Core-periphery structures in national higher education systems. A cross-country analysis using interlinking data

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Abstract

This paper presents a comparative analysis of the structure of national higher education networks in six European countries using interlinking data. We show that national HE systems display a common core-periphery structure, which we explain by the lasting reputational differences in sciences, as well as the process of expansion and integration of HE systems. Furthermore, we demonstrate that centrality in national networks (*coreness*) is associated with organizational characteristics, reflecting that interlinking is motivated by access to resources and the status of the organizations concerned, and that national policies impact network structures by influencing the level of inequality in the distribution of resources and status. Finally, we show that, as an outcome of the core-periphery structure, the strength of ties between two HEIs is largely determined by their individual coreness, while the impact of distance is too small-scale to alter the network structure generated by organizational attributes.

Keywords

core/periphery networks; higher education institutions; weblinks; geography; network centrality

1 Introduction

In recent years, a growing body of literature has investigated relational patterns between higher education institutions (HEI), using data from co-publications (Glänzel and Schubert 2005, Jones, Wuchty and Uzzi 2008), collaborations in European projects (Heller-Schuh, Barber, Henriques, et al 2011) and weblinks (Bar-Ilan 2009; Thelwall and Zuccala 2008). Following social network theory, we contrast two types of studies: those focusing on *connectivity* (Laumann, Galaskiewicz and Marsden 1978), i.e. understanding the determinants of the relationship between two units (Rivera, Soderstrom and Uzzi 2010), including geographical distance (Hoekman, Frenken and Tijssen 2010; Thelwall 2002b), size (Thelwall 2002a) and international reputation (Seeber, Lepori, Lomi, Aguillo and Barberio 2012) on the one side; and studies focusing on the network structure, dealing with concepts like structural equivalence (White, Boorman and Breiger 1976), network centrality (Freeman 1978/79.; Abbasi, Hossain and Leydesdorff 2012) and core-periphery structures (Borgatti and Everett 1999) on the other (see for example Thelwall, Tang and Price 2003, Ortega, Aguillo, Cothey and Scharnhorst 2008, Thelwall and Zuccala 2008).

In this context, this paper aims to provide empirical evidence on the structure of higher education (HE) *national* networks, highlighting cross-country patterns, as well as differences related to national policies. More specifically, we focus on three main questions: first, we show that national HE systems in Europe display a common core-periphery structure (Borgatti and Everett 1999), which we explain by the lasting reputational differences in science, as well as by the process of expansion and integration of HE systems

(Kyvik 2004). Second, we demonstrate that centrality in national networks (*coreness*) is associated with organizational characteristics, reflecting that interlinking is motivated by access to resources and the status of the organizations concerned (Gonzalez-Bailon 2009) and that national policies impact network structure by influencing the level of inequality in the distribution of resources and status. Third, we show that, as an outcome of the core-periphery structure, the strength of ties between two HEIs is largely determined by their individual coreness, while the impact of distance is too small-scale to alter the network structure generated by organizational attributes.

We explore our propositions through a cross-comparative analysis of six western European national systems (Germany, Italy, Netherlands, Norway, Switzerland and UK). We measure relationships between HEIs through counts of web-links between their websites (Bar-Ilan 2009, Thelwall and Sud 2011), while organizational data is extracted from the EUMIDA census of European HEIs (Lepori and Bonaccorsi 2013). Finally, we draw on literature concerning higher education policies and funding systems, in order to characterize national systems in terms of competition for funding (Nieminen and Auranen 2010) and functional differentiation between HEI types (Lepori and Kyvik 2010).

2 Background and theoretical framework

2.1 Core periphery models

Core/periphery models designate a relational pattern in which two groups of organizations can be identified: a central group of organizations strongly interacting among themselves, as well as a group of peripheral organizations interacting mainly with the core and to a minor extent among themselves (Borgatti and Everett 1999). This notion comes with the understanding that the network is organized around a single center and that the strength of the relationships between two nodes is determined by their closeness to the center.

Core-periphery structures have been important since early social network studies (Snyder and Kick 1979), while more recent empirical tests range from organization theory (Cattani, Ferriani, Negro and Perretti 2008) to physics (Holme 2005). They tend to underline the assumption that a status hierarchy is in place between the two roles, with the core clustering actors holding higher status (Owen-Smith and Powell 2008).

Economic sociology considers that position in a social network is closely associated to their access to resources (White 1981, Burt 1988), with more central HEIs benefitting from better access to resources, collaborations, and people. Accordingly, in the structuring process of organizational fields, status hierarchy and network centrality are expected to coevolve and reinforce mutually to maintain the observed core/periphery structure (Owen-Smith and Powell 2008).

