in the 1990's, which is about 30% of all nodes. Likewise, the percentage of isolated authors has fallen from about 50% in the 1970's to about 32% in the 1990's. Thus the order of the network is increasing while the network is becoming more integrated. We note however that there is no trend in average distances in the giant component in the period under consideration. With regard to the micro statistics, Table 9 tells us that mean number of links per author has increased from 0.885 in the 1970's to 1.386 in the 1990's.

We finally consider a fixed set of five core journals, namely, *American Economic Review, Econometrica, Journal of Political Economy, Quarterly Journal of Economics* and *Review of Economic Studies*. Table 9 show the results we obtain. The size of the giant component has increased from 7% in the 1970's to 25% in the 1990's. Further, the number of per capita collaborators has increased from .833 in the 1970's to 1.429 in the 1990's and the clustering coefficient has remained high over time. There is no trend is average distance however.

The observations lead us to conclude that there is a significant increase in the size of the giant component as well as in the average degree of the network. This is consistent with our earlier observations. Further, geodesic distances are small, but average distance does not show a declining trend. This is in contrast with our earlier observations. However, the results are in line with the analysis of the adjusted networks in which we control the networks for the increase in order and degree. We conclude that the growth of the giant component is a robust feature of the collaboration networks, while declining distances are not.

4 An incentives based explanation

In this section we develop a simple model of network formation to explain the observed empirical patterns, specifically, the existence of inter-linked stars and the growth in the giant component. Our model has three main aspects: a technology of knowledge production, productivity differences across individuals, and academic reward schemes.[18]

We suppose that there are n players and that a player can be either of High type or Low type. There are n_h High-type players, and n_l Low-type players, and $n = n_h + n_l$. We assume that $1 < n_h << n_l$ and that n_l is sufficiently large. We denote the set of players by N. Players make decisions on their research strategy: whether to write alone or with others, and if with others, how many co-authorships to form and with which types of players; they also decide how many papers to write and how much effort to put in each paper that they write.

A paper x is either single-authored or it has two authors. Let $g_{ij}^x \in \{0,1\}$ model i's decision on whether to participate in a project x with author j, where a value of 1 signifies participation while a value of 0 signifies non-participation. Let e_{ii}^x denote the effort that player i spends on a single-authored paper x, and let e_{ij}^x, refer to the time that he spends on a joint paper x with coauthor j. We assume that for a paper to be written the total effort put in by its authors must be at least 1. A research strategy of a player is then given by a row vector, $s_i = \{(g_{ij}^x, e_{ij}^x)_{x \in \{1,..,m\}, j \in N}\}$, where m is the number of projects that a player participates in either individually or with any other single coauthor. A player j is a coauthor of player i if $g_{ij}^x = g_{ji}^x = 1$ for some paper x. Let $\eta_i(\mathbf{s})$ be the number of coauthors of player i in research strategy $\mathbf{s}$.

A paper consists of ideas and routine/technical work.[19] The quality of a paper depends only on the quality of the ideas it contains and the ideas of the paper in turn depend on the type of the authors of the paper. A High-type author has high quality ideas, while a Low-type author has low quality ideas; the high and low quality types of ideas are denoted by t_h and t_l, respectively, where $t_h > t_l > 1$. It is natural to assume that a type i author will write single-authored papers of quality t_i only, $i = h, l$; we assume that if two authors i and j jointly work on a paper the quality of the paper is given by $t_i \cdot t_j$. Thus quality of a paper can be $q \in \{t_h^2, t_h t_l, t_h, t_l^2, t_l\} = Q$.[20]

We assume that the marginal costs of writing papers increase with the number of papers, reflecting increasing marginal opportunity costs of time. Maintaining a coauthor relationship involves communication and coordination across different projects and possibly different partners and these costs are likely to increase as the number of co-authors

[18]For a related model of co-authors, see Jackson and Wolinsky (1996). Their interest is in complementarities in collaboration and their equilibrium networks are characterized by complete components of different sizes.

[19]This is similar to the formulation used in Ellison (2002b).

[20]In economics, quality of original ideas appears to be the crucial variable and physical capital and infrastructure seems to play a relatively minor role in the production of knowledge. This is quite different from the situation in subjects such as medicine and physics, where experiments require very substantial infrastructure and the provider of these resources is very critical role. Our formulation is therefore better suited for the study of collaboration in economics.

increases. This leads us to assume that the marginal cost are increasing in the number of coauthors, $\eta_i(\mathbf{s})$. Given these considerations, we are able to write down the costs of a research strategy s_i for a player i faced with a research strategy profile $\mathbf{s_{-i}}$, as

$$\sum_{j\in N} c\left[\sum_{x\in\{1,..,m\}} e_{ij}^x\right]^2 + f\frac{\eta_i(\mathbf{s})^2}{2} \tag{1}$$

with $f > 0$. This first part of the cost specification captures the idea that a collaboration relation between two individuals i and j is a research project and that the costs of coming up with interesting ideas and papers increase as more papers are written within the project. This leads us to suppose that writing m papers with m different coauthors is less costly than writing m papers with a single coauthor. This assumption pushes individuals toward diversification of collaborators. On the other hand, our assumption that costs of linking with others are convex in the number of links pushes toward fewer collaborators. The optimal number of collaborators trades off these two pressures.

We shall suppose that a person is rewarded on the basis of quality weighted index of papers he publishes, there is discounting of joint work and that there is a minimum quality requirement such that only papers *above* this quality are accepted for publication. We shall suppose that this threshold is given by $\bar{q}$ where $\bar{q} \in [1, t_h^2]$. One interpretation of this threshold is in terms of different journals: a higher ranked journal can be more selective in the papers it publishes and so it will have a higher threshold as compared to a lower ranked journal. We suppose that a single-author paper of quality q gets a reward q, while a 2-author paper of quality q yields a reward rq to each author, where $r \in [0, 1]$ reflects the discounting for joint work in the market.[21]

For a strategy profile $\mathbf{s}$, let $I_{ij}^x(\mathbf{e})$ be an indicator function, which takes on value 1 if $g_{ij}^x = g_{ji}^x = 1$, $e_{ij}^x + e_{ji}^x \geq 1$, and $q_{ij}^x \geq \bar{q}$, and it takes a value of 0, otherwise. Given these considerations, for a strategy s_i and faced with a strategy profile $\mathbf{s_{-i}}$, the payoffs to a player are as follows:

$$\Pi_i(s_i, \mathbf{s_{-i}}) = \sum_{j\neq i}\sum_{x\in\{1,..,m\}} I_{ij}^x r q_{ij}^x + \sum_{x\in\{1,..,m\}} I_{ii}^x q_{ii}^x - \sum_{j\in N} c\left(\sum_{x\in\{1,..,m\}} e_{ij}^x\right)^2 - f\frac{\eta(\mathbf{s})^2}{2}. \tag{2}$$

We study the architecture of networks that are strategically stable. Our notion of strategic stability is a refinement of Nash equilibrium. A strategy profile $s^* = \{s_1^*, s_2^*, ..., s_n^*\}$ is said to be a Nash equilibrium if $\Pi_i(s_i^*, \mathbf{s}^*_{-\mathbf{i}}) \geq \Pi_i(s_i, \mathbf{s}^*_{-\mathbf{i}})$, for all $s_i \in S_i$, and for all $i \in N$. In our model a coauthoring decision requires that both players wish to participate in the paper. It is then easy to see that an autarchic situation in which no one does any joint

[21] We are assuming here that different types involved in a collaboration get the same reward; our results do not change qualitatively if we assume that Low types get a lower payoff than High types.

work is always a Nash equilibrium. To avoid these types of coordination problems we supplement the idea of Nash equilibrium with the requirement of pair-wise stability. We define pair-wise stable equilibrium as follows:

