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Temporary employment agencies make the world smaller: Evidence from labour mobility networks

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Abstract - This paper investigates how employment intermediaries affected the inter-firm network of worker mobility in an region of Italy in response of the reform that first allowed for temporary employment agencies in 1997. We map worker reallocations from a matched employer-employee dataset onto a directed graph, where vertices indicate firms, and links denote transfers of workers between firms. Using network-based methodologies we find that temporary employment agencies significantly increase network integration and practicability, while fastly increasing control over hiring channels. The policy implications of the results are discussed, highlighting the potential of network analysis as monitoring tool for regional and local labour markets.

Keywords: Inter-firm networks, labour mobility, temporary employment agencies

JEL Codes: D85, C46, J63

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1. Introduction

This paper aims at offering an original grasp of the effects of employment intermediation on worker mobility between firms in a regional labour market; we examine two related issues: (1) how and to what extent the arrival of labour intermediaries in the market following a reform affects the integration of the market and the reachability of different employers for people who reallocate within the market; (2) whether and how the power of intermediaries in controlling and directing worker flows grows over time, and which are the fundamental dynamics of this process.

Such questions derive straightforwardly from the fundamental trade-off characterizing brokerage activity, according to which intermediation on one side may increase matching opportunities by reducing information costs for the parties, on the other side it produces monopolistic rents for intermediaries, because of the information asymmetries inherent in information brokerage, also favouring the concentration of the market in the hands of a few intermediaries. To appreciate quantitatively these effects and their evolution is a way of keeping the labour market functioning monitored in order to support policy action intended to improve job matching efficiency through intermediation, while preventing the market from becoming dominated by a few intermediaries.

We explore these topics by applying a complex network approach to employer-employee matched data covering the universe of private employment in a highly industrialized region of Italy, Veneto; we use the network representation as a way of organizing individual mobility events over a decade; then we employ established network models to capture the effects of labour intermediaries on the structure of inter-firm reallocations.

The paper focuses on a special category of intermediaries, temporary employment agencies (TEAs), and exploits the labour market reform of 1997, that allowed TEAs to be the first and only intermediaries operating in Italy, in order to appreciate the effects of labour intermediation in the very first years after its introduction, that is during the five-year period 1997-2001. The data keep track of all worker reallocations involving TEAs either as origin or destination, thus allowing us to capture the whole labour mobility involving intermediaries.

The main object of analysis is a directed graph, whose vertices indicate employers, private firms or TEAs, and whose links denote transfers of workers between employers. Our first focus is on how much the labour mobility network works as an integrated and easily practicable system for workers who reallocate from one job to another. We appreciate these properties by measuring the small-world characteristics of the network; next we identify the impact of TEAs on the network architecture, interpreting the tendency of the world of worker mobility to become smaller as a signal that the labour market is more accessible and pervious to reallocation flows.

We subsequently focus on the position TEAs take in the reallocation market, more specifically, on the TEAs power of controlling hiring channels as revealed by the number of incoming links the intermediaries exhibit in the labour mobility network. To this purpose, we track the evolution of the statistical distribution of connections over vertices, locating TEAs, and we highlight how labour flows globally adjust to the presence of labour market intermediaries; then we discuss the predictions of several models of network formation describing the evolution of the link distribution in presence of information cost.

The paper is organized as follows: Section 2 provides a brief overview of the theoretical foundation of labour market intermediations, with a specific focus on TEAs; Section 3 describes the role of TEAs in Italy in the period under study; Section 4 introduces the network analytical framework; Section 5 describes the data; Section 6 presents the results; Section 7 discusses the TEAs capacity of controlling worker flows; finally, Section 8 concludes.

2. Outline of labour market intermediation

The conceptual foundation of labour intermediation is rooted in the existence of market imperfections that hamper an efficient matching between demand and supply. One major feature of real, imperfect labour markets is the difficulty, for both individuals and firms, to locate partners for matches, and/or to effectively negotiate over the terms of matching agreements. Some third parties – the intermediaries – may hence come into play to exploit such circumstances and to realize profits by selling ad hoc matching services or information to workers and firms.

David Autor define labour market intermediaries as follows: “Labor market intermediaries (LMIs) are entities or institutions that interpose themselves between workers and firms to facilitate, inform, or regulate how workers are matched to firms, how work is accomplished, and how conflicts are resolved” (Autor, 2009, 1). Two main categories of market imperfections are addressed and exploited by LMIs: (1) costly information; (2) asymmetric information, resulting into adverse selection of matching counterparts.

Workers bear the direct cost of exploring the employers side of the market, applying for job, and sitting in interviews, and the indirect cost of foregone work or leisure. Employers bear the direct cost of vacancy advertising and applicants screening, and the indirect cost of foregone output until vacancies are filled. LMIs reduce search costs by way of collecting information about players on one side of the market, and then selling them to players on the other side of the market, at a price lower than the cost the latter players would incur if searching by themselves.

Noticeably, when information is costly, very often they it is also asymmetric. Workers might hide or blur some information in their curricula or credentials, in order to appear more attractive to potential employers. Similarly, firms might exploit asymmetric information to the detriment of workers, for instance by underpromoting deserving workers, so as to pay lower wages (Garcia-Perez and Muñoz-Bullón, 2005), or by omitting or misrepresenting real job conditions, in order to attract aspirant workers (Lee, 2009). LMIs can mitigate the problem of adverse selection due to asymmetric information by way of performing accurate screening of both job seekers and employers, and by assuming direct responsibility for selection through special contractual provisions.

The literature also points to a third element of informational asymmetry that is specific to intermediation activity, namely, the asymmetry between the LMI itself and its clients. LMIs which are in the business of selling information are inherently better informed about the information they sell, than are their customers. Therefore, the informational advantage of LMIs over the participants in a labour market transaction represents a potentially strong incentive for the intermediary to use its information in order to extract a rent from intermediation services. The analyses of Lee (2009) and Kleiner and Todd (2009) illustrate with examples exactly how intermediaries can use their advantage to the detriment of customers.

The potentially harmful consequences of this sort of informational asymmetry bring to light the compelling trade off – inherent in any process of information brokerage/concentration – between the benefits of increased accessibility of information, in our case represented by availability of huge information chunks at low price, and the detriments resulting from the monopolistic and/or monopsonistic position of mass information provider, in our case represented by non competitive markups charged by LMIs for intermediation services, or by promotion of high-markup matches, rather than matches that are optimal for the parties.

Moreover, since the amount of information available to the parties through a broker depends positively on the broker's actual market share, a self-reinforcing incentive mechanism is at play, according to which the bigger the broker the more people apply to that broker, further increasing the broker's influence in the market. But also the informational advantage of the intermediary over its clients and the resulting monopolistic/monopsonistic behaviour do increase with the market share, up to possibly neutralizing the benefits of information brokerage, and producing net damages, when the market reaches a deep level of concentration.

According to standard arguments, competition between private LMIs, and/or between private LMIs and public employment agencies, can significantly favour workers and firms, by keeping low (competitive) the price of intermediation services, and preventing dominant positions to emerge, while guaranteeing matching quality. In this respect, the role played by policy makers in shaping market structure and regulating market functioning is of fundamental importance for a good performance of intermediated labour markets.

The present work focuses on a particular category of LMIs, that is temporary employment agencies. People apply to TEAs both for accessing short-term employment with negligible investment in job search, and as an entry stage to more stable occupations (Autor, 2001; Autor and Houseman, 2002). Firms rely on TEAs so as to reduce the fixed costs of search for temporary workers, but they often outsource to TEAs the staffing of critical categories of workers, or even the selection of the whole workforce; in this case, people who want to get a job in such firms simply must start working through a TEA (Houseman, 2001; Ichino et al., 2004).

Garcia-Perez and Muñoz-Bullón advance the strong argument that TEAs "in fact offer a unique screening device that matches the individual with the most appropriate skill-level to the job in question" (Garcia-Perez and Muñoz-Bullón, 2005, 1). The authors highlight that hiring TEA workers, in order to screen them and then offer permanent positions only to the most suitable ones, has become nowadays a common strategy for firms. Along the same lines, Autor shows that in several sectors of the US economy TEA services represent the most important channel for recruiting permanent workers (Autor, 2001).

In Italy, throughout the period considered in this study, TEAs are the only intermediaries operating; therefore, hiring through TEAs is the unique means available to firms and workers for accessing searching and screening services. Such a particular context extends the scope of TEAs to the whole range of LMIs typical functions. As thoroughly discussed in Section 4, there is far strong evidence that Italian TEAs do search and select people aimed at eventually filling permanent positions, very often appointing skilled workers, technicians, and even professionals.

3. Network setup and empirical strategy

The analysis of labour mobility at the individual level using network concepts dates back to the seminal work of Granovetter (1973) which illustrates the importance of different types of social connections for successful job search. Since then, joint research on labour mobility and network analysis has attracted a great deal of attention from scholars in economics and economic geography, mostly focusing on innovation mechanisms, knowledge spillovers, and spatial diffusion of economic activities.[1]

[1] Comprehensive reviews of network analysis and its applications in many fields of science can be found in Albert and Barabasi (2002) and Newman (2003).