In science studies, even if formal models of core/periphery have rarely been investigated (see however Kronegger, Ferligoj and Doreian 2011, Chinchilla-Rodriguéz, Ferligoi, Miguel, Kronegger and de Moya-Anegón 2012), there is an understanding that networks of scientific collaboration have a core/periphery structure as an outcome of reputational effects (Wagner and Leydesdorff 2005; Burris 2004). An extensive literature has shown that status differences apply to entire HEIs as well and have practical implications on the distribution of funding, mobility of researchers, and student's choices (Burris 2004, Volkwein and Sweitzer 2006).

The hypothesis that *national* higher education (HE) fields display a *common* core/periphery structure is justified on the one hand by the importance of reputational differences among HEIs and on the other hand by the process of integration and structuring that these fields underwent in previous decades, under the pressure of increasing demand for tertiary education (Schofer, E., Meyer, J. 2005). While stratified HE systems – like in the US and the UK after the 1992 reform – are historically characterized by a well-defined status hierarchy, other European HE system were based on functional differentiation between different types of educational organizations, which constituted largely distinct social spaces (Kyvik 2004). In the previous decades these systems moved towards a stronger integration in a single HE field characterized by common regulations, implying a clearer and more formalized hierarchy of status ordering (Bleiklie 2003). An important driver of this process was the introduction of quasi-market governance arrangements (Ferlie, Musselin and Andresani 2008), which led to increased freedom for customers when choosing their HE provider, as well as the impact from the emergence of international rankings (Marginson 2006; Hazelkorn 2009). Accordingly, it is expected that a core/periphery structure has become a general feature of the European HE systems, a structure independent from national governance arrangements.

We expect national variations in this structure to be related to differences in the regulatory arrangements through which integration was managed (Paradeise, Reale, Bleiklie and Ferlie 2009). The adoption of a binary policy is expected to sharpen the distinction between core and periphery as the national system includes two types of HEIs with different missions and legal statuses (Kyvik 2004). The introduction of quasi-market arrangements and competition for funding (Nieminen and Auranen 2010) should increase the level of contrast between core and periphery, as competitive logics will tend to reinforce status hierarchies via a selective distribution of resources (Lepori 2011). In non-competitive systems, boundaries between core and periphery are expected to be blurred, with the core including a greater share of HEIs.

2.2 Coreness and organizational characteristics

While discrete models identify two groups of nodes belonging to the core and to the periphery, continuous models attribute to each node a continuous attribute called *coreness*, which is a more realistic representation of many social networks, especially when there are large variations in the strength of relationships. Coreness can be interpreted as a measure of the proximity of an HEI to the (unique) network center (Borgatti and Everett 1999).

Core/periphery models attribute coreness values so that the strength of the relationship between two nodes is associated to the product of their coreness – the core/periphery algorithm computes coreness values that maximize the correlation between this product and the observed values for each dyad. This associates core/periphery models with the notion of loglinear independence, i.e. that in a matrix the cell values are proportional to the product of values of marginals (i.e. the sum of rows and columns respectively). If linear independence holds, a core/periphery model will also fit the data. Then, an important interpretation of the existence of a core/periphery structure is that the strength of the relationships between two nodes is associated to the individual characteristics of each node (as measured by coreness) and not to their mutual position (for example belonging to the same region or their distance), nor to endogenous network effects (like triadic closure).

Social network studies show that the formation of ties between an organization can be explained by a number of mechanisms, including identity (belonging to the same social space; Rivera, Soderstrom and Uzzi 2010), legitimacy seeking (linking preferentially to high-status organizations; Cattani, Ferriani, Negro and Perretti 2008) and resource mobilization (linking to organizations who control a large share of resources). Previous studies support the assumption that interlinking patterns on the web are motivated by the strategic behavior of organizations, reflecting an unequal distribution of resources (as measured by organizational size) and status in the real world (Seeber, Lepori, Lomi, Aguillo and Barberio 2012). Accordingly, interlinking networks have a less skewed distribution of links than reputation-based networks, like citation counts of scientific publications (Gonzalez-Bailon 2009).

We expect coreness of an *individual* HEI to be associated to a similar set of attributes that determines the likelihood of one HEI linking to another one. More specifically, we test associations with the following characteristics:

- Size, as larger organizations have a larger volume of activities and hence of relationships, but at the same time control a larger share of resources (and are more desirable partners for establishing ties).
- Status, as organizations will link preferentially to high-status organizations both because of their higher value and legitimacy-seeking behavior.
- Age, since older organizations are likely to be more established and to attract a larger number of ties.
- Research intensity, as in the academic world research represents the most valuable activity and thus research-oriented HEIs are expected to be more attractive partners.
- Disciplinary specialization, as generalist HEIs are expected to be more central and to develop a higher number of ties because of their broader coverage of scientific domains.

2.3 Connectivity and geography

A core/periphery model implies that the number of links between two nodes is associated to the proximity of individual organizations to the network center (as measured by coreness; Borgatti and Everett 1999) and thus, depends only on their individual attributes. In other words, a direct relationship between *structural position* and *connectivity* is expected.