Definition 1 *A strategy profile* $\mathbf{s}^*$ *is a pair-wise stable equilibrium if the following conditions hold:*

1. $\mathbf{s}^*$ *constitutes a Nash equilibrium.*
2. *For any pair of players,* $i, j \in N$ *there is no strategy pair* (s_i, s_j) *such that*

$$\Pi_i(s_i, s_j, \mathbf{s}^*_{-\mathbf{i}-\mathbf{j}}) > \Pi_i(s^*_i, s^*_j, \mathbf{s}^*_{-\mathbf{i}-\mathbf{j}})$$

and

$$\Pi_j(s_i, s_j, \mathbf{s}^*_{-\mathbf{i}-\mathbf{j}}) > \Pi_j(s^*_j, s^*_j, \mathbf{s}^*_{-\mathbf{i}-\mathbf{j}}).$$

We shall use the short form – pws-equilibrium – to refer to pair-wise stable equilibrium. This notion of equilibrium is taken from Goyal and Joshi (2003); it generalizes the original formulation of pair-wise stability due to Jackson and Wolinsky (1996) by allowing pairs of players to form and delete links simultaneously. We shall say that a network is *symmetric* if all equal-type players have the same number of links with each of the two types of players. This will allow us to talk of the number of collaborations between a typical i and j type of players and use η_{ij} to refer to this number.

We first characterize equilibrium networks under the assumption that, in a joint project, each author contributes one half of the time needed for routine work and gets credit r for the joint paper. This may be interpreted as a model with no transfers. We note that the optimal choice of number of papers is independent across pairwise collaboration ties. This is due to the cost specification which is additive across projects with different co-authors and own projects. Our first result derives the optimal number of papers that High type and Low type authors will write on their own and with others.[22]

Proposition 1 *Suppose* $\bar{q} < t_l$*. A High type player optimally chooses* $m^*_h = t_h/2c$ *single author papers,* $m^*_{hh} = 2rt_h^2/c$ *papers in a HH collaboration, and* $m^*_{hl} = 2rt_ht_l/c$ *papers in HL collaboration. A Low type player optimally chooses* $m^*_l = t_l/2c$ *single author papers,* $m^*_{lh} = 2rt_ht_l/c$ *papers in a LH collaboration, and* $m^*_{ll} = 2rt_l^2/c$ *papers in LL collaboration.*

Proof: For a High type the optimization problem with respect to single author papers is

$$\max_{m_h} \; t_h m_h - c m_h^2 \tag{3}$$

[22] In what follows we treat the number of papers and the number of co-authors as continuous variables.

Straightforward calculations yield $m_h^* = t_h/2c$. Similarly, for a High type the optimal number of papers in an HH collaboration is the solution to the following optimization problem:

$$\max_{m_{hh}} \; rt_h^2 m_{hh} - c\left[\frac{m_{hh}}{2}\right]^2 \tag{4}$$

This optimization problem yields us the solution that $m_{hh}^* = 2rt_h^2/c$. Similarly, the optimal number if papers for a H type in a HL collaboration are given by $m_{hl}^* = 2rt_h t_l/c$. Given that the publication threshold is below t_l, L types will also write papers on their own. The computations for these players are similar and omitted. ■

This proposition tells us that H-types will write more single authored paper than L-types. Moreover, the optimal number of papers in a HH relationship is greater than the number of papers in a LL co-author relation. These results follow directly from the initial quality differences across players. We also note that the number of optimal papers varies negatively with the costs of writing papers, while they vary positively with the individual credit given in co-authored papers.

Let π_i refer to the payoff that a i type player gets from working alone, and π_{ij} refer to the reward that a type i player gets from working with a type j player. Then the above proposition allows us to write down the payoffs for different type players.

$$\pi_h^* = \frac{t_h^2}{4c};\ \pi_{hh}^* = \frac{r^2 t_h^4}{c};\ \pi_{hl}^* = \frac{r^2 t_h^2 t_l^2}{c}; \tag{5}$$

$$\pi_l^* = \frac{t_l^2}{4c};\ \pi_{lh}^* = \frac{r^2 t_l^2 t_h^2}{c};\ \pi_{ll}^* = \frac{r^2 t_l^4}{c}. \tag{6}$$

In what follows, our interest is primarily in the nature of co-author networks that arise and we shall omit mention of single author papers throughout the discussion. The following result characterizes equilibrium networks.

Proposition 2 *Suppose that $n_h - 1 \geq r^2 t_h^4/cf$, $\bar{q} = t_l$ and n_h and n_l are even numbers. A symmetric equilibrium network exists and it has the following properties.*

1. *If $f > 2r^2 t_h^4/c$ then it is empty.*
2. *If $2r^2 t_l^4/c < f < 2r^2 t_h^4/c$, then $\eta_{hh}^* = \frac{r^2 t_h^4}{cf}$, $\eta_{lh}^* = 0$ and $\eta_{ll}^* = 0$.*
3. *If $f < 2r^2 t_l^4/c$, then $\eta_{hh}^* = \frac{r^2 t_h^4}{cf}$, $\eta_{hl}^* = 0$ and $\eta_{ll}^* = \frac{r^2 t_l^4}{cf}$.*

Proof: We first characterize the incentives to collaborate. Part (1) follows directly from noting that $\pi_{hh}^* < f/2$ implies that there is no incentive for two H-types to collaborate. Since this is the highest possible return from co-authorship no links can arise in equilibrium. We now prove part (2). First, we note that since $\pi_{hh}^* > \pi_{hl}^*$ an H-type will not link up with an L-type if there is an H-type available. The assumptions $n_h - 1 \geq r^2 t_h^4/cf$

and n_h is an even number guarantee that this will be the case (the critical number of high types is derived below). Second, we note that an L type would only be willing to collaborate with L-types if $f/2 < \pi^*_{ll}$.

We now turn to optimal choice of partners. If $f/2 < \pi^*_{hh}$ then the optimal number of links for an H type, η_{hh}, solves:

$$\max_{\eta_{hh}} \quad \eta_{hh}\pi^*_{hh} - f\frac{\eta_{hh}^2}{2} \tag{7}$$

The solution is given by $\eta^*_{hh} = \frac{r^2 t_h^4}{cf}$. Thus if $n_h - 1 > \frac{r^2 t_h^4}{cf}$, then there are enough H-types around and an H-type will not collaborate with an L-type. The computations for L-type players in case (3) are similar and omitted.

The existence of symmetric equilibrium follows directly from the fact that an optimal number of papers and co-authors exist, n_h and n_l are even and large enough to make optimal linking feasible. ■

Proposition 2 tells us that if two persons involved in a collaboration equally share the effort required to write a paper, then only links between same type players will form in a symmetric equilibrium. Moreover, H-types will have more co-authors than L-types. Figure 5 presents the equilibrium networks; in this figure $f_{hh} = 2r^2t_h^4/c$ and $f_{ll} = 2r^2t_l^4/c$.

We now comment on the role of the two institutional reward variables: the threshold level for publication, $\bar{q}$, and the credit for joint work r. The threshold $\bar{q}$ is critical in defining the level and types of co-authorship. This leads us to ask: does an increase in $\bar{q}$ always raise the proportion of co-authored papers? The answer to this depends on the relative value of t_h and t_l. If $t_h < t_l^2$ then the proportion of co-authored papers is increasing in $\bar{q}$. If $t_h > t_l^2$ then there is a non-monotonicity: as $\bar{q}$ crosses t_l the proportion increases and as it increases beyond t_l^2 it falls before rising again to a value of 1 as $\bar{q}$ crosses t_h. We also note that the number of joint papers as well as the number of co-authors is increasing in r, the level of individual credit for co-authored work.