The phenomenon of knowledge spillovers embedded in workers mobility between organizations has been addressed, among others, by Almeida and Kogut (1999), Owen and Powell (2004), Audretsch and Keilback (2005). Insightful analyses of the role of worker mobility in sustaining firm dynamics and cluster formation can be found for instance in Fallick et al. (2006) who discuss the relationship between innovation performance and mobility of skilled personnel in the Silicon Valley cluster, and Casper (2007) who focuses on the mobility of managers as a cohesive force of the San Diego biotechnology cluster; while Agrawal et al. (2006) highlight the role of interpersonal relationships or social embeddedness in sustaining knowledge flows beyond physical mobility of people. Some recent studies address the territorial localization of spillovers due to worker mobility making extensive use of employer-employee matched data (Eriksson et al., 2009; Boschma et al., 2009).

Still missing from this picture are comprehensive analyses of general labour mobility dynamics in local labour markets using the lens of complex networks; notably, the role of labour intermediaries in shaping the web of inter-firm worker flows appears to be a new argument both for labour economics and for network studies. In this paper we attempt tackling this issue by analysing a temporal series of networks where the vertices are firms and the binary, directed links represent worker flows occurred in a one-year span. The precise graph-theoretic definitions used in the paper are given in the Appendix.

Our attention is first devoted to the extent to which the arrival of a special kind of vertices with the function of intermediaries, the TEAs, affects the degree of integration and practicability of the web of inter-firm flows, that is whether and how TEAs contribute to link together different portion of the labour market in a robust and reliable way, while shortening the network distance between firms; thus making the reallocation market potentially more accessible for moving workers.

Network theory directly relates the notions of integration and practicability of a network to a specific network model known as small world (Watts and Strogatz, 1998; Newman, 2000; Goyal et al., 2006), where vertices are easily reachable from one to another via a minimum assembly of links. The small-world model has been demonstrated to be extremely efficient in enabling reliable communication and flows between vertices (Latora and Marchiori, 2001). We use measurable small-world properties as indicators of the effects of TEAs.

A network is said to be a small world if the following four conditions simultaneously apply:

1) a large number of vertices are reachable from/can reach many other vertices in the network, that is, there are uninterrupted sequences of links connecting a relevant fraction of possible pairs of vertices;
2) vertices are reachable with little effort, that is, interconnected vertices on average are just a few steps/links apart (going along a link is assumed to be costly);
3) the system is parsimonious overall, that is, the actual number of links is much smaller than the maximum possible if there is a link between every possible pair of vertices (providing additional links is assumed to be costly);
4) vertices form cohesive groups, that is, vertex neighbours or vertices directly connected to the given one tend also to be interconnected with each other, resulting in alternative ways of reaching a former neighbour vertex should the direct connection be lost.

Reframing these conditions in economic terms, a network is considered a small world when, whichever vertex is considered, the number of vertices potentially reachable is high (condition 1), the cost of actually reaching these vertices, on average, is low (conditions 2 and 3), and the system is robust to local disconnections (condition 4). The small world architecture guarantees maximum reachability while minimizing the costs to both the system designer (i.e. the cost of providing links) and the system user (i.e. the cost of moving through sequences of links in order to reach a given target).

Descriptively, a small-world network appears to be an integrated system dominated by local clustering, with a relatively small number of long-range links acting as shortcuts between different clusters of vertices that otherwise would be much farther away from each other. A giant strongly connected component guarantees the existence of connecting paths between all possible vertices within its boundaries, while short distance indicates that vertices can be reached with little effort. Clustering, or redundancy of links at local level, promotes robustness to link disconnection and also reliable connectivity based on multiple independent pathways (White and Houseman, 2002).

The four defining properties of the small-world model can be re-framed within a directed network in exact graph-theoretical terms, obtaining the four propositions presented column 2 of Table 1; the evaluation rules reported in column 3 of Table 1 identify a range of network parameter values within which a network exhibits small-world characteristics. Based on these rule, in Section 6.1 we establish how far the empirical labour mobility network resembles a small world, and how TEAs push the network architecture farther or closer to a small world.

Table 1 around here

The second research question is how TEAs affect the distribution of labour flows, namely whether and how reallocation flows crowd into TEAs resulting in appreciable concentration of the market in the hands of intermediaries. We approach this problem by calculating some descriptive statistics of the distribution of both incoming and outgoing labour flows, that is the total-degree distribution in network terminology, determining the TEAs ranking within the distribution each year after their establishment. Then we focus on hiring channels, as given by the in-degree of vertices in the network, or the number of incoming labour flows, representing the capacity of firms to attract applicant workers from other source firms in the regional labour network. The in-degree provides a proxy of firm shares of new hires, we then study the evolution of TEAs market power by examining the statistical distribution of incoming links, locating TEAs within the distribution, and assessing how the distribution globally evolves over time before and after TEAs arrival.

Looking at the functional shape of the whole degree distribution, and not just at the number of links incident to TEAs, allows us to grasp how the system globally adjusts to the presence of TEAs, and to relate the observed behaviours to the vast literature on models of network formation, so possibly increasing our understanding of the dynamics involving intermediation activity.

The presence in networks of pivotal or central actors, hubs in network terminology, is usually signalled by a right-skewed degree distribution, with a long or fat tail containing vertices with many more connections than average. The literature on complex networks shows that the degree distribution of a network with a hub backbone can often be approximated in the tail by a Pareto distribution or a negative power law (Albert and Barabasi, 1999, 2002; Newman, 2003). In order to verify whether TEAs emerge as labour hubs, we explicitly direct the empirical analysis in search for Paretian behaviours in the in-degree distribution of labour flows, having the power law as a benchmark for evaluation.

In Section 6.2 the empirical distributions are obtained and fitted to power-law-like distributions using the procedure proposed by Clauset et al. (2009); the goodness of the estimates IS assessed rigorously. In Section 7 the results are discussed in the light of different models of network formation explaining the evolution of the degree distribution on the basis of linkage mechanisms.

4. The first season of temporary employment agencies in Italy (1997-2001)

Private temporary employment agencies constitute a relatively new phenomenon in Italy. They were allowed to operate by Legge (Law) n. 196 of 1997, the so called Treu reform of the labour market, and the first companies were established between 1997 and 1998.[2] The reform ended the public monopoly of employment services and introduced a new type of employment agreement, the "interinale", that is a provisional contract in which an agency hires people for the purpose of putting them at the disposal of a client firm for a period of fixed duration. Up to 2003, the only type of contract Italian intermediaries could deal with was the interinale.[3]

Until 1997, the Italian legislation strictly prohibited the intermediation of subordinate labour, even when such activity was freely given, and it inflicted heavy penalties for failures to comply with this rule.[4] Before Treu reform, employment services were a public monopoly operated through a network of provincial agencies, which were usually very inefficient, and in most cases were of little help to unemployed people (Barbieri et al., 2001). TEAs thus represent the very first example of private employment intermediary in contemporary Italy.

Fixed-term contracts that can be signed by the parties without the intervention of an intermediary were also allowed in post-war Italy, and their use has massively increased during the 90s, up to represent 42% of total engagements in the private sector in Veneto during the year 2001, which is the last year relevant for our analysis, corresponding to 6.2% of employment in terms of days worked (Veneto Lavoro, 2008a, 2008b). Provisional contracts also exhibited a rapid diffusion immediately after their introduction, generating 58,500 engagements in 2001 in the Veneto region, corresponding to 11% of total engagements in the private sector, and 0.8% of employment in terms of days worked. One should bear All this notwithstanding, in 2001 the share of days worked with open-ended contracts was still 84%, revealing a labour market largely dominated by arrangements characterized by high firing costs and tight regulatory restrictions.[5]

As pointed out by the Italian Department of Labour in 2001, the use of provisional contracts in practice responds to a variety of reasons which go far beyond needs for strictly temporary workers. In particular, Italian employers significantly resort to provisional agreements to select candidates to fill posts, pending permanent appointments (Ministero del Lavoro e delle Politiche Sociali, 2001). In this way – differently from what happens with other forms of fixed-term contracts – firms can

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2 The precise normative references is Legge 196/1997 (artt. 1-11), integrated by Decreto Ministero del Lavoro 381/97 and 382/97, Circolare esplicativa Ministero del Lavoro 141/97, Decreto Ministero del Lavoro 31/05/1999 and 29/11/1999, and modified by Legge 488/1999 and 388/2000. See also CCNL "Imprese fornitrici di lavoro temporaneo" (National Labor Contract for the temporary employment sector) of 1998.

3 The relevant normative was modified in 2003 by D.lgs. 276/03, the so called Biagi reform, enlarging the scope for labor market intermediaries.