Yet, micro-level studies of connectivity demonstrate that spatial distance influences the likelihood of linking and the number of ties (Rivera, Soderstrom and Uzzi 2010), as confirmed by empirical studies on scientific collaborations (Hoekman, Frenken and Tijssen 2010) and on interlinking between HEI websites (Holmberg and Thelwall 2009, Seeber, Lepori, Lomi, Aguillo and Barberio 2012; Lee and Park 2012).

The interaction between network structural characteristics on the one side, and spatial distance on the other, represents a central issue in social network studies (Adams, Faust and Lovasi 2012); central issues in this respect concern the independence of structural and geographical effects (Daraganova, Pattison, Koskinen, et al 2012) on the one hand, and the extent to which heterogeneity in the distribution of human activities might generate specific network structures, like spatially bounded clusters, on the other (Butts, Acton, Hipp and Nagle 2012).

To this aim, we model the number of ties between two HEIs as a function of organizational characteristics, explaining network centrality and the distance between nodes. This allows for an investigation of the relative contribution of distance and position in the core/periphery structure on interlinking patterns, identifying the geographical scale where distance is more important and determining under which conditions geography might have a significant impact on network structure.

3 Methods

3.1 Sources and data

HEI sample. Organizational data has been derived from the EUMIDA (European University Micro Data) dataset, which includes information on HEIs in 28 European HE systems (Seeber, Lepori, Lomi, Aguillo and Barberio 2012). We only consider 'research active' institutions due to the availability of more complete data, and because these institutions constitute the largest portion of the system – as they comprise almost all doctoral-awarding institutions, as well as most non-university-type institutions in binary countries. A few HEIs have been excluded because of lack of data or because they are focused on research and graduate education, with very few students at the undergraduate level. Our sample is composed of 643 HEIs comprising 96.4% of the students in the full HEI perimeter in the six countries considered. The reference year for this data is 2008.

Relational data. To characterize the relational structure of HEI systems, we use interlinking data between the web domains of HEIs. The data was obtained from the Cybermetrics lab (Ortega et al., 2008) by using commercial public search engines following the methodology described in Aguillo, Granadino, Ortega, and Prieto (Aguillo, Granadino, Ortega and Prieto 2006). Two mirrors of the "Yahoo Search!" database were used, the Spanish and the British versions, to avoid collection problems derived from restrictions due to the limited bandwidth available, or from errors in the automatic scripts used for extracting the data. If the results for the same request were not identical, then the maximum value of the two was used. The collection took place in January 2011. From the original dataset, national matrices were created which included, for each pair or HEIs in the same country (*dyad*), the counts of weblinks between them – the matrix is asymmetric since the count of links from HEI A to HEI B might differ from those in the opposite direction.

Literature in webometrics shows that weblinks between HEIs are related to all kinds of academic activities (research, education, institutional cooperation; Bar-Ilan 2004; Wilkinson, Harries, Thelwall and Price 2003), while aggregated numbers display statistical regularities – depending on distance, reputation, and country – supporting their interpretation as indicators of relationships between HEIs (Seeber, Lepori, Lomi, Aguillo and Barberio 2012). As a matter of fact, it can be argued that weblinks are a better measure of aggregate social relationships than indicators referring only to research collaboration (like co-authorships).

Organizational characteristics. A set of variables are introduced to explore their association with coreness. These are: (a) the *type* of organization, as a dummy variable taking the value 1 for universities and 0 for non-universities; (b) the *research intensity,* which estimates the orientation of HEIs towards research, as the ratio between the number of PhD students and undergraduate students; (c) the *organizational size,* measured as the number of academic staff; (d) the *discipline concentration* calculated as the Herfindahl index of concentration of undergraduate students across the nine fields comprised in the fields of educational statistics, ranging from 1 (all students in one field) to 1/9 (students evenly distributed across the nine fields), (e) *age* as a dummy set to 1 for organizations founded after the year 1970.

We introduce two measures of geography: first, we measure the *urban centrality* of individual nodes using Globalization and World Cities Network (GAWC) classification of cities, 2010 (Taylor 2004; http://www.lboro.ac.uk/gawc/world2010.html); the index takes the value 1 for London, 0.33 for Frankfurt, Madrid, and Milan, and then decreases towards 0. Second, we measure *geographical distance* in kilometres between two HEIs. Each web domain corresponds to an IP, which has been related to the latitude and longitude coordinates used to compute the distances. Manual data cleaning identified the cases when IP did not correctly locate the HEI.