Proposition 2 implies that there are no connections between Low and High type players. Moreover, in equilibrium, links only exist between players with the same number of links. This seems to be at variance with one of the crucial aspects of empirically observed networks: the existence of a large number of stars (which arise when highly connected players connect with very poorly connected players, see Table 8). This difference between observed patterns and equilibrium predictions leads us to explore two aspects of the model more closely: the number of H-types available and the possibility of transfers between High and Low types.

One reason for the 'same-type collaboration only' result is that there are enough players of each type. What happens if an H-type wants to collaborate with 10 H-types but there are only 5 H-types around? In this case, High type players may be induced to collaborate with L-type players. This observation leads us to the following result.

Proposition 3 *Suppose that $n_h - 1 < r^2 t_h^4/cf$ and the threshold for publication is $\bar{q} = t_l$. Then a symmetric equilibrium has the following features.*

1. *If $f > 2r^2 t_h^4/c$ then it is empty.*
2. *If $2r^2 t_l^4/c < f < 2r^2 t_h^4/c$, every H-type has $n_h - 1$ H-type co-authors, and also has $\eta_{hl} = \max\{0, \frac{r^2 t_h^2 t_l^2}{cf} - n_h + 1\}$ L-type co-authors. L-types do not work with each other.*
3. *If $f < 2r^2 t_l^4/c$ an H-type has exactly the same co-author pattern as in (2), while each L-type has $\eta_{lh} \in (1, n_h)$ H-type co-authors and $\max\{0, \frac{r^2 t_l^4}{cf} - \eta_{lh}\}$ L-type co-authors.*

Proof: Part 1 follows as in Proposition 2. We now prove part 2. Since $n_h - 1 < r^2 t_h^4/cf = n_{hh}^*$, it follows that there are not enough High-type players around so that a High-type may find it worthwhile to form collaborations with Low-types. Since $\pi_{lh}^* > \pi_{ll}^*$ a Low-type always prefers to collaborate with a High-type rather than with another Low-type. Thus, the payoff to a High-type may be written as

$$\left(t_h m_h - c m_h^2\right) + (n_h - 1)\pi_{hh}^* + \eta_{hl}\pi_{hl}^* - f\frac{(n_h - 1 + \eta_{hl})^2}{2}. \tag{8}$$

It is now easy to see that the optimal number of HL collaborations is given by $\eta_{hl} = r^2 t_h^2 t_l^2/cf - n_h + 1$. We now consider the incentives of L types. First note that since $f > 2r^2 t_l^4/c$ there will be no LL co-authored papers. It then follows that an L-type player will have $\eta_{lh} \in \{1, n_h\}$ H-type co-authors in a symmetric equilibrium. This completes the proof of part 2. The proof of part 3 is similar and omitted. ■

A scarcity of H-types implies that there is a wide range of parameters for which HL collaborations arise in equilibrium. Moreover, since $n_h << n_l$, in part (2) equilibrium networks will have an inter-linked stars structure: all H types will co-author with each other while each of them will co-author with a number of L-types, who do not co-author with each other. Figure 6 presents equilibrium networks when the number of H types is small; in this figure f_{hh} and f_{ll} are defined as before, while $f_{hl} = r^2 t_h^2 t_l^2/(n_h - 1)c$

We now examine the scope of 'a sharing of scarce resources' motivation for collaboration between an H-type and an L-type. We start by examining a case in which L-types offer 'time' for routine work and in return get High quality ideas from H-types. An important issue here is how the exchange of ideas and time takes place. We first discuss the case where an L-type only shares in the routine work and does not share the costs of maintaining links f. In this case it is possible to show that there will be no collaboration between H-types and L-types. The intuition here is as follows: when two H-types collaborate the surplus generated (at the optimal level of projects m_{hh}^*) is much higher as compared to the surplus generated when an H-type and an L-type collaborate. To induce an H-type to collaborate with an L-type the share for the H-type must therefore be much higher. This however reduces the share of the L-type and leads to lower number of projects undertaken which in turn renders an HL collaboration less attractive than a fair HH collaboration for a H-type player.[23]

This argument leads us to ask: are there other richer transfer schemes which would allow mutually profitable HL collaboration? An obvious candidate is an arrangement by which an L type does all the routine work and also bears the costs of maintaining the relation. In that extreme case, an H type incurs no costs in writing papers with an L-type, while a L-type has to compare the relative returns of entering into such an unequal relation as compared to working on equal terms with another L-type. Suppose the L-type contributes all the time needed for the routine work. Then the payoffs to an L-type from such an HL relation are: $\pi_{lh} = r^2 t_h^2 t_l^2/4c$. On the other hand, the payoffs to an L-type from an LL relation are $\pi_{ll}^* = r^2 t_l^4/c$. Now it is easy to see that if $t_h > 2t_l$, then an L-type would prefer to link with an H type rather than link with another L type. Moreover, since the H-type bears no costs, clearly he is happy to enter into such a collaboration. This collaboration relation corresponds to a simple trade: an H-type player offers ideas in return for which the L-type collaborator offers time and resources for routine work. This collaboration relation leads to a network in which every H-type has η_{hh}^* HH-collaborations and possibly a very large number of HL-collaborations. Moreover, each of the L-type partner has relatively very few HL-collaborations and a few LL-collaborations (assuming $\bar{q} < t_l^2$.) This is consistent with an inter-linked stars architecture as depicted in Figure 6.

5 Concluding remarks

The structures of social interaction affect individual behavior and economic performance in important ways. This leads us to ask: does the architecture of social interaction exhibit particular patterns and are these patterns stable over time?

We examine the evolution of interaction among economists by looking at co-authorship relations over a thirty year period. We find that in the 1970's this world was quite fragmented with the largest set of inter-connected individuals – the giant component – covering only 15% of the population, while in the 1990's this world was much more integrated, with the giant component covering close to half the population. At the same time, the distance between individuals on the giant component fell significantly, leading us to conclude that economics is an *an emerging 'small world'*.

We then ask: what is it about the number and distribution of co-authorships that accounts for these aggregate patterns? We have two principal findings here. Our first finding is that

[23]A formal proof of this is available in the working paper version of the paper.

the distribution of links is very unequal (fat tails are present) and there are many stars (these are highly connected economists who work with economists who have few or no other co-authors). Thus the world of economists is spanned by a set of inter-linked stars. Our second finding is that changes in average degree are the main factor underlying the growth in the giant component and the fall in distances in the expanding giant component.

We propose a simple model of production of knowledge in economics with the feature that a paper consists of novel ideas and routine work. The quality of the paper depends on the quality of ideas. We embed this basic technology in a setting where individuals are differentiated by the quality of ideas they have. Every individual chooses how many papers to write, and also with whom to write them. We find that an unequal distribution of collaborations and inter-linked stars arise naturally in this environment. Falling costs of communication and higher individual credit for co-authored work both lead to greater co-authoring and this is consistent with a growth in the giant component.

Our paper identifies certain stable features of collaboration networks in economics as well as provides an explanation for the emerging smallness of this academic world. We argue that there are good incentive based reasons to expect such architectures to arise in academic environments. These findings raise the question: Is the inter-linked stars structure of economics conducive for the generation and spread of knowledge?

Appendix: Tinbergen Institute List of Journals

Journals (AA): 1. American Economic Review 2. Econometrica 3. Journal of Political Economy 4. Quarterly Journal of Economics 5. Review of Economic Studies

Journals (A): 1. Accounting Review 2. Econometric Theory 3. Economic Journal 4. European Economic Review 5. Games and Economic Behavior 6. International Economic Review 7. Journal of Accounting and Economics 8. Journal of Business and Economic Statistics 9. Journal of Econometrics 10. Journal of Economic Literature 11. Journal of Economic Perspectives 12. Journal of Economic Theory 13. Journal of Environmental Economics and Management 14. Journal of Finance 15. Journal of Financial Economics 16. Journal of Health Economics 17. Journal of Human Resources 18. Journal of International Economics 19. Journal of Labor Economics 20. Journal of Marketing Research 21. Journal of Monetary Economics 22. Journal of Public Economics 23. Management Science(*) 24. Mathematics of Operations Research (*) 25. Operations Research (*) 26. Rand Journal of Economics / Bell Journal of Economics 27. Review of Economics and Statistics 28. Review of Financial Studies 29. World Bank Economic Review.