4 The normative reference are: codice civile (Civil Code) art. 2127; Legge 264/49, and Legge 1369/60.

5 During the period considered in the present study, the Italian labour market maintained a very strict employment protection legislation, as far as standard employment is concerned. In 1999, the OECD still ranked Italy 23rd over 27 countries in terms of "overall strictness of protection against dismissals", where lower ranking indicates stricter regulation (OECD, 1999). Noticeably, according to Brandt et al. (2005), Italy has been the country with the largest drop in the OECD Employment Protection Legislation sub-index for temporary employment since the mid-90s.

access the searching and screening services provided by TEAs, in order to identify the professional and individual profiles which are most suitable for the vacancies they have to fill.

As for the initial years of TEA activity, the importance of the screening motivation is well illustrated by the high rate of transformation of temporary positions into permanent ones. A survey conducted by the Italian Department of Labor shows that, in both 2000 and 2001, roughly one fourth of provisional contracts were subsequently transformed into permanent positions (Ministero del Lavoro e delle Politiche Sociali, 2001). But in terms of head count such percentage is actually much higher, since the same individual can sign a series of distinct provisional contracts with the same employer.

The role of TEAs in terms of searching and screening is furthermore revealed by the fact that firms very often ask agencies for workers who meet strict requirements and/or who have high-skill profiles, as highlighted by Iacus and Porro (2002). In the years immediately after the Treu reform, in Veneto low-skilled workers occupied only 50% of provisional jobs, with a marked tendency to decrease over time (Veneto Lavoro, 2008b). More in general, Italian TEAs have been proved to have a truly multivocal capacity of treating a variety of professional profiles; they do not just deal with the traditional figure of young, male, low-skilled worker, but they also treat more mature, manual workers with specialized skills, as well as young men and women with medium-high educational attainment, who typically work in the service sector (Porro et al., 2004).

5. Data

The empirical investigation is based upon the Veneto Worker Histories panel (VWH), a matched employer-employee dataset derived from administrative records of the Italian Social Security Institute (Inps), covering the entire population of workers and employers in Veneto in the period 1975-2001.

Veneto is a dynamic regional economy, centred on manufacturing, whose labour market, starting from the middle 80s, has been characterized by nearly full employment and by a positive rate of job creation in almost every economic sector. The industrial system is characterized by a large population of small and medium firms, frequently organized in industrial districts, whose specializations are garments, textiles, leather and shoes, goldsmiths, mechanical products, furniture, and plastics.

The VWH data cover every individual worker employed in the private sector, and every establishment with at least one employee. The available information allows to build a monthly history of the working lives of all employees hired for at least one day by an establishment based in Veneto during the period of observation.

The labour mobility network is obtained by counting the individual reallocations that occur within a one-year window, where a reallocation is defined by a pair of events: a separation (i.e. the end of a job relationship with a given employer) and a subsequent engagement of the same individual in a job relationship with another employer. Reallocations are mapped onto a binary directed graph, where vertices represent firms and TEAs, and links represent flows of workers from one firm to another, or from firms to and TEAs and vice versa.

Given the triangular structure of provisional contracts, we observe TEAs as formal employers of temporary workers. We do not know which are the client firms temporary employees actually work for while engaged through TEAs, but we can track all the reallocations having TEAs either as origin or destination. Importantly, we can keep track in our network of mobility episodes related to people – especially young people – who first enter the labour market through a TEA, and then find a job as direct employees of some private firm.

We construct 11 networks each of which covers one year for the period 1991-2001; the analytical focus is restricted to reallocations of workers of both sexes, aged between 15 and 65 years, whose engagement – following a separation – occurred within the 1st of January and the 31st of December of each year, and where at most 6 months elapsed between the separation and the subsequent engagement.[6] We keep track of the reallocations cutting across the administrative boundaries of Veneto, so that firms located outside the region enter the network sample as well, as long as they transfer/receive workers to/from firms located in Veneto. No restrictions are imposed on the duration of job spells, nor on the type of occupation; reallocations in the same firm are excluded.

6. Results

6.1 TEAs and the small-world model

For every network-year we calculate the following indicators: number of vertices and links, density, size of the giant weakly connected component (WCC) and of the giant strongly connected component (SCC), the average path length (APL), and the average clustering coefficient (ACC).

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[6] Long periods of apparent inactivity could possibly hide voluntary exits from the labor force, hence, we make the relatively conservative choice of excluding from the analysis people remaining inactive for more than 6 consecutive months.

We compare the structural properties of the actual networks in the period 1997-2001 with the corresponding properties of two series of null models obtained according to the following rules:

- null model (1): we take the actual network and remove all TEAs together with the incident links, obtaining a new network with the same architecture of the actual one, but with no TEAs vertices and no reallocation flows involving TEAs;
- null network (2): we take the actual network and for each TEA vertex j, we remove the non-TEA vertex i that satisfies $k_i = \min(k)$ subject to the condition $k \geq k_j$, where k is the total-degree; i.e. we remove from the network the non-TEA firms most equivalent to TEAs in terms of number of connections.

The difference between the actual networks and the null model (1) provides us with an estimate of TEAs impact conditional on TEA mobility – that is labour mobility involving TEAs either as origin or destination – having no substitute in the labour market; in this way we obtain an upper bound to the real TEAs effect. The difference between the actual network and the null model (2) yields an estimate of the mobility effect of firms which are most similar to TEAs in terms of just the number of labour flows involved; assuming such effect as a proxy for the substitution of TEAs mobility by other non-TEA firms, the difference between null model (1) and null model (2) then yields a more reliable approximation of TEAs effect. In practice, for TEAs to have substantial role in shaping the network architecture, null model (1) should be sizably different from the actual network, while null model (2) should be close to it.

Figure 1 around here

Figure 1 shows the evolution of network size. The system exhibits minimum extension in 1993, with 67,578 vertices and 86,602 links, and maximum extension in 2001, with 104,439 vertices and 207,504 links. The link density is always very low, around 2.0e-05, with a minimum of 1.84e-05 in 1992, and a maximum of 2.23e-05 in 1995. All over the period considered, the network is extremely sparse, as required by the small-world model.

Time series of labour mobility networks of the kind considered in the analyses that follow are affected by the business cycle, since worker turnover tend to be markedly procyclical, and job-to-job mobility constitute the most dynamical component of such trend.[7] The business cycle thus

[7] For the US labor market, see for example Davis et al. (1996); Fallick and Fleischman (2004). For the Italian labour market, see Tattara and Valentini (2010); Leombruni and Quaranta (2005).

affects the size and the density of the reallocation network; when the business cycle is low – as it was in Italy during the recession of 1992-93 – the network would appear comparatively much sparser and less interconnected than in periods of high cycle – such as in 1994-95 in Veneto.

A procyclical pattern in the number of links is evident during the period 1991-1997. There is a pronounced downward spike in correspondence of the 1992-93 recession (-25% links), followed by a rapid growth in 1994-95 (+47% links), as the economy recovers in consequence of a Lira devaluation that boosted export competitiveness, which in turn especially favoured the largely export-oriented economy of Veneto. After 1997, the impact of the business cycle appears to be less clear: all over the period 1997-2001, in presence of moderate economic growth, the network exhibits an intense, sustained increase in vertices and links (+49% links, +29% vertices), with a partial slow down in 2001, again in correspondence of a downturn induced by the burst of the new-economy bubble and by increasing uncertainty in the international geopolitical scenario.

Comparing the actual trend with the null model (1), we notice that TEA links significantly contribute to explain the observed increase in connections, increasing the null model base by 1% in 1998, 5% in 1999, 10% in 2000, and 14% in 2001. Noticeably, the null model (1) exhibits a decrease of links in 2001 compared to the year 2000, so that, in the last year of observation, the action of labour market intermediaries turns out to be the sole factor driving the increase in the actual number of labour channels between firms. In 2001, the null model (2) has 8% more links than null model (1); this figure represents our prudential estimate of TEAs impact at the end of the observation period, revealing that the 1997 reform, through the establishment of private intermediaries, indeed appears to be able to unlock unprecedented mobility opportunities.

Figure 2 shows the extent of the largest strongly/weakly connected components in terms of percentage of vertices covered, allowing us to cast a first look at network interconnection or integration. A procyclical pattern is again neatly recognizable. The SCC records a minimum in 1993 at 13% and a maximum in 2000 at 30%, for the WCC such figures are 77% and 90% respectively. Starting from 1995, the SCC keeps on permanently above 25%, and the WCC remains above 85%; in the same period, the second largest strongly connected component never covers more than 6 vertices, while the second largest weakly connected component has just 14 vertices. From 1995, the system exhibits the inter-connectivity structure distinctive of a small world.

Figure 2 around here

In 1997, the giant components enter a steady growth path, leading to a cumulative increase of 13% for the SCC, and 4% for the WCC, over the period 1997-2001. In 2001, the SCC of null model

(2) substantially superimposes the actual SCC, and both are 6% larger than the SCC of null model (1), revealing that the mutual connectivity appears to be positively affected by TEAs, while it is insensitive to the exclusion of non-TEA firms; accordingly, TEAs seem to appreciably favour the integration of the system.