A measure of *international reputation* is constructed as the product between normalized impact factor and the total number of HEI publications ("brute force" indicator; van Raan 2007), normalized by the number of academic staff; this indicator builds on the insight that the international visibility of an HEI is related both to quality and volume of output. Data is derived from the SCIMAGO institutions rankings for the year 2011 (http://www.scimagoir.com/). We hold data for 240 HEIs in our sample – the other HEIs had less than 100 publications in Scopus in the reference year 2009. Despite normalization by size, this index remains correlated with output (as a result of scaling properties of research output; van Raan 2007); accordingly, when the level of output approaches the threshold, the index approaches 0 as well. For the remaining HEIs, we compute expected values of output based on the correlation between output and academic staff (Pearson correlation 0.866**) with a threshold of 100 publications; we then calculate reputation by setting the impact to the world average. As an outcome, 262 HEIs with less than 200 academic staff received an international reputation of 0, while 141 HEIs received a low reputation score below the HEIs included in the ranking.

Characterization of national systems. National HE systems are distinguished between unitary and binary. In unitary systems, all HEIs have the same legal status and are entitled to perform research and award PhD degrees; in binary systems, there is a legal distinction between the two institutional types, with non-university HEIs oriented towards professional education, in most cases without the authority to award PhDs (Kyvik and Lepori 2010). We characterize the level of competition in HE funding through i) the level of output vs. input orientation in institutional funding and ii) the share of third party funding (Nieminen and Auranen 2010).

3.2 Analysis

Core-periphery structure. We test the fit of web-links data to a core/periphery model using two models as specified in Borgatti and Everett (1999). The procedure takes as an input the observed web-links, using an asymmetric weighted matrix, and fits both a continuous and a discrete core/periphery model to it. We applied a logarithmic transformation to the weblinks (y=log(x+1)), as it can be assumed that the strength of relationships is better measured by proportions, rather than by their absolute number, andthe transformation strongly reduces the skewedness of the data.

The first model entails a clustering of nodes into two discrete classes (the core and the periphery), while the second ranks of nodes according to their continuously distributed property of being core (coreness). We compare the sharpness of the core-periphery model using the Gini coefficient of coreness scores in each country. Since we are analyzing national networks, we run separate models for each country considered.

To find the partitions that maximize the correlation between observed and ideal structures, UCINET uses a combinatorial optimization technique. The result will be statistically significant by design (Borgatti, Everett and Freeman 2002), and thus the algorithm does not provide any measure of statistical significance. A rigorous test would require randomly generating a large number of permutations of the considered network and then computing for each permutation the level of fit (Boyd, Fitzgerald and Beck 2006). In this paper, we follow a simpler strategy by considering as indicators of significance, the overall level of fit of the model, the correlation between coreness and degree, and lastly whether coreness is significantly related to meaningful organizational attributes like size and reputation.

Determinants of coreness. We compute descriptive statistics for HE organizations' *coreness* and organizational characteristics. To test associations with organizational variables, we run a linear regression by using as a dependent variable, national coreness normalized on a scale from 0 to 100 (to take into account differences between national models). We apply a square root transformation to reduce skewedness (from .791 to 0.091). We apply the square root transformation also to size and international reputation variables, but not to research intensity and disciplinary concentration, which are limited between 0 and 1. Further, as descriptive statistics display that the relationship with size is non-linear, we introduce a quadratic term for size. While our variable is constrained to be positive and thus other statistical models could be used (negative binomial, tobit regression), we choose to adopt ordinary least squares (OLS) regression, since, if its assumptions are sufficiently satisfied, the OLS estimator is the best available.

We define the *relational mass of a HEI* as the value of coreness predicted by the regression. While the values of relational mass and of coreness in our sample are strongly correlated (.920), these two concepts are quite different in their nature: coreness is a structural property of the nodes of national networks, which depends on how weblinks are distributed across the network. On the contrary, the relational mass is a combination of HEI attributes, or more precisely, the best combination that allows fitting the observed coreness value in our sample and across different national networks – something similar to the level of network centrality an HEI would receive from its organizational attributes – independent of the country, geography, and other network effects.

Importantly, while coreness is endogenous to the network structure, relational mass is not and thus can be used in predicting connectivity together with other attributes (like distance).

Connectivity. After providing some link-level descriptive statistics on distribution of links by distance of the nodes, we perform regressions between the number of links (dependent variable) on the one side, and relational mass and distance on the other. Since we deal with count data, we use a *negative binomial regression* which includes a parameter to model overdispersion. Furthermore, since the number of null dyads (dyads with no links) is rather high (74% of the sample), we use a *hurdle* negative binomial, which specifies a separate model for predicting zeros – the underlying assumptions being that factors explaining zeros might be different from those explaining counts (Mullahy 1986). This type of model is robust against non-normality of distributions and the presence of outliers (Seeber, Lepori, Lomi, Aguillo and Barberio 2012).

The interpretation of the regression results differs from ordinary regressions, as the model provides a probability distribution for different values of counts and, especially when there is overdispersion, the distribution of probabilities is not normal around the expected mean. Accordingly, the expected count value is not necessarily a good predictor of observed counts, but has to be complemented with measures based on probabilities (for example the probability that a dyad has no links).

4 Results

4.1 Descriptive statistics

Descriptive statistics on the six HE education systems considered, displays a number of relevant differences (Table 1).