Journals (B): 1. Accounting and Business Research(*) 2. Accounting, Organizations and Society(*) 3. American Journal of Agricultural Economics 4. Applied Economics 5. Cambridge Journal of Economics 6. Canadian Journal of Economics 7. Contemporary Accounting Research(*) 8. Contemporary Economic Policy 9. Ecological Economics 10. Economic Development and Cultural Change 11. Economic Geography 12. Economic History Review 13. Economic Inquiry / Western Economic Journal 14. Economics Letters 15. Economic Policy 16. Economic Record 17. Economic Theory 18. Economica 19. Economics and Philosophy 20. Economist 21. Energy Economics 22. Environment and Planning A 23. Environmental and Resource Economics 24. European Journal of Operational Research(*) 25. Europe-Asia Studies(*) 26. Explorations in Economic History 27. Financial Management 28. Health Economics 29. Industrial and Labor Relations Review 30. Insurance: Mathematics and Economics 31. Interfaces(*) 32. International Journal of Forecasting 33. International Journal of Game Theory 34. International Journal of Industrial Organization 35. International Journal of Research in Marketing(*) 36. International Monetary Fund Staff Papers 37. International Review of Law and Economics 38. International Tax and Public Finance 39. Journal of Accounting Literature(*) 40. Journal of Accounting Research 41. Journal of Applied Econometrics 42. Journal of Applied Economics 43. Journal of Banking and Finance 44. Journal of Business 45. Journal of Comparative Economics 46. Journal of Development Economics 47. Journal of Economic Behavior and Organization 48. Journal of Economic Dynamics and Control 49. Journal of Economic History 50. Journal of Economic Issues 51. Journal of Economic Psychology 52. Journal of Economics and Management Strategy 53. Journal of Evolutionary Economics 54. Journal of Financial and Quantitative Analysis 55. Journal of Financial Intermediation 56. Journal of Forecasting 57. Journal of Industrial Economics 58. Journal of Institutional and Theoretical Economics / Zeitschrift für die gesamte Staatswissenschaft

59. Journal of International Money and Finance 60. Journal of Law and Economics 61. Journal of Law, Economics and Organization 62. Journal of Macroeconomics 63. Journal of Mathematical Economics 64. Journal of Money, Credit and Banking 65. Journal of Population Economics 66. Journal of Post-Keynesian Economics 67. Journal of Risk and Uncertainty 68. Journal of the Operations Research Society(*) 69. Journal of Transport Economics and Policy 70. Journal of Urban Economics 71. Kyklos 72. Land Economics 73. Macroeconomic Dynamics 74. Marketing Science 75. Mathematical Finance 76. National Tax Journal 77. Operations Research Letters(*) 78. Organizational Behavior and Human Decision Processes(*) 79. Oxford Bulletin of Economics and Statistics / Bulletin of the Institute of Economics and Statistics 80. Oxford Economic Papers 81. Oxford Review of Economic Policy 82. Probability in the Engineering and Informational Sciences(*) 83. Public Choice 84. Queuing Systems(*) 85. Regional Science and Urban Economics 86 Reliability Engineering & System Safety(*) 87. Resource and Energy Economics / Resource and Energy 88. Review of Income and Wealth 89. Scandanavian Journal of Economics / Swedish Journal of Economics 90. Scottish Journal of Political Economy 91. Small Business Economics 92. Social Choice and Welfare 93. Southern Economic Journal 94. Theory and Decision 95. Transportation Research B - Methodological 96. Transportation Science(*) 97. Weltwirtschaftliches Archiv / Review of World Economics 98. World Development 99. World Economy

(*) Journal not covered by EconLit

Table 1: Coverage of EconLit: Basic statistics

	1970's	1980's	1990's
Books	5	5302	16156
Book Review	0	0	1029
Collective Volume Articles	0	35422	96307
Dissertation	0	2649	9649
Journal Article	62518	95033	156601
Working Paper	41	12215	23446

Table 2: Number of journals in Econlit: 1970-1999

Years	Number of Journals	Number of Journals in TI List
1970	196	46
1971	198	48
1972	198	47
1973	209	53
1974	203	55
1975	200	56
1976	220	58
1977	227	61
1978	242	64
1979	248	65
1980	256	67
1981	264	67
1982	262	68
1983	285	74
1984	304	79
1985	311	81
1986	318	86
1987	317	87
1988	324	90
1989	340	95
1990	353	98
1991	368	101
1992	425	104
1993	439	106
1994	491	107
1995	535	109
1996	590	110
1997	624	111
1998	656	112
1999	687	113

Table 3: Summary statistics for articles in EconLit.

dataset	All journals			TI list		
period	70's	80's	90's	70's	80's	90's
total papers	62569	95027	156454	26802	38133	52469
mean pages per paper	12.85	14.45	16.49	12.17	13.76	16.29
standard deviation	(9.94)	(10.27)	(10.59)	(8.69)	(8.40)	(9.08)
Authors per paper: Distribution						
single-authored	.753	.678	.578	.716	.616	.504
two authors	.210	.256	.309	.244	.311	.371
three authors	.031	.055	.090	.035	.064	.104
four or more authors	.005	.011	.023	.005	.009	.020

Table 4: Descriptive statistics for six networks based on articles in EconLit.

dataset	All journals			TI list		
period	70's	80's	90's	70's	80's	90's
total authors	33770	48608	81217	14051	19694	28736
size of giant component	5253	13808	33027	2775	7283	14368
as percentage	.156	.284	.407	.197	.370	.500
second largest component	122	30	30	74	32	31
isolated authors	16735	19315	24578	5859	5999	6156
as percentage	.496	.397	.303	.417	.305	.214
average degree	.894	1.244	1.672	1.058	1.467	1.896
standard deviation	(1.358)	(1.765)	(2.303)	(1.433)	(1.815)	(2.224)
clustering coefficient	.193	.182	.157	.188	.180	.167
Giant Component						
average degree	2.48	2.77	3.06	2.48	2.70	2.95
standard deviation	(2.09)	(2.40)	(2.93)	(2.05)	(2.25)	(2.61)
average distance	12.86	11.07	9.47	11.99	11.12	9.69
standard deviation	(4.03)	(3.03)	(2.23)	(4.02)	(3.07)	(2.35)
diameter	40	36	29	33	31	26

Table 5: Network statistics for the economists with the highest number of links.