Figure 3 shows the APL and the ACC; the former is expressed as number of links between vertices (left axis), the latter is expressed as an index number that varies between 0 and 1 (right axis). All over the period, the ACC is at least two orders of magnitude higher than the ACC of a network of the same size of, and with the same in-degree distribution as the actual one, but with links placed at random; this clustering pattern is typical of a small world network. Up to the year 1998, the ACC fluctuates between 0.007 and 0.010, with only a very slight tendency to increase over time; from 1999 to 2001, it undergoes a phase of extremely intense growth, scoring 0.015 at the end of the period, 57% above the level of 1997.

Figure 3 around here

The ACC of the null model (1) remains substantially flat at the pre-reform level, while the ACC of null model (2) closely follows the actual path. In 2001, the actual ACC is 63% higher than the null model (1), while the ACC of null model (2) lays 46% above null model (1), pointing to a strong, positive effect of TEAs on clustering.

The APL reaches a maximum in 1993 at 8.5, a minimum in 2001 at 5, and all through the period it is strictly lower than $\ln(n_{scc})$, as required in order for the network to be a small world. After the 1997 reform, mutually interconnected vertices become significantly closer to each other: between 1997 and 2001, the average distance is reduced by as much as 24%.

The null model (1) exhibits an almost flat behaviour, while null model (2) lays just 1 percentage point above the actual APL. In 2001, the actual APL is 20% less than the APL of null model (1). This evidence indicates that TEAs provides effective shortcuts for network traversal, substantially reducing distances between firms.

Comparing the null model (1) in Figure 1 and Figure 3, we notice that links increase considerably over time, but such expansion has no appreciable effect on the internal arrangement of links, as revealed by the ACC and the APL. On the contrary, the increase in network size directly connected to labour intermediation does modify the network structure in the direction of higher cohesion and lower distances.

The analytical results all suggest that TEAs act in the sense of making the small-world network of labour mobility significantly smaller, hence more integrated and permeable to reallocation flows, through the establishment of shortcut paths that span the economy from side to side, knitting together distant vertices into more cohesive communities, and reducing average distances.

6.2 TEAs and the distribution of links

We derive the total-degree distribution of links for every network-year, and we report some descriptive statistics in Table 2: average degree (k_G), median degree (k_{50}), degree of the 99th percentile (k_{99}), and maximum degree (k_{max}).

Table 2 around here

The total-degree sequences exhibit a quite broad range of values, that tends to widen over time. Despite the relatively high maxima (315 in 1992, increasing to 6,524 in 2001), the average degree is always very low, ranging from 2.6 in 1993 to 4 in 2000 and 2001; this is due to the extreme concentration of the distribution around the minimum degree, as revealed by the median values, which take the value 1 up to 1994, and 2 thereafter. Two striking features are thus revealed: by far the largest fraction of vertices has a degree less than average, with the bulk of vertices exhibiting just the minimum degree; a small fraction of vertices has degree many times larger than average, as shown by the scores of the 99th percentile, which is 6 to 9 times greater than average.

All through the period, the total-degree distribution exhibits a markedly right-skewed pattern, with a heavy or fat tail. The same is true if we consider the in-degree and the out-degree distributions separately. The network architecture of labour mobility thus appears to be dominated by a few vertices, referred to as hubs, having many more connections than average. Moreover, maximum degrees increase steeply just after 1997, with an average annual growth of about 100%, suggesting that the 1997 reform favoured the formation of large hubs.

Table 3 reports the overall ranking of the 10 biggest TEAs, denoted *a* to *k*, in terms of total-degree. In 1997, only two TEAs are operating with a very limited activity, as revealed by their low ranking. Already in 1998, one TEA reaches the extreme tail of the connectivity distribution, ranking fourth overall, while other four TEAs are positioned within the first hundred positions, and all the first ten TEAs are within the 99th percentile of the distribution. In 1999, TEAs definitively take over the degree distribution, with four intermediaries firmly occupying the first four positions. Soon after their appearance in the system, TEAs show high attractiveness and strong capacity to redirect labour flows, becoming the far most important hubs in the mobility network.

Table 3 around here

After the labour market reform of 1997, the system become progressively more dependent on TEAs, in particular on a handful of them. This situation is especially critical, because the collapse or malfunction of even a small number of TEA hubs may compromise connectivity at a great extent (Albert et al., 2000); moreover, policy makers may be concerned about the growing monopolistic/monopsonistic power a few TEAs can exert on the labour reallocation market.

Figure 4 around here

We next examine the distributions of hiring channels, the in-degree distribution, as it is of particular relevance for capturing the evolution of TEAs market power. In Figure 4 the complementary cumulative in-degree distributions, CCDDs, are plotted on a double logarithmic scale, together with the corresponding power-law fits. Power-law-like degree distributions have been the object of extensive investigation in network science, and they are widely accepted to represent a benchmark model for many real-world phenomena (Albert and Barabasi, 1999; Newman, 2005). Most relevant for the present study, power-law models support the existence of hubs.

In Figure 4 each year plot follows a negative and almost linear trend; in the extreme tail of the distribution, a downward departure from the power-law fit is evident in the years 1991, 1992, 1995, 1996, 1997, and 1998, while it is much less pronounced in 1993, and 1994. In 1999 the empirical data overlap almost exactly the straight line, whereas in 2000 and 2001 the distribution tail drifts progressively more upward, concentrating greater weight than predicted by a pure power law.

The visual inspection of the plots yields several considerations. First, a necessary condition for data to be power-law distributed is to align on a straight line on a double logarithmic plot, and the empirical distributions seem to match this condition; second, the fast decay of the extreme tail or the truncation observed up to the year 1998 means that extremely massive events are actually less likely to occur than in a pure power law; third, after 1998 and in coincidence with the materialization of TEAs effects on the connectivity structure, the in-degree distribution shows a transition from an upper truncated pattern to a much more unequal one, with a much heavier tail.

In 1999, 2000, and 2001 the four biggest hubs are TEAs, and several other intermediaries occupy the extreme percentiles of the degree distribution, concentrating shares of hiring channels which are constantly increasing in time and being ultimately responsible for the transitions observed in the distribution tail. Intermediaries produce a sharp polarization of the degree distribution, that deviates consistently from both the pure, and the truncated power law distribution.

We explore such evidence more rigorously by comparing the empirical distributions with pure power-law models and then with power laws with exponential cutoff that allows for tail decay. The general form of a power-law distribution for the quantity k is $p(k) = ck^{-\alpha}$ for $k > k_{\min}$, c being a constant of proportionality; the general form of a power-law distribution with exponential cutoff is $p(k) = ck^{-\alpha}e^{\beta k}$. We follow the procedure developed in Clauset et al. (2009):

- we fit the complementary cumulative in-degree distribution using maximum likelihood, simultaneously estimating the scaling parameter α and the minimum threshold above which the power law behaviour holds $k_{\min}$;
- we evaluate the goodness of the power-law fit by calculating an appropriate p-value;
- we then contrast the pure power law with the power law with exponential cutoff by means of a likelihood-ratio test.[8]

Table 4 around here

In Table 4 the key parameters of the fitted power laws, together with the p-values of the related goodness-of-fit tests, are shown; the likelihood-ratio tests of the comparison between the pure power law and the power law with exponential cutoff, together with the related p-values, are reported in the last two columns.[9] In all years, except 1992 and 1995, the power-law model provides good fits, with excellent performance in 1991, 1994, and all over the period 1998-2001; in 1993,

[8] The power law and the power law with exponential cutoff are nested distribution; as highlighted in Clauset et al. (2009), it is always the case that the larger family of distributions, the power law with exponential cutoff, provides a fit at least as good as the smaller family, since every member of the smaller family is also member of the larger one. The p-value associated to the likelihood-ratio test is precisely meant to indicate whether the fitting improvement of the power law over the pure power law with cutoff is substantial or not.

[9] In the goodness of fit test for the pure power law, p-values are used to rule out the power-law hypothesis, hence for the power law to be a plausible model, p-values must be high, and vice versa (we make the standard choice of rejecting the power law for p-values less than 0.05). Whereas, in the likelihood-ratio test a small p-value and a positive (negative) likelihood ratio indicate that the power law wins (loses) over the alternative; on the contrary, when the p-value is large enough (>0.05), the test does not favour one model over the other.

1996, and 1997 there is only a moderate evidence in favour of the model, but overall the power law performs quite well, hence revealing itself to be a reasonable theoretical benchmark for the data.