		CH	DE	IT	NL	NO	UK
HEI characteristics	HEI total	35	291	75	55	42	143
	N. universities	12	117	75	15	7	143
	Size (average)	857	518	1298	721	410	939
	Reputation (average)	1.84	1.21	3.32	3.25	.67	3.64
	Research intensity (average)	.07	.03	.02	.01	.02	.05
	Disc-conc (average)	.64	.51	.40	.66	.42	.34
Policy	Level of competition	medium	medium	weak	medium	Medium-strong	strong
	Functional differentiation	Strong b.	Strong b.	Unitary	Strong b.	Weak b.	Unitary
Weblinks statistics	Mean count of links	100	13	36	21	59	18
	% of dyads with 0 links	55%	79%	32%	75%	35%	45%
	Maximum	37’700	39’100	27’100	8’080	11400	16’600
	Average distance of dyads (km)	132	388	456	152	656	301
	Average distance of links (km)	59	326	357	110	526	259

	Average distance of active dyads (at least one link)	125	351	450	123	635	286

Table 1. Descriptive statistics on national HE systems. Source: EUMIDA. Reference year 2008.

The UK and Italy are unitary systems, where all HEIs are granted the same status, while the other countries are binary. The Norwegian system can be characterized as a soft binary, as UAS can be accredited to award PhD degrees, while colleges can request accreditation to become universities – as a matter of fact three colleges became universities in 2005 and in 2007.

Concerning the level of competition in resource allocation, the UK represents the extreme case of high competition (output-oriented, high share of external funding), while Italy represents the extreme case of low competition (input-oriented, small share of external funding). The other countries remain in intermediate positions, with Norway probably being more competitive (Lepori, Benninghoff, Jongbloed, Salerno and Slipersaeter 2007, Nieminen and Auranen 2010).

In the whole sample, size and reputation are strongly correlated (.631**) despite the fact that the latter has been normalized by size; both also display moderate correlations with research intensity (.437** and .462** respectively). In binary systems, organizational characteristics of the two types of HEIs are quite different: non-university HEIs are more numerous but smaller, and their research intensity and reputation is low, characteristics consistent with the fact that they don't have the right to award doctorate degrees and have a mission oriented towards education and transfer. National averages of organizational characteristics need to be considered with care, given that the underlying distributions are quite different.

Statistics on weblinks display the well-known skewed distribution, with a large number of non-active dyads, as a well as a few very high counts (Seeber, Lepori, Lomi, Aguillo and Barberio 2012). Consistent with the expectation that the presence and strength of relationships increases with decreasing distance, the average distance of links – i.e. the average distance between pairs of HEIs weighted by the count of weblinks – is smaller than the pairs of HEIs (dyads). Also active dyads – pairs of HEIs with at least one weblink – are less distant than average dyads, however the difference is limited, showing that connectivity is by large national.

4.2 Testing the core-periphery structure

As shown in table 2, the fit between the core/periphery model and our data, expressed as the correlation between ideal models and observed data, is very high for all countries reaching the maximum level for the Netherlands (.873) and the minimum for Norway (.798). Moreover, as it should be expected, coreness is closely associated to the total number of links sent and received, the correlation coefficient between coreness normalized, indegree and outdegree on the matrix of loglinks being 0.910** and 0.918** respectively.

Measures of connectivity display expected differences: in all countries, relationships within the core are active (at least one weblink), whereas most relationships in the periphery are not.

		CH	DE	IT	NL	NO	UK
Test of core-periphery	Correlation	0.845	0.864	0.859	0.873	0.798	0.852
	Gini Coeff. coreness	0.48	0.59	0.32	0.59	0.25	0.39
Dimension of the core	% of HEIs	37%	23%	55%	23%	16%	42%
	% of academic staff	77%	76%	83%	56%	61%	71%
	% of undg. students	69%	64%	83%	36%	46%	58%
	% of phd students	99%	95%	87%	100%	85%	84%
Connectivity (% of ties active)	Core-core	.99	1.00	.99	1.00	1.00	.99
	Periphery -core	.54	.35	.76	.35	.97	.59

	Core - periphery	.45	.36	.57	.38	.93	.60
	Periphery - periphery	.22	.06	.27	.11	.48	.23
Medians of attributes within the core	N Org.	13	66	41	13	7	61
	N. Universities	11	65	41	13	4	61
	research intensity	.17***	.06***	.02*	.03***	.09	.07***
	size	1675***	1553***	1654***	1694***	1135***	1157***
	disc_conc	.33***	.24***	.24***	.45	.24	.22***
	Reputation	5.36***	4.97***	4.32***	11.17***	4.19***	7.09***
Medians of attributes within the periphery	N Org	22	225	34	42	35	82
	N. Universities	1	52	34	2	3	82
	research intensity	.00***	.00***	.02*	.00***	.00	.01***
	size	84***	111***	436***	186***	149***	439***
	disc_conc	.00***	.49***	.42***	.90	.28	.27***
	Reputation	.00***	.00***	.19***	.02***	.00***	.23***