Author	Papers	% Coauthored	Links	Distance 2	Clust.Coeff
		1970s			
tollison rd	44	0.955	25	57	0.053
heady eo	30	0.833	23	13	0.028
feldstein ms	73	0.288	21	40	0.024
schmitz a	23	0.870	20	29	0.042
smith vk	72	0.514	20	26	0.032
Average top 100	23.87	0.724	11.94	25.67	0.062
Average all	2.35	0.243	0.89		0.193
		1980s			
mccarl ba	36	0.889	35	97	0.022
thisse jf	34	0.971	30	80	0.055
lee cf	36	1.000	29	106	0.030
whalley j	52	0.808	29	44	0.022
schmitz a	26	0.846	26	118	0.058
Average top 100	28.42	0.827	16.36	49.80	0.062
Average all	2.65	0.315	1.24		0.182
		1990s			
thisse jf	66	0.970	54	244	0.022
lee j	58	0.586	45	158	0.019
sirmans cf	67	1.000	41	172	0.045
nijkamp p	67	0.940	41	57	0.034
michel p	48	0.938	34	169	0.036
Average top 100	37.69	0.849	25.31	99.40	0.043
Average all	2.82	0.409	1.67		0.157

Table 6: Error and attack tolerance of the network based on all articles in EconLit.

period	70's	80's	90's
Size of the giant component (in perc.)			
Whole network	.156	.284	.407
w/o random 2%	.149	.276	.398
w/o random 5%	.137	.263	.389
w/o top 2%	.002	.067	.256
w/o top 5%	.000	.001	.001
Average distance within giant component			
Whole network	12.86	11.07	9.47
w/o random 2%	12.88	11.17	9.58
w/o random 5%	12.89	11.21	9.68
w/o top 2%	9.26	29.80	19.00
w/o top 5%	2.64	5.71	8.91
Clustering coefficient			
Whole network	.193	.182	.157
w/o random 2%	.193	.183	.158
w/o random 5%	.192	.182	.157
w/o top 2%	.318	.280	.250
w/o top 5%	.440	.380	.344

Table 7: Simulation experiment to control for changes in size and degree in the networks.

dataset	All journals			TI list		
sample size	200	200	200	1000	1000	1000
period	70's	80's	90's	70's	80's	90's
total authors	33770	33770	33770	14051	14051	14051
average degree	.67	.67	.67	.90	.90	.90
giant component (as perc.)	.090	.110	.116	.151	.169	.169
	(.003)	(.004)	(.004)	(.005)	(.008)	(.009)
isolated authors (as perc.)	.580	.583	.585	.471	.471	.472
	(.001)	(.002)	(.002)	(.002)	(.003)	(.003)
clustering coefficient	.146	.141	.151	.160	.155	.162
	(.003)	(.005)	(.005)	(.004)	(.005)	(.006)
Giant Component						
average degree	2.28	2.30	2.31	2.36	2.33	2.34
	(.01)	(.01)	(.02)	(.01)	(.02)	(.02)
average distance	14.50	15.47	15.47	12.97	14.84	14.84
	(.56)	(.70)	(.87)	(.52)	(.84)	(.98)
diameter	42	43	42	37	41	41
	(4.1)	(4.2)	(4.7)	(4.2)	(4.5)	(5.0)

Networks are adjusted by; 1) deleting *nodes* randomly until the order is 33770 (14051); 2) deleting *links* randomly until the average degree is .67 (.90). The sample mean is given without parentheses. The sample standard deviation is given in parentheses.

Table 8: Test statistics to test hypotheses that other factors than the increase in average degree have contributed to the emergence of a small world.

dataset		All journals		TI list	
test statistic		t-test	Wilcoxon	t-test	Wilcoxon
H_0	H_a				
$\tilde{n}_{gc,1980's} = \tilde{n}_{gc,1970's}$	$\tilde{n}_{gc,1980's} > \tilde{n}_{gc,1970's}$	53.82	17.30	58.68	35.86
		(.000)	(.000)	(.000)	(.000)
$\tilde{n}_{gc,1990's} = \tilde{n}_{gc,1980's}$	$\tilde{n}_{gc,1990's} > \tilde{n}_{gc,1980's}$	14.03	11.62	1.75	1.34
		(.000)	(.000)	(.041)	(.090)
$\tilde{d}_{1980's} = \tilde{d}_{1970's}$	$\tilde{d}_{1980's} < \tilde{d}_{1970's}$	15.26	12.53	59.94	37.17
		(1.00)	(1.00)	(1.00)	(1.00)
$\tilde{d}_{1990's} = \tilde{d}_{1980's}$	$\tilde{d}_{1990's} < \tilde{d}_{1980's}$	.09	.35	-.31	-.30
		(.535)	(.637)	(.438)	(.384)

All tests are one-sided. The Wilcoxon test statistic is normalized to compare to the t-statistic. p-values are given in parentheses

Table 9: Network statistics for two networks based on articles in two fixed subsets of journals.

data set	Entire period[a]			Core journals[b]		
period	70's	80's	90's	70's	80's	90's
total authors	22960	27539	32773	3186	3387	3171
size of giant component	3076	5899	10054	237	608	779
as percentage	.134	.214	.307	.074	.180	.246
isolated authors	11260	11062	10572	1507	1143	701
as percentage	.490	.402	.323	.473	.337	.221
average degree	.885	1.134	1.386	.833	1.142	1.429
standard deviation	(1.312)	(1.508)	(1.695)	(1.095)	(1.279)	(1.405)
clustering coefficient	.198	.218	.216	.253	.259	.257
Giant Component						
average degree	2.45	2.62	2.70	2.45	2.45	2.55
standard deviation	(2.03)	(2.11)	(2.18)	(1.80)	(1.77)	(1.82)
average distance	12.15	12.63	12.33	7.94	11.92	11.02
standard deviation	(3.75)	(3.65)	(3.36)	(3.43)	(5.22)	(4.12)
diameter	29	37	34	22	33	29

[a] Network is based on articles in journals that appear in EconLit for the entire sample period from 1970 to 1999.

[b] Network is based on articles in *American Economic Review*, *Econometrica, Journal of Political Economy, Quarterly Journal of Economics* and *Review of Economic Studies.*

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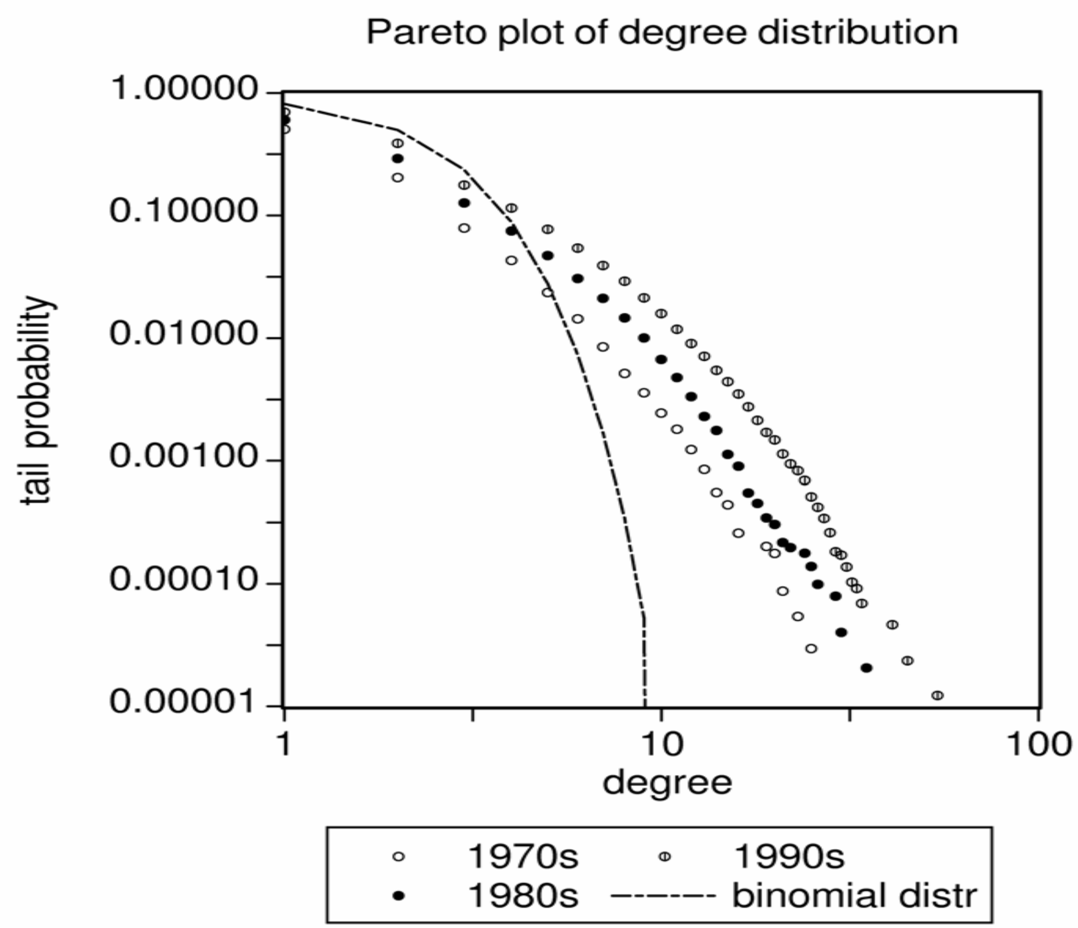
Figure 1