The power law with exponential cutoff is strictly preferred over the pure power law in 1991, 1996, 1997, and 1998. While in 1999, 2000, and even more so in 2001, the two models are not statistically different according to the likelihood-ratio test, but from the plotting in Figure 4 the cutoff distribution appears to be unquestionably unfavoured compared to the pure power law.[10]

On the whole, the analyses performed reveal a series of facts that can be summarized as follows: up to the year 1998 the data are well fitted by a power law with upper truncation; in 1999, as TEAs reach the tail of the distribution, a pure power-law sets in; in 2000-2001 the tail of the distribution, led by the biggest TEAs, drifts upward away from the power law prediction, pushing the system towards an increasingly polarized configuration, in which a few biggest TEA hubs control massive shares of hiring channels.

7. Insights from models of network formation

Several models of network formation have been proposed that produce degree distributions with functional forms similar to those observed in the labour mobility network, as well as account for transition paths comparable to the one triggered by the arrival of intermediaries. Two classes of models build essentially upon a information cost argument and are particularly insightful in order to understand the possible dynamics of intermediation in the labour reallocation market.

In the literature on complex networks, right-skewed degree distributions with heavy tails are usually associated with link formation mechanisms based on preferential attachment rules, where the probability that a vertex connects to another is assumed to be proportional to the degree of the recipient vertex (Albert and Barabasi, 1999). Based on this simple framework, scholars have built models that account for upper truncation to the power-law behaviour, by introducing constraints to the attachment mechanism that limit the addition of new links to vertices. Varying the intensity or the bindigness of constraints a whole range of distributions are obtained, with cutoff more or less pronounced, of which a pure power law is a special case, up to producing extremely concentrated distributions if attachment constraints are weak enough.

In Mossa et al. (2000) the constraint to link formation is explicitly modelled as an information cost. Agents/vertices are assumed to bear a cost in order to gather and analyse information concerning other vertices, and especially when the system is large, agents are unlikely to know the state of the entire network. The decision about which vertex to connect with, is thus taken based

[10] We do not have a model that can specifically account for the observed rise in the extreme tail of the distribution.

only on information about a subset of possible vertices, either a fraction or a fixed number of vertices; some form of preferential attachment then comes into play within such a subset. The link distribution resulting from these rules turns out to be power law with an upper exponential cutoff whose strength depends on the incidence of information costs.

Other studies propose a paradigm of network formation in which preferential attachment is not directly assumed, but arises naturally from the simultaneous optimization of multiple competing objectives. This approach is of particular interest from an economic perspective, because it explicitly models the trade off between costs and benefits agents typically face when taking decisions in a context of scarce resources, as it is typically the case in job search.

The fundamental outline of this sort of models is described and discussed in Fabrikant et al. (2002), and further developed in D'Souza et al. (2007). Agents/vertices are randomly arranged in a given space; they are assumed to benefit from linking with vertices that are centrally located in the system, that is vertices with high degree, but they bear an attachment cost that is proportional to the Euclidean distance between the current location and the target one. Linking decisions would hence aim at targets which are simultaneously close to the actual position in the space and centrally located in the network.

In other words, networking activity amounts to optimize a trade off between search or attachment costs, represented by distance, and benefits or option value represented by network centrality. As search costs fall relative to centrality benefits, the resulting degree distribution will shift from power law with cutoff to pure power law and even beyond, ultimately resulting in a one-takes-all distribution, corresponding to a star configuration network in which one single vertex receive all incoming connections.

The behaviour of such trade-off models resembles a story about the introduction of intermediation in a system where link formation is subject to information costs; and while taking into account the models abstractness, the empirical evidence collected in the previous Section seems to match the theoretical predictions. In the real world, intermediaries gather information and provide low-cost shortcuts to employment opportunities, and because of their value as gateway for future employment they become attractive to workers.

In the Veneto mobility network, a few years after their introduction, a small bunch of TEAs dominated the power law distribution of labour flows, triggering to an evident polarization of the system that might deepen in time. This tendency, as detected and made visible by the network approach we adopted, is most relevant for policy; the theory indeed hints that the polarization process is self sustaining and could eventually produce a strong concentration of the market in the hands of a few TEAs. Intermediaries would hence increase the systemic risk of the labour reallocation system, while also developing a growing monopolistic/monopsonistic power.

8. Conclusions

This paper investigates the role of temporary employment agencies in shaping the inter-firm network of worker mobility in a regional labour market. The particular methodology we adopted allows to quantify the effects constituting the terms of a major trade-off inherent in intermediation activities. We show that TEAs significantly enhanced integration and practicability of the reallocation market, while leading a process of market concentration which we detect at its very beginning, whose determinants are inborn in the activity of intermediation, and whose dynamics are thoroughly discussed.

On one side, TEAs prove to be very effective in fostering labour market inter-connection; on the other, larger TEAs increasingly corner the labour market, exacerbating the consequences of information asymmetries to the potential detriment of their clients. Overall, network analysis appears to be an effective tool for monitoring intermediated labour markets at regional level and keeping under control the activity of single intermediaries, while also allowing for early detection of market concentration processes that might be harmful to labour market functioning.

An efficient reallocation of labour is essential in order for the economy to be productive, to allocate the available resources effectively, and to absorb local and transitory shocks that hit sectors, and industries selectively. Furthermore, an easy and smooth reallocation process is fundamental in guaranteeing workers more rapid and less costly job market transitions, with immediate and long-lasting benefits on individual income profiles. A decrease in the dimensions of the small world of labour mobility favours the good functioning of a reallocation market.

When intermediation is allowed, however, policy interventions might be needed, so as to guarantee competition in the intermediation sector, and some regulative mechanisms should be devised, in order to prevent the market to end up excessively concentrating in the hands of intermediaries. In this respect, given the trend observed in the empirical distribution of hiring channels, we might be concerned that the observed rise in TEA shares may deepen in time, meaning the market for hiring services tends to be controlled by a few TEAs, which, once gained dominant positions, can exploit their informational advantage to the detriment of their customers. Such a scenario would be harmful, both because of the high rent TEAs could extract from their activity, and because of the bad matching services firms and workers receive in a non-competitive intermediation market.

Whenever the first tangible signs of market concentration are in sight, prudent policy makers may want to intervene, in the spirit of market regulation, so as to monitor market trends and then decide whether and how to limit the action of intermediaries, by means of passing appropriate regulative measures, or fostering competition in the intermediation sector, for instance establishing efficient public intermediaries.

Theoretical insights on network formation make the call for well-timed policy interventions even more compelling, because, as self-sustaining mechanisms of linkage, e.g. preferential attachment, set in motion, it becomes more and more difficult to intervene in order to modify the underlying individual-level incentive structure. In such cases it is much better to uncover market trends in the very bud, and, where appropriate, to rectify them while they are not yet widespread. Essential to such practice is market monitoring.

We believe the analysis carried out in this paper provides new promising tools in support of labour market policies. The set of techniques we have presented nevertheless calls for further refinement, and we still need more sophisticated analyses yielding finer indications about market evolution. The present study offers an illustration of the possible applications of network methodologies to labour mobility on the basis of matched employer-employee data at regional level, and in the light of the results we obtained, labour market studies that use network-based methodologies are an interesting field for future research.

Appendix: Network definitions

This Appendix provides the formal definitions of the graph-theoretic concepts used in this study (Boccaletti et al., 200[6]). Let $V = \{i: 1, 2, ..., n\}$ be a finite set of firms, representing network vertices. For each ordered pair of firms (i, j), with $i, j \in V$ and $i \neq j$, let $l_{ij} \in \{0,1\}$ be a link pointing from i to j, with $l_{ij} = 1$ if a flow of workers has passed from firm i to firm j (active link), and $l_{ij} = 0$ otherwise (inactive link); let then $L = \{l_{ij}\}$ be the collection of such links. The set of firms and the set of links form the binary, directed labour mobility network $G(V, L)$, of which an instructive graphical example is given in Figure A1. The total number of vertices in a graph is n, the number of active links is $m = \sum_{i \in V} \sum_{j \in V} l_{ij}$; the number of active links divided by the total number of links gives the network *density*, denoted by $\delta(G) = m / n(n-1)$. The word links is used in the text to refer to just active links.

FIGURE A1 AROUND HERE

The number of links pointing towards i is defined *in-degree* of vertex i, and it is denoted by k_i^{in}; similarly, the number of links originating from i is defined *out-degree* of vertex i, and it is denoted by k_i^{out}. The *total-degree* of vertex i, indicated by k_i^{tot}, is the sum of the in-degree and the out-degree. In formal terms the following expressions can be written

$$k_i^{in} = \sum_{j \in V} l_{ji} \quad , \qquad \text{(A1a)}$$

$$k_i^{out} = \sum_{j \in V} l_{ij} \quad , \qquad \text{(A1b)}$$

$$k_i^{tot} = k_i^{in} + k_i^{out} \quad . \qquad \text{(A1c)}$$

For the sake of simplicity, in the text the word degree is used to refer to total-degree. The average degree of a network is equal to the average degree of its vertices, denoted by $k(G)$. The vertices with highest degree are usually termed *hubs*. If we think of the degree of a vertex as a realization of a random variable K, the *degree distribution* is then the probability distribution of K, i.e. the probability that a vertex has degree exactly equal to k, and it is indicated by $p(k) = \Pr(K=k)$. In directed networks there exist three different degree distributions for the in-degree, the out-degree, and the total-degree. The *complementary cumulative degree distribution* (CCDD) is denoted by $P(k)$, and it is defined to be $P(k) = \Pr(K \geq k)$.