Table 2. Test of the core-periphery hypothesis and descriptive statistics of organizational variables per country

Test of differences of Medians, Mann-Whitney, two-tailed; *<0.001, **<0.01, *<0.05.**

In all countries, there is a clear distinction between core and periphery, and the characteristics of organizations in the two groups are significantly different. Core organizations are larger, have higher research intensity and reputation, and cover a wider spectrum of disciplines; differences are statistically non-significant only in the Netherlands (disciplinary concentration), Norway (research intensity and disciplinary concentration) and Italy (research intensity). These associations are confirmed by the fact that a binomial regression, with reputation as the independent variable, correctly classifies 91.8% of the cases between core and periphery (size provides a slightly less good fit). In Germany and Norway, reputation allows the classification of HEIs more effectively than the binary type: in Germany, it distinguishes between core and periphery universities (106 out of 117 are classified correctly), whereas in Norway it discriminates between core and periphery universities.

There is some evidence of the impact of national policies on the core/periphery structure: in binary systems the core includes a lower share of HEIs and the distinction is clearer (with the exception of Norway). Even if comprising less than half of the institutions, the core includes most of the resources (as measured by academic staff) and research activities (as measured by PhD students); concentration is lower for undergraduate students, with the exception of Italy. The inequality of the distribution of coreness is larger in the binary countries (CH, DE, NL) than in the UK, Italy and in Norway (Figure 1).

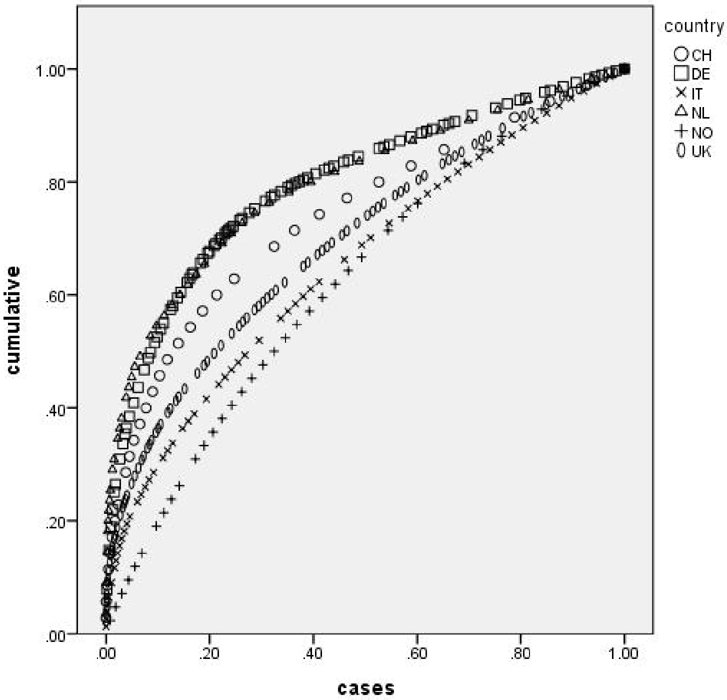

Figure 1. Lorenz curve for coreness by country

In Switzerland and the Netherlands, there is a close correspondence between the core/periphery distinction and HEI types. In Germany, the core is composed of universities, but a significant number of university-type HEIs are periphery. These comprise specialized universities (for example medical universities), very small and specialized universities, as well as teacher training and theological HEIs (which have a university status). In Norway, the three colleges accredited to universities after 2000 (Agder, life sciences and Stavanger) belong to the periphery as well. Thus, if the university type is extended beyond research universities, it does not imply that those HEIs display a high level of network centrality.

Despite its current unitary system, the UK displays traces of the integration process: the core is composed by the oldest (pre-1992) universities, as well as by some of the former Polytechnics, which were integrated into the university system in 1992. The periphery is composed by the remaining post-1992 universities, as well as by a number of specialized HEI's, arts, and educational colleges. Competitive allocation of resources largely maintained the pre-existing hierarchy (Stiles 2000), which was however softened by some mobility of the former Polytechnics.

Italy displays a large core, comprising more than half of the HEIs, as well as 83% of staff; the distinction between core and periphery matches almost exactly the one of students – setting a threshold of 15,000 students would correctly classify 69 over 77 HEIs. This can be interpreted as the consequence of the lack of distinction between types of HEIs, as well as of a system of resource allocation, which to a large extent is directly or indirectly related to the number of students, lacking the concentration effect associated to research activities. The massification of higher education was tackled through the foundation of new universities, especially in the south of Italy; once these reached the students' threshold, they moved into the core which expanded to comprise most of the HE system (with a few exceptions due to geographic position).