Pareto plot of degree distribution
tail probability
1.00000
0.10000
0.01000
0.00100
0.00010
0.00001
1
10
100
degree
1970s
1990s
1980s
binomial distr

Figure 2

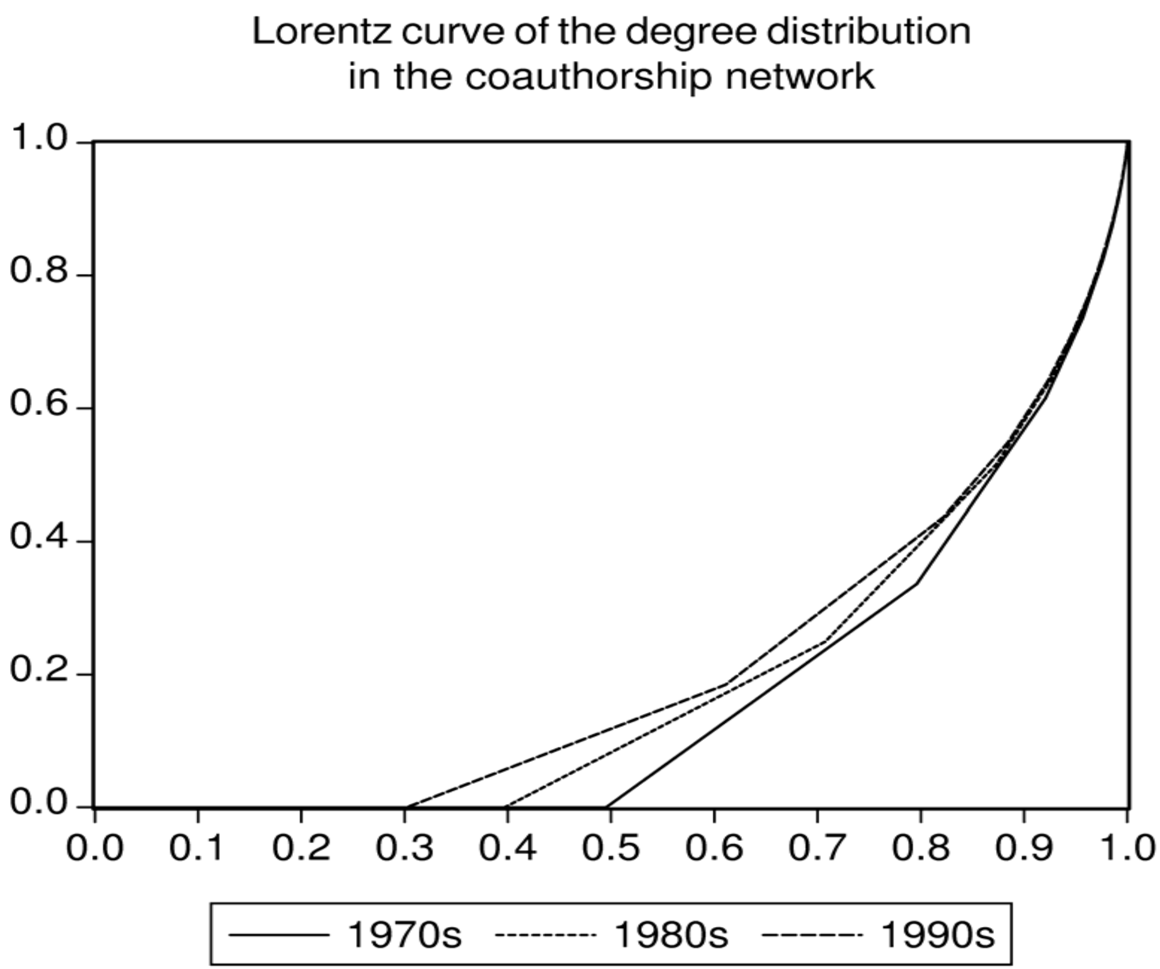
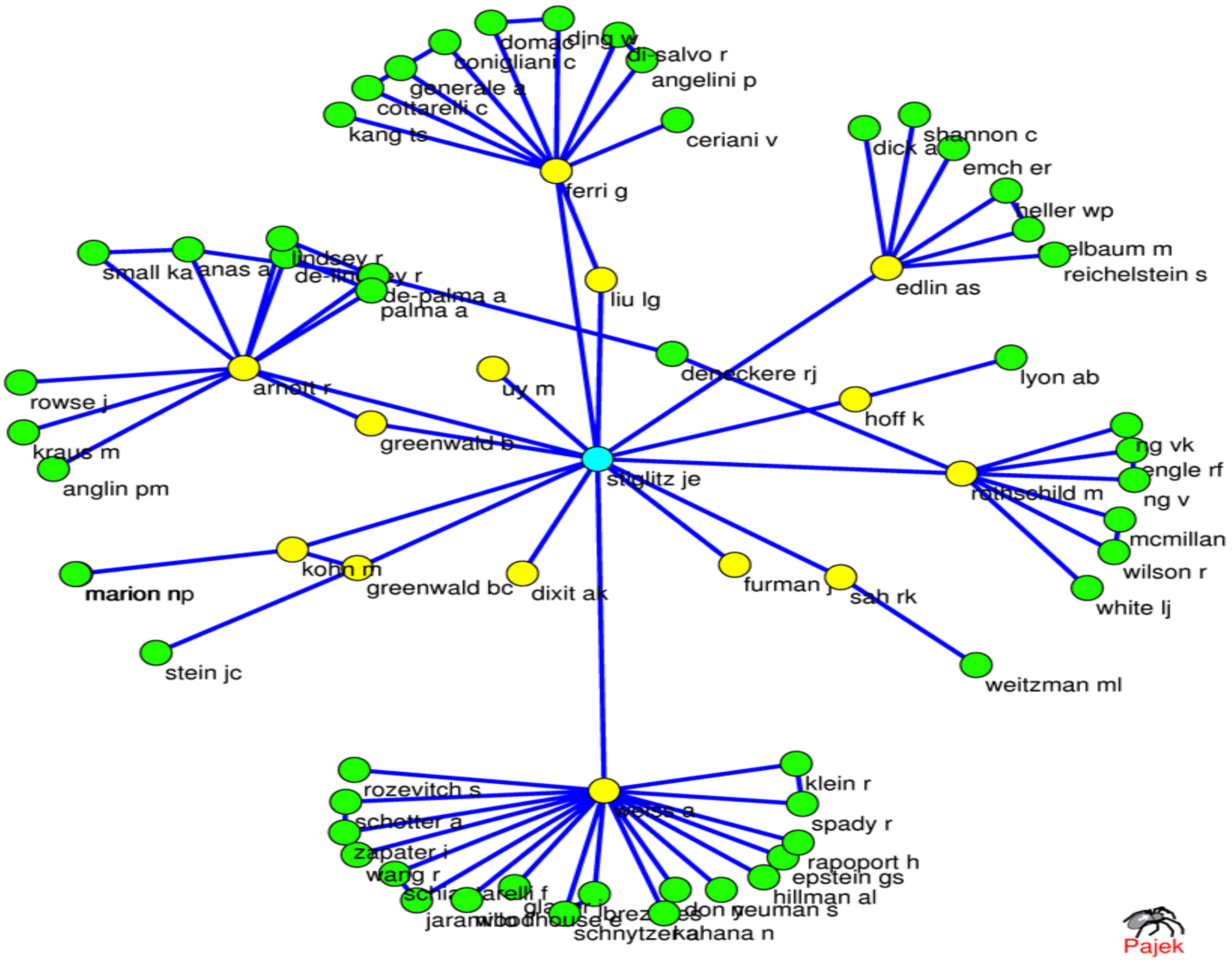
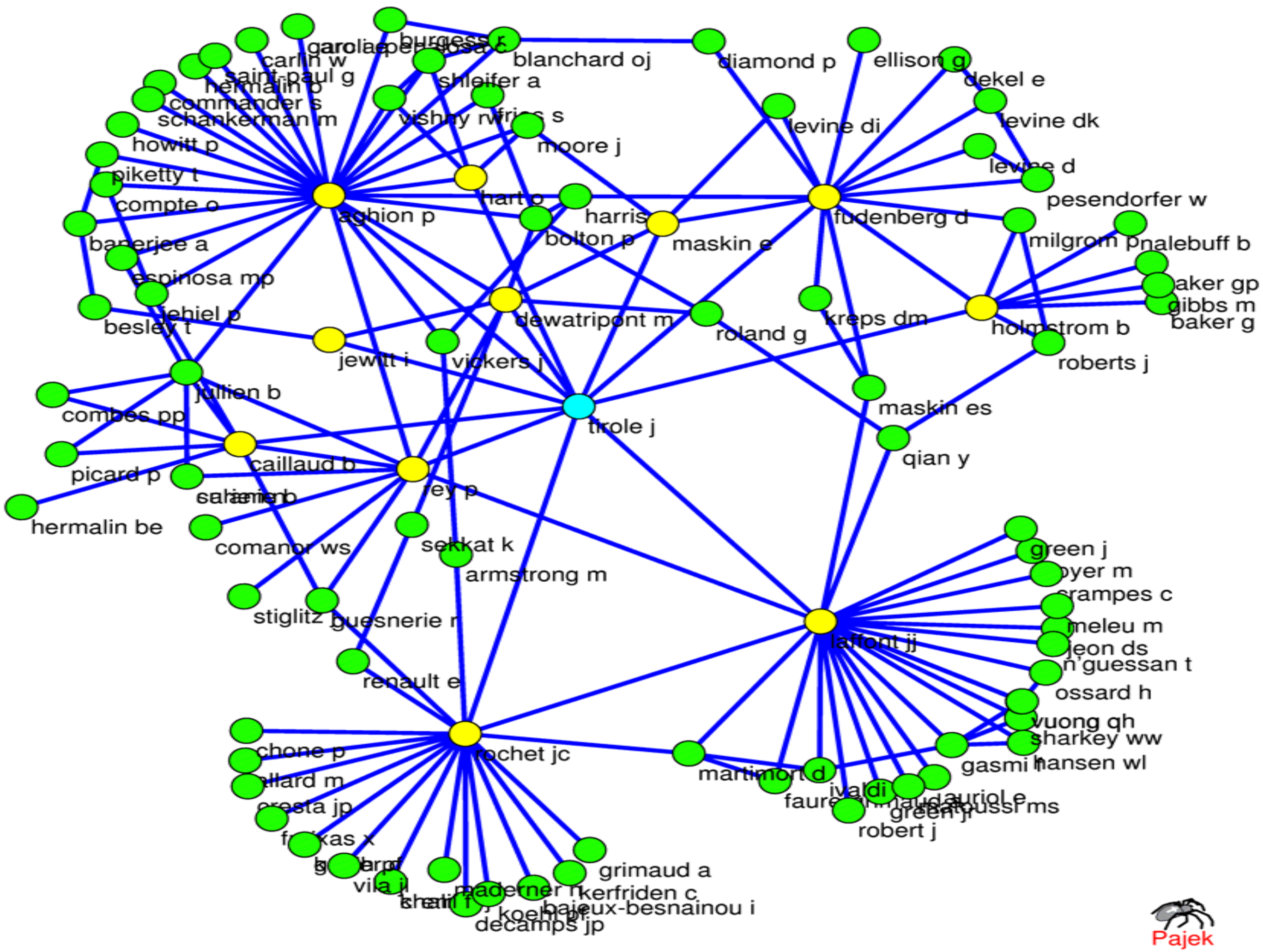