A *path* from vertex i to vertex j is said to exist either if $l_{ij} = 1$, or if there is a set of distinct intermediate vertices $j_1, j_2, ..., j_n$ such that $l_{ij_1} = l_{j_1 j_2} = ... = l_{j_n j} = 1$. A network *component* is a set of vertices which are all reachable through paths, either mutually reachable, obtaining a *strongly connected component*, or just one-way reachable, obtaining a *weakly connected component*. A network may consist of several components, which can be ordered according to their size, i.e. the number of vertices they comprise. A network is said to exhibit a *giant component*, when the largest weakly connected component covers at least 50% of vertices ($n_{\text{wcc}} \geq n/2$), the largest strongly connected component covers at least 25% of vertices ($n_{\text{scc}} \geq n/4$), and the other components are small (typically of order $\ln(n)$). Giant weakly/strongly connected components are referred to with the acronyms WCC and SCC, respectively. Path and components are exemplified in the Figure A2.

FIGURE A2 AROUND HERE

The length of a path from i to j is equal to the number of links one has to run along to reach j starting from i. The shortest path from i to j is called *geodesic*, and its length is denoted by d_{ij}. The *average path length* (APL) of a network is defined to be the average length of the geodesics between all possible pairs of vertices in the SCC, and it is denoted by $d(G)$, yielding

$$d(G) = \frac{\sum_{i \in SCC} \sum_{j \in SCC} d_{ij}}{n_{SCC}(n_{SCC} - 1)} \ . \quad \text{(A2)}$$

The set of vertices with which vertex i is directly connected, both on entry and exit, is called (*nearest*) *neighbourhood* of i, and it is defined as $N_i = \{j \in V : l_{ij} = 1 \vee l_{ji} = 1\}$; the number of neighbour vertices of i is thus $\eta_i = |N_i|$. This notion leads to the definition of a metric called *clustering coefficient*. The clustering coefficient of vertex i, denoted by C_i, measures the extent to which the neighbour vertices of i are linked together, forming a densely connected group. Following Watts and Strogatz (1998), the clustering coefficient of vertex i is defined as the ratio between the actual number of links between the neighbours of i, and the maximum possible number of such links. Denoting by u and v two generic neighbours of i, the following expression is obtained

$$C_i = \frac{\sum_{u \in N_i} \sum_{v \in N_i} l_{uv}}{\eta_i(\eta_i - 1)} \quad , \tag{A3}$$

which takes values in the interval [0,1]. Vertices with $\eta_i = 1$ are assigned $C_i = 0$. The average clustering coefficient of a network is indicated by $C(G)$, and it is referred to with the acronym ACC. In Figure A3 different graphical examples of clustering for the green vertices are given.

FIGURE A3 AROUND HERE

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Table 1 – The four defining properties of a small-world network

	Properties		*Evaluation criteria*
	Description	*Network-theoretic definition*	
1.	A large number of vertices are reachable from or can reach many other vertices in the network	Network exhibits a giant weakly connected component (WCC) and a giant strongly connected component (SCC)	The SCC and the WCC cover a minimum of 25% and 50% respectively of vertices; the other components are small (typically of the order ln(n), where n is the total number of vertices)
2.	The system is parsimonious	The density of links is low	The link density is several orders of magnitude lower than the maximum possible value
3.	Vertices are reachable with little effort	Average path length (APL) in the SCC is appreciably small	The APL in the SCC is of the same or lower order as $\ln(n_{scc})$
4.	Vertices form cohesive groups	Average clustering coefficient (ACC) is appreciably high	The ACC is at least two orders of magnitude higher than the ACC of a similar sized random network with the same in-degree distribution.

Table 2 – Total-degree distributions: main descriptive statistics

year	*n*	k_G	k_{50}	k_{99}	k_{max}
1991	80,680	3.1	1	23	429
1992	78,300	2.9	1	21	315
1993	67,578	2.6	1	17	507
1994	69,816	3.0	1	22	527
1995	78,450	3.5	2	28	467
1996	78,966	3.4	2	27	358
1997	80,820	3.4	2	29	480
1998	84,823	3.6	2	30	731
1999	91,136	3.8	2	32	2,100
2000	100,671	4.0	2	35	4,635
2001	104,439	4.0	2	33	6,524

Table 3 – Ranking of the 10 biggest TEAs according to total-degree

	ranking (1=highest total-degree)				
TEAs	*1997*	*1998*	*1999*	*2000*	*2001*
a	162	4	1	1	1
b	162	16	2	2	2
c	-	37	3	3	3
d	-	56	4	4	4
e	-	103	7	6	6
f	-	135	22	8	7
g	-	137	27	10	9
h	-	138	30	13	11
i	-	150	36	22	13
k	-	156	55	23	14
Total n. of positions	163	189	204	215	220

Table 4 – Distribution fitting

	Power-law fits			*Comparison with power law with cutoff*	
year	a	k_{min}	*p-value*	*LR test*	*p-value*
1991	2.752	5	0.520	-2.354	0.030
1992	2.822	5	0.000	-0.552	0.293
1993	2.827	4	0.060	-0.262	0.469
1994	2.857	12	0.780	-0.268	0.464
1995	2.630	5	0.000	-11.176	0.000
1996	2.787	10	0.140	-2.749	0.019
1997	2.595	5	0.080	-7.779	0.000
1998	2.609	6	0.500	-4.958	0.002
1999	2.554	6	0.540	-1.604	0.073
2000	2.556	8	0.560	-0.065	0.716
2001	2.576	7	0.880	0.000	1.000

Figure 1 – Vertices and links

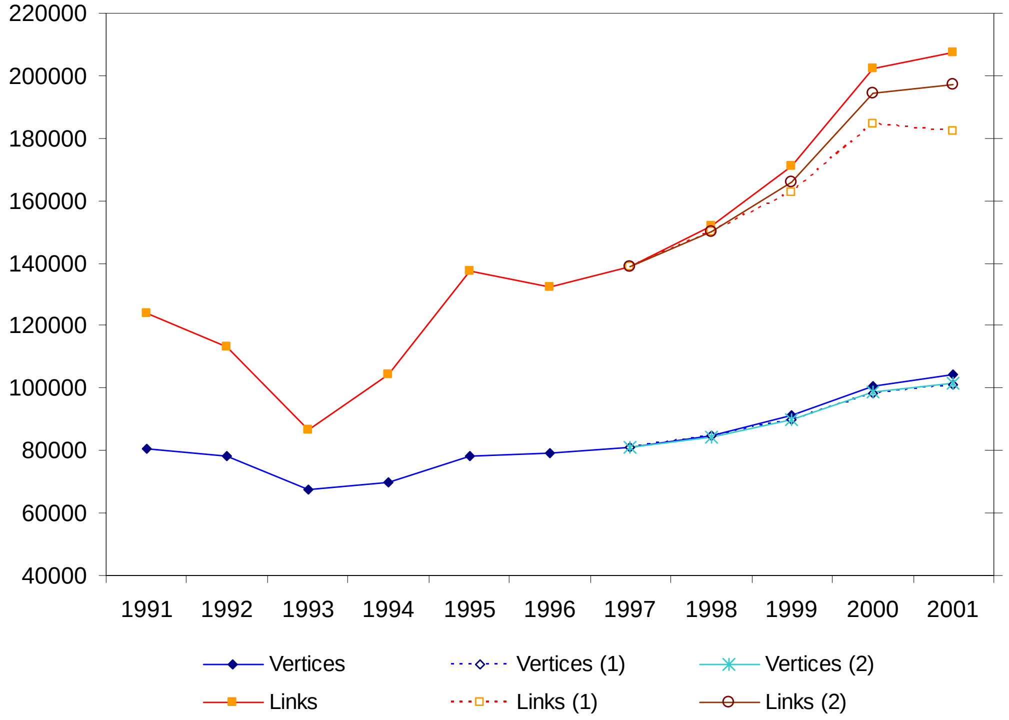


Figure 2 – Largest connected components (% coverage of the entire network)