In Norway, the four historical universities with high international reputations are the most central and display a very high level of coreness. Large colleges located in the largest cities (Oslo and Bergen) develop strong relationships with universities and move towards the network center, reaching a level of coreness larger than the three "new" universities (colleges upgraded to universities in 2005). We consider that the flat distribution of coreness and the less good fit to a core/periphery model is explained by three factors: (1) the blurring of the distinction between universities and colleges, (2) the specific geographical structure of the country, where most HEIs are clustered in large cities which are very far apart and (3) the very small number of historical universities with high international reputations.

Interestingly, Norway is the only country where even the smallest and least reputed HEIs are connected to the core of the system – the minimum of coreness is 0 in all countries except Norway (49), while the minimum total degree (sum of inlinks and outlinks) is below 20 in all countries except in Norway where it is 120.

4.3 Determinants of coreness

The level of *national coreness* (normalized) is predicted with a high level of precision from the organizational attributes (Table 3).

	Staff only		Staff only		Staff and reputation		All variables			
	Estimate	SE	Estimate	SE	Estimate	SE	Estimate	SE	Beta	VIF
Intercept	1.241	.100***	-.246	.138’	.192	.141***	.780	.255**		
SQRT size	.156	.004***	.306	.011**	.248	.013***	.230	.015***	1.264	25.355
(SQRT size)^2			-.003	.000***	-.002	.000***	-.002	.000***	-.698	16.749
SQRT Int. reputation					.609	.073***	.531	.075***	.214	3.509
Res Intensity							5.758	1.031***	.108	1.430
Disc. Concentration							-.834	.203***	-.090	1.845
Found. year (dummy)							.024	.102	.004	1.232
		Df		Df		Df		Df		
Adjusted Rsquare	..735	643	.796	643	.816	643	.833	641		
Residual mean sum of squares	2.081	641	1.598	640	1.444	639	1.312	634		
F statistics	1781.168	1	1257.011	2	950.376	3	533	6		
Durbin-Watson	1.245		1.620		1.644		1.681			
Rsquare original data	.692		.794		.832		.845			

Table 3. Determinants of coreness

Ordinary least square model. Dependent variable: square root of coreness normalized. N=643

Unstandardized residuals show a normal distribution (Kolmogorov-Smirnov statistics .940, p=0.340), thus the transformation of the dependent was effective in addressing normality problems. The introduction of international reputation affects the coefficient of staff, but both are significant and the model is statistically superior to the one with staff only (while the Variance Inflation Factor for international reputation remains moderate).

The standardized coefficients display that size is the most important factor influencing coreness. The negative sign of the quadratic term implies that its impact decreases with size. Figure 2 helps to disentangle the relative effects of size and international reputation. For small HEIs, size has the most important effect, whereas quality has only a minor influence on coreness. The only HEI with high reputation and low size in the sample (the London Business School) reaches a level of coreness (normalized) of only 10. In the middle range region (500-1500 academic staff), size remains the main factor, but reputation becomes increasingly important and thus middle-sized international universities tend to be more central in national networks than non-university HEIs of similar size. Finally, for the largest HEIs, coreness depends only on international reputation.