Lorentz curve of the degree distribution
in the coauthorship network
1.0
0.8
0.6
0.4
0.2
0.0
0.0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1.0
1970s
1980s
1990s

Figure 3: Local network of J. Stiglitz in 1990’s



Note: Some economists might appear twice or are missing due to the use of different initials or misspellings in EconLit.

Figure 4: Local network of J. Tirole in 1990's



Note: Some economists might appear twice or are missing due to the use of different initials or misspellings in EconLit.

Figure 5: Symmetric equilibrium networks

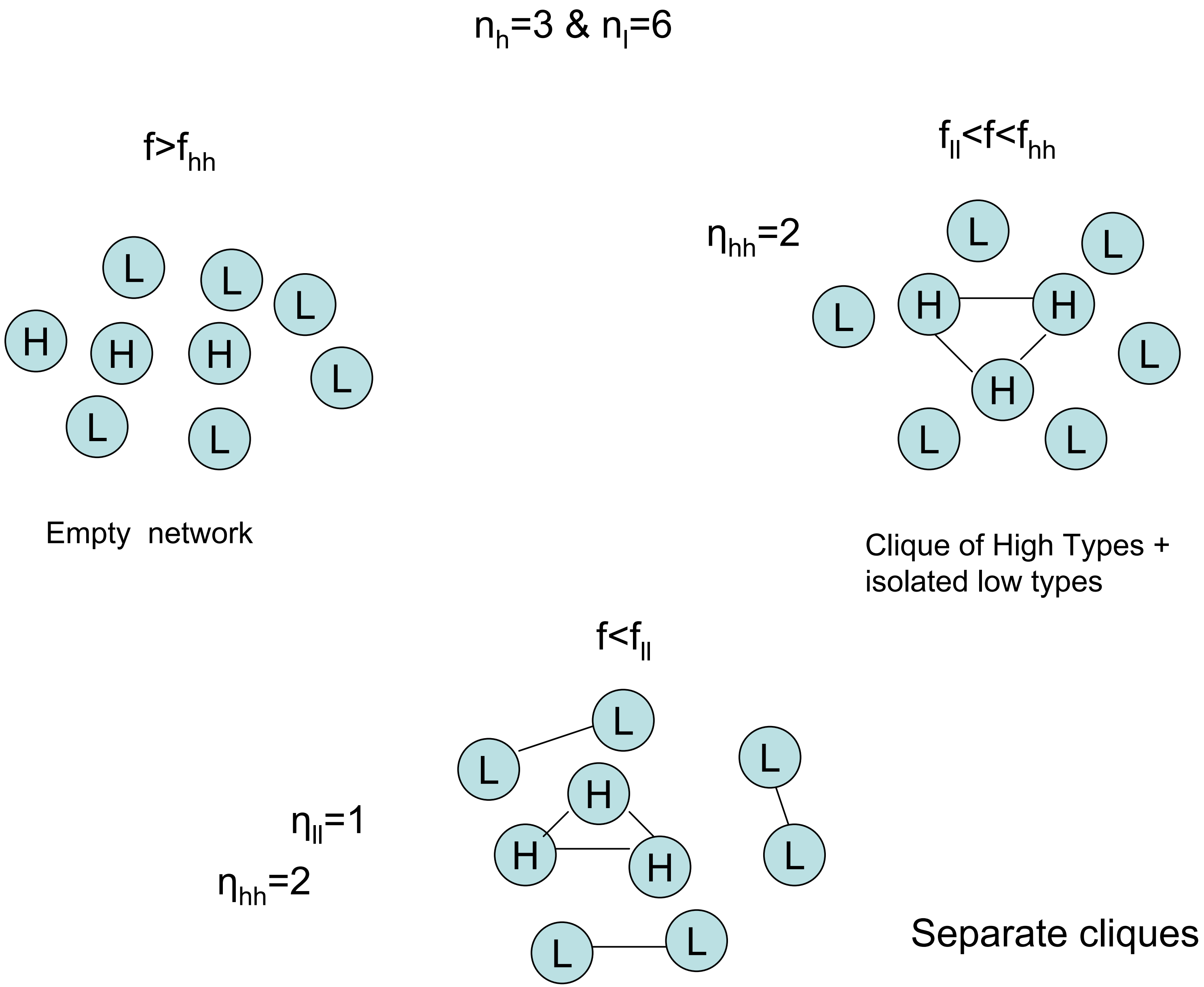
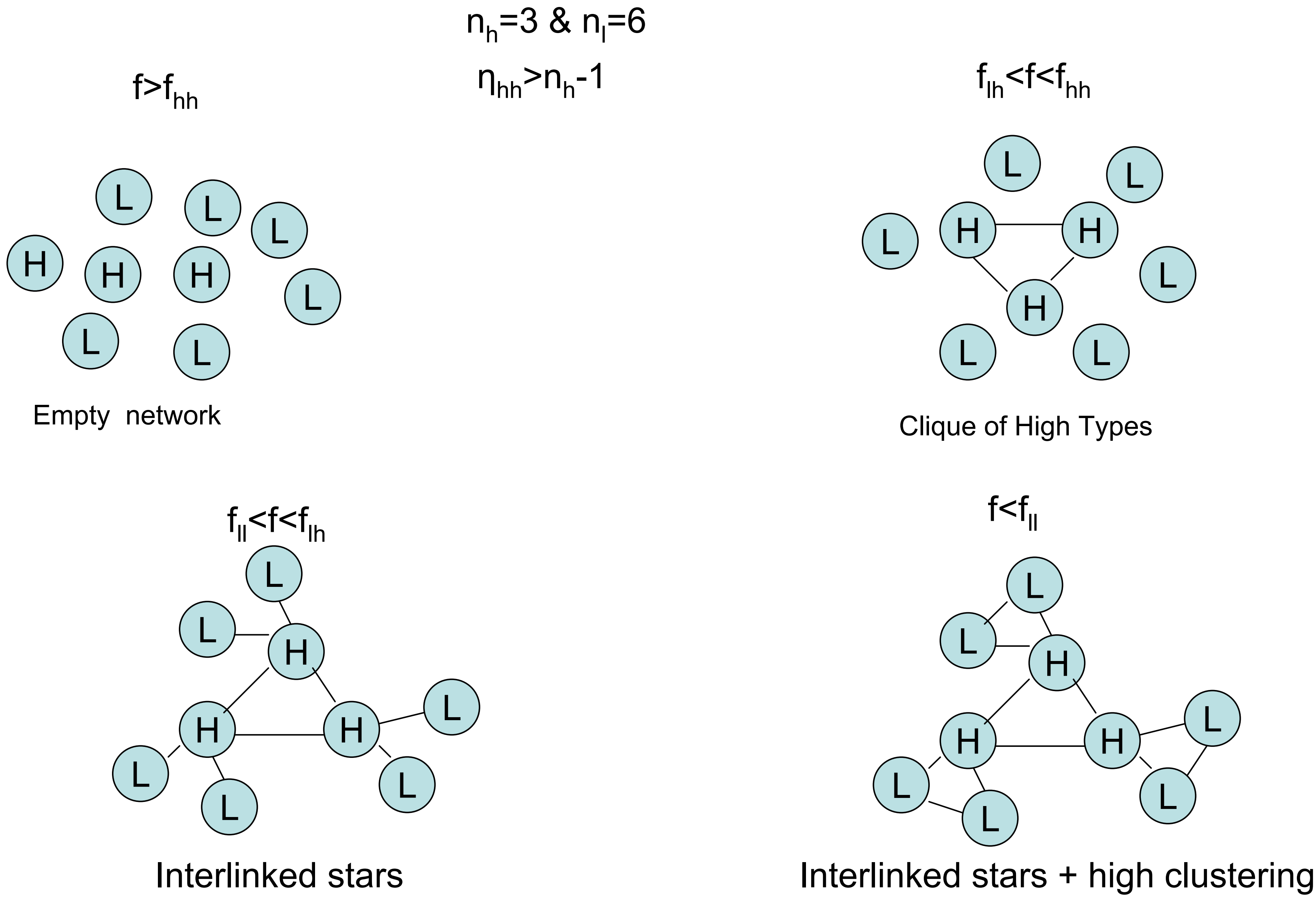


Figure 6: Symmetric equilibrium networks with size constraints.



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(lix) This paper was presented at the ENGIME Workshop on “Mapping Diversity”, Leuven, May 16-17, 2002
(lx) This paper was presented at the EuroConference on “Auctions and Market Design: Theory, Evidence and Applications”, organised by the Fondazione Eni Enrico Mattei, Milan, September 26-28, 2002
(lxi) This paper was presented at the Eighth Meeting of the Coalition Theory Network organised by the GREQAM, Aix-en-Provence, France, January 24-25, 2003
(lxii) This paper was presented at the ENGIME Workshop on “Communication across Cultures in Multicultural Cities”, The Hague, November 7-8, 2002
(lxiii) This paper was presented at the ENGIME Workshop on “Social dynamics and conflicts in multicultural cities”, Milan, March 20-21, 2003
(lxiv) This paper was presented at the International Conference on “Theoretical Topics in Ecological Economics”, organised by the Abdus Salam International Centre for Theoretical Physics - ICTP, the Beijer International Institute of Ecological Economics, and Fondazione Eni Enrico Mattei – FEEM Trieste, February 10-21, 2003
(lxv) This paper was presented at the EuroConference on “Auctions and Market Design: Theory, Evidence and Applications” organised by Fondazione Eni Enrico Mattei and sponsored by the EU, Milan, September 25-27, 2003
(lxvi) This paper has been presented at the 4th BioEcon Workshop on “Economic Analysis of Policies for Biodiversity Conservation” organised on behalf of the BIOECON Network by Fondazione Eni Enrico Mattei, Venice International University (VIU) and University College London (UCL) , Venice, August 28-29, 2003
(lxvii) This paper has been presented at the international conference on “Tourism and Sustainable Economic Development – Macro and Micro Economic Issues” jointly organised by CRENoS (Università di Cagliari e Sassari, Italy) and Fondazione Eni Enrico Mattei, and supported by the World Bank, Sardinia, September 19-20, 2003
(lxviii) This paper was presented at the ENGIME Workshop on “Governance and Policies in Multicultural Cities”, Rome, June 5-6, 2003
(lxix) This paper was presented at the Fourth EEP Plenary Workshop and EEP Conference “The Future of Climate Policy”, Cagliari, Italy, 27-28 March 2003
(lxx) This paper was presented at the 9th Coalition Theory Workshop on "Collective Decisions and Institutional Design" organised by the Universitat Autònoma de Barcelona and held in Barcelona, Spain, January 30-31, 2004

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