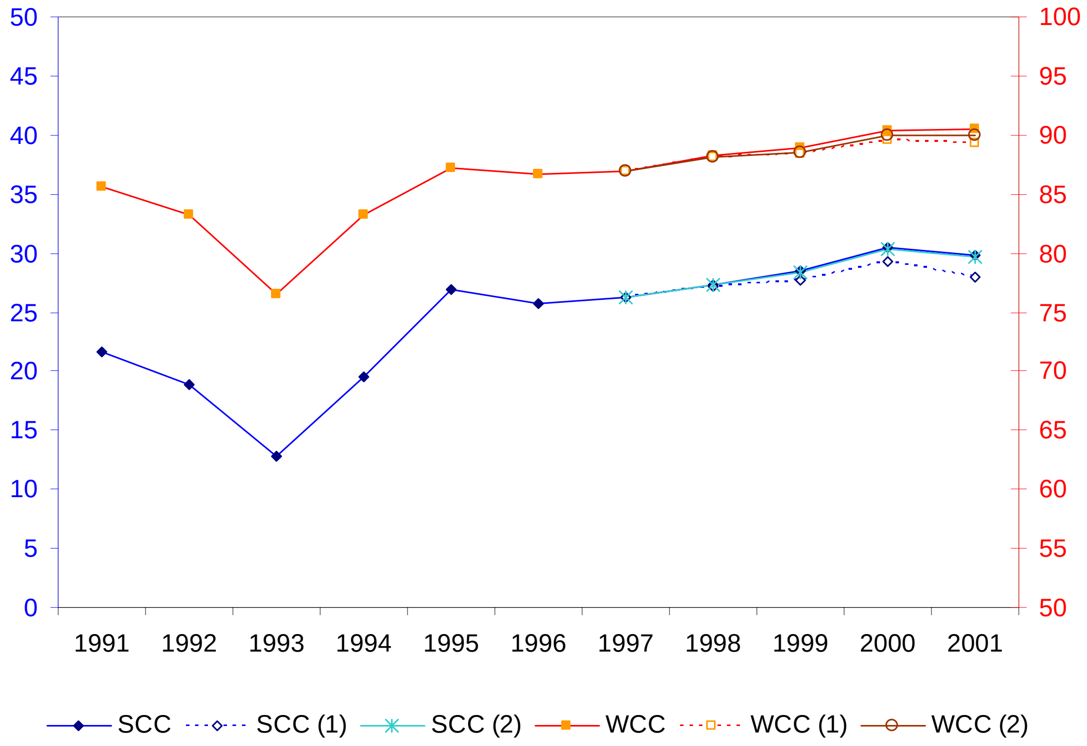


Figure 3 – APL and ACC

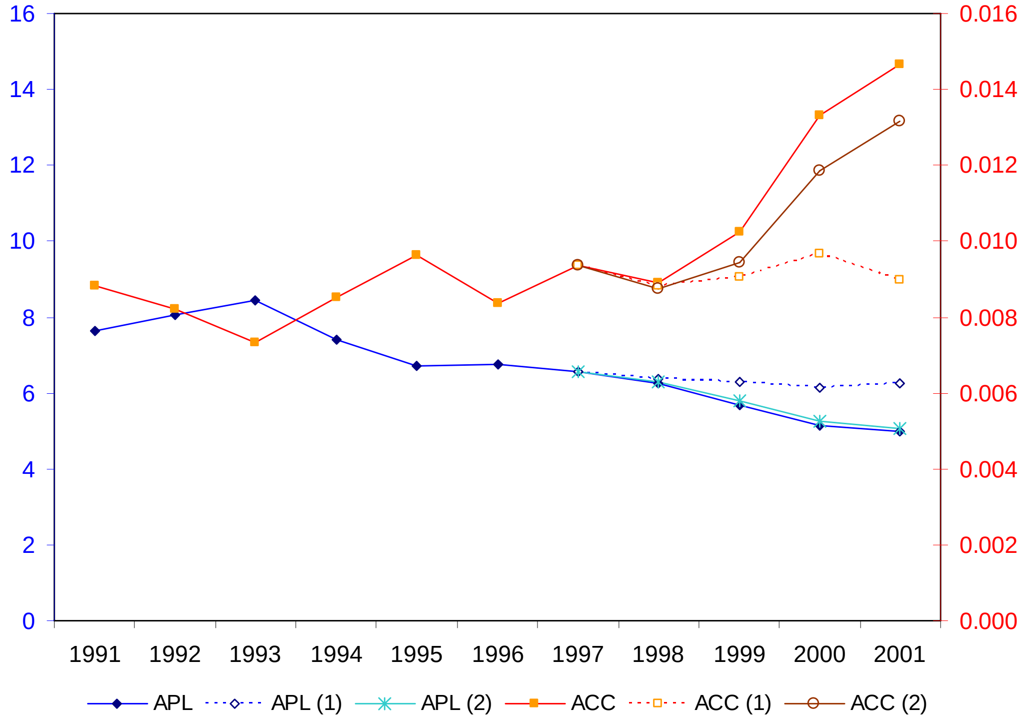
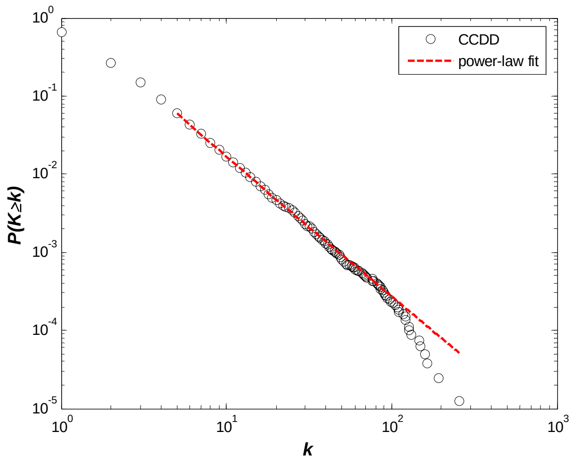
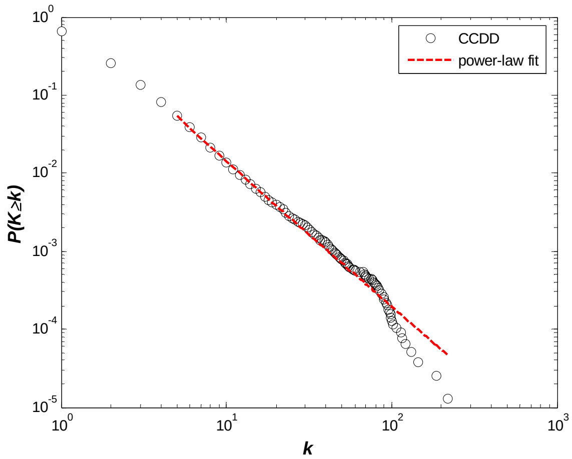


Figure 4 – In-degree distributions, power-law fits

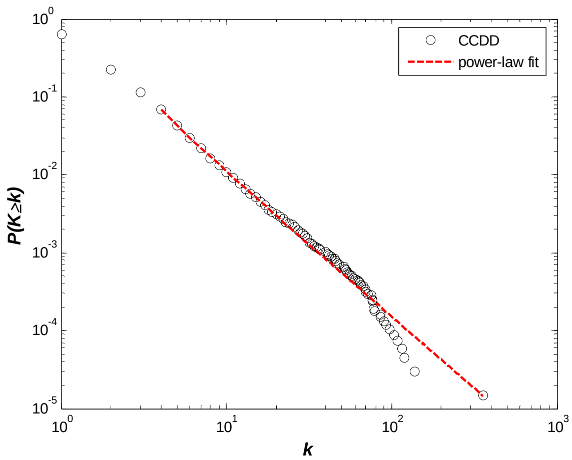
1991



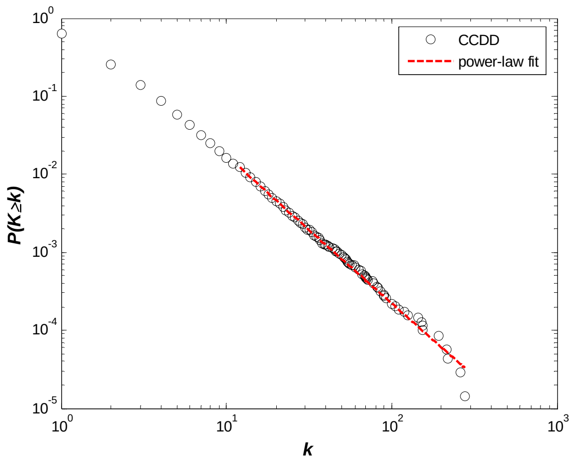
1992



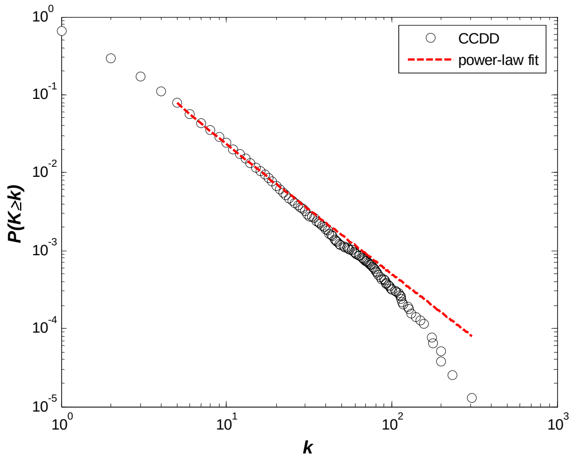
1993



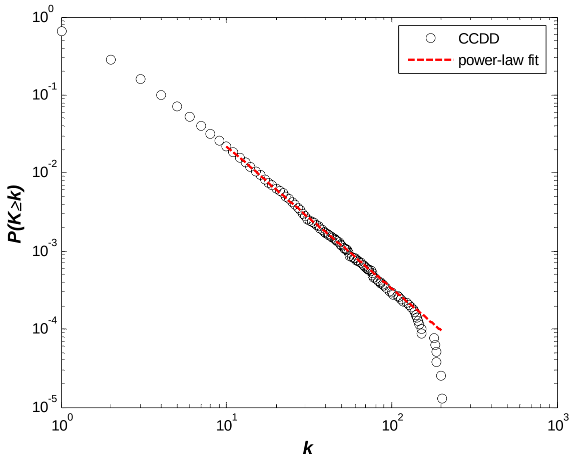
1994



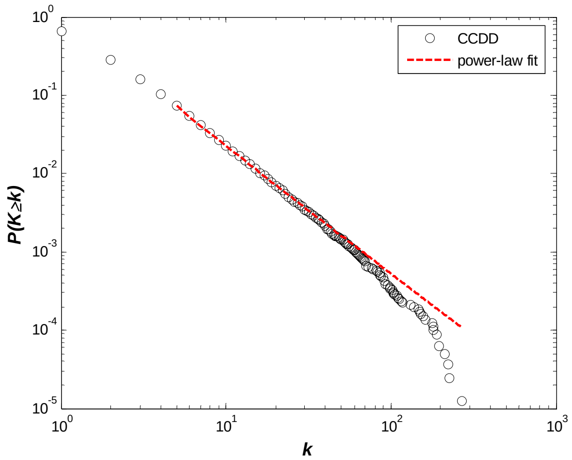
1995



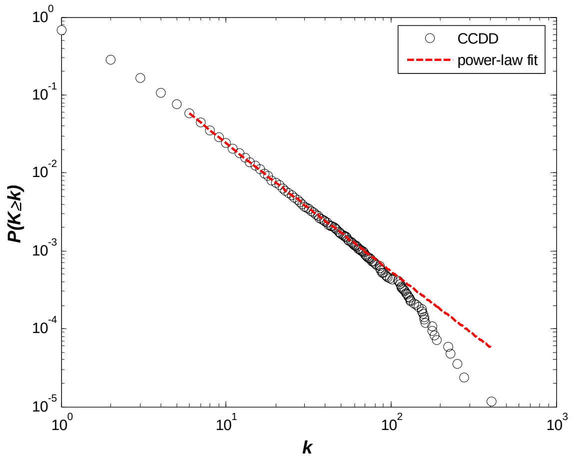
1996



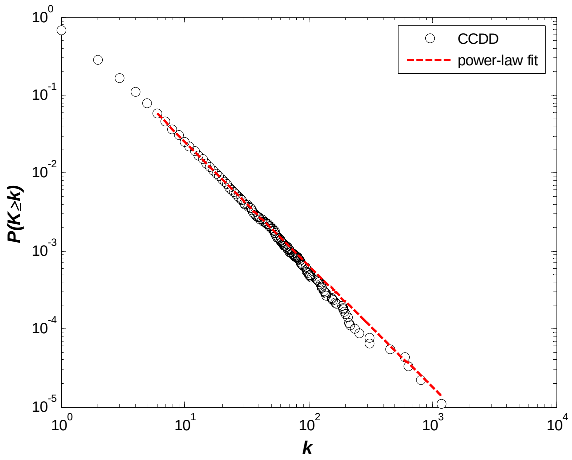
1997



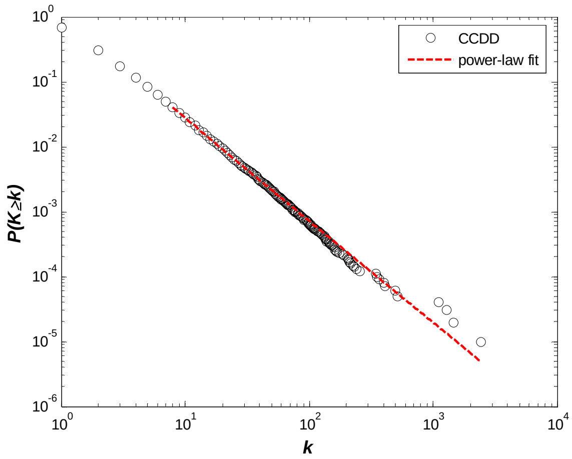
1998



1999



2000


CCDD
power-law fit
P(K≥k)
k
10^0
10^-1
10^-2
10^-3
10^-4
10^-5
10^-6
10^1
10^2
10^3
10^4

2001

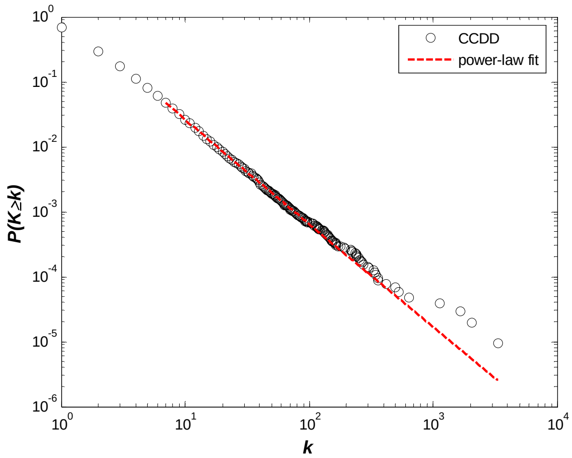

CCDD
power-law fit
P(K≥k)
k
10^0
10^-1
10^-2
10^-3
10^-4
10^-5
10^-6
10^1
10^2
10^3
10^4

Figure A1 – Network with *n*=9, and *m*=10

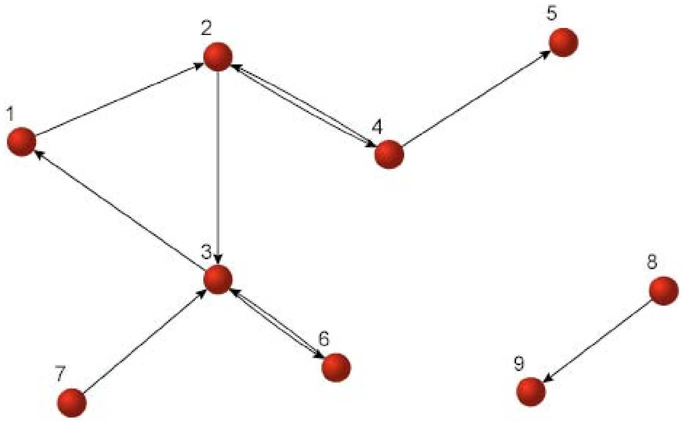


Figure A2 – Strong components (blue, dotted), weak components (orange, dashed), and shortest path from vertex 6 to vertex 4 (green links)

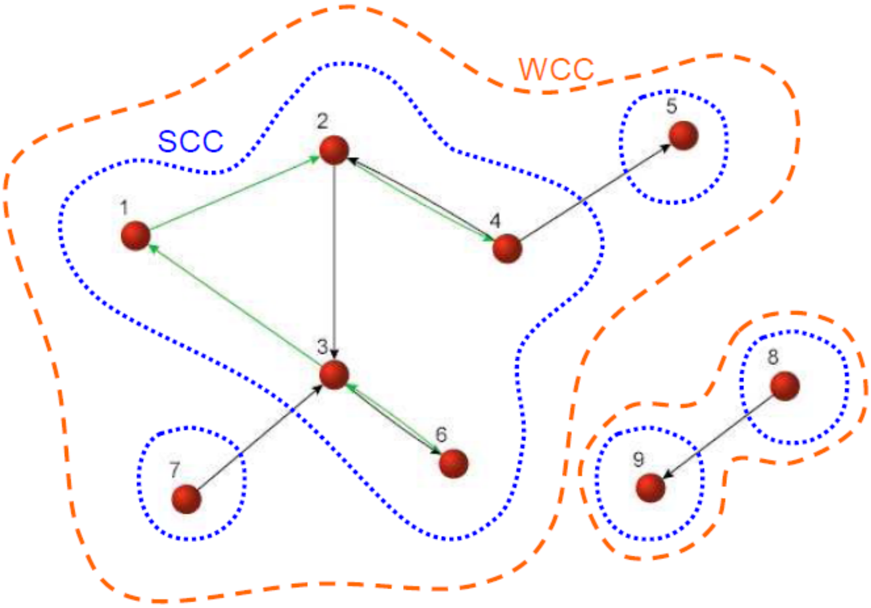


Figure A3 – Clustering coefficient, vertex 1 has: (a) C_1 = 1; (b) C_1 = 0.4; (c) C_1 = 0

(a) **(b)** **(c)**