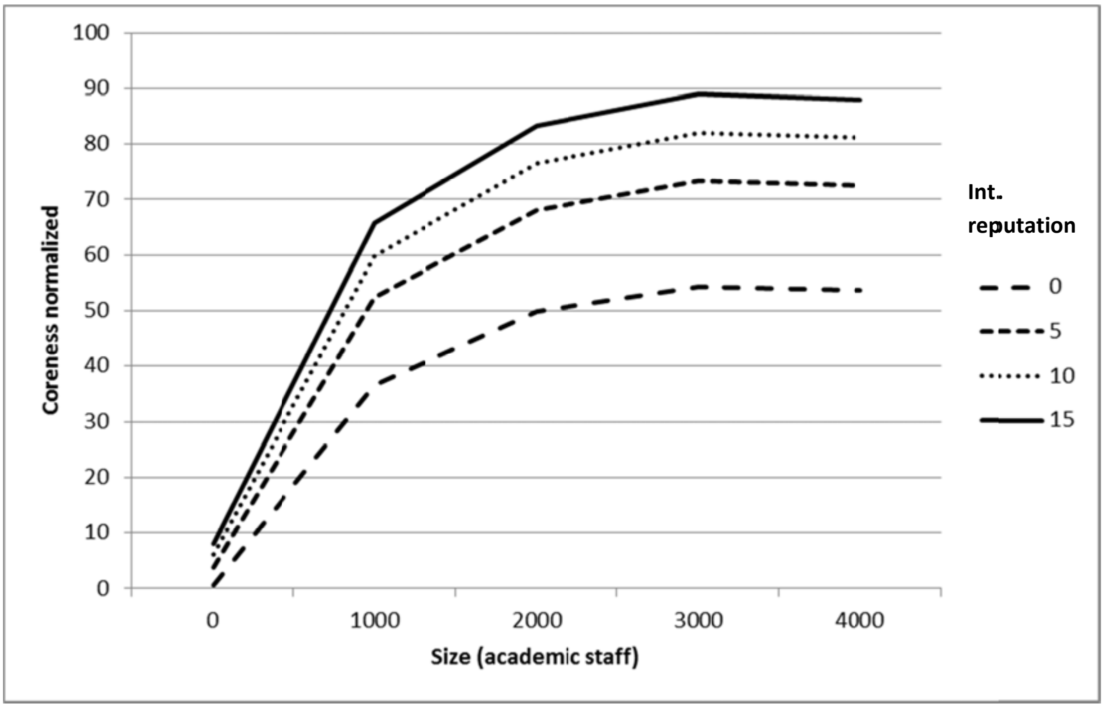

Figure 2. Relationships between size, international reputation and coreness predicted

On the contrary, foundation year and national type for binary countries are statistically not significant. The urban centrality variable is not significant for both the general regression and for the specific case of the UK (where there is spatial concentration around London). This can be explained by the fact that large cities not only host some of the largest and most reputed HEIs, but also a number of smaller and more specialized ones.

At the country level, the model explains between 73% (Switzerland) and 89% of the variance (the Netherlands) in the original data, while this drops to only 49% in Norway. Accordingly, there is substantial evidence that the relationship between organizational variables and coreness is largely independent of the specific national characteristics. National policies do not directly influence the network structure, but might do it indirectly through the inequality in the distribution of resources and status (which tends to be larger in binary countries than in the UK and even more than in Italy).

4.4 Geography, coreness and connectivity

As show by Table 4, most dyads in the countries considered have a distance above 100 km; expectedly this share is higher in the three large countries (DE, IT and UK), while in Switzerland and the Netherlands, a large number of relationships are below 100 km. Norway presents a peculiar cluster structure, with a high share of short-range relationships, but most dyads with very large distances. Weblinks tend to be concentrated in shorter distances, but the impact on the overall repartition of links by distance remains limited - in Switzerland, the high share of links below 10 km is due to a single case (EPFL-UNIL), accounting for 35% of total links.

	CH		DE		IT		NL		NO		UK	
	Dyads	Links	Dyads	Links	Dyads	Links	Dyads	Links	Dyads	Links	Dyads	Links
<10 km	8%	45%	1%	7%	3%	5%	8%	15%	7%	24%	4%	8%
10-99 km	31%	33%	6%	15%	4%	9%	38%	43%	8%	6%	10%	16%

100-500 km	61%	23%	63%	54%	51%	54%	51%	42%	28%	25%	70%	59%
> 500 km	0%	0%	30%	24%	42%	33%	4%	0%	58%	46%	16%	17%

Table 4. Distribution of links by class of distance and country

Percentage of dyads and of counts of links.

To analyze the interplay between organizational characteristics and geographic distance, we characterize organizations by their *relational mass*. We first classify dyads by their total mass and distance, and then we analyze the percentage of counts in each class by the number of counts.

Table 5 shows that the share of non-active dyads (0 links) is consistently larger for low mass, independent of distance. Furthermore, the effect of distance is stronger for peripheral HEIs and, when mass increases, it moves toward higher counts: if the sum of masses is below 60, distance strongly influences the likelihood of having at least 1 link, whereas between 60 and 120 it mostly influences the likelihood of counts above 100 links; finally, when total mass is very high, the effect is not significant for all levels of counts considered.

	Sum of mass < 60			Sum of mass between 60 and 119			Sum of mass > 119		
	0 links	1-99 links	>100 links	0 links	1-99 links	>100 links	0 links	1-99 links	>100 links
<10 km	70%	28%	1%	22%	68%	10%	6%	57%	38%
10-100 km	80%	20%	0%	32%	64%	4%	3%	51%	47%
100 - 500 km	90%	10%	0%	46%	53%	1%	4%	65%	31%
>500 km	92%	8%	0%	51%	48%	1%	2%	70%	29%

Table 5. Distribution of dyads by class of counts as related to distance and sum of masses

A binomial hurdle regression shows that both mass and distance are highly significant predictors of counts of weblinks (Table 6).

	Null model		**Mass only**		**Mass and distance**	
	Estimate	Std. Error	Estimate	Std. Error	Estimate	Std. Error
(Intercept)	-8.318	8.151	-10.10	6.638	-10.12	12.80
Mass-sender			.02695	.00053***	.02794	.00054***
Mass-receiver			.02815	.00055***	.02878	.00058***
Log_distance					-.5424	.02154***
Log(theta)	-14.106	8.151’	-12.84	6.638’	-14.00	12.80
Zero hurdle model coefficients (binomial with logit link)						
(Intercept)	-.8415		-3.664	0.020***	-2.141	0.0439***
Mass-sender			.0479	.00034***	.0484	0.00034***
Mass-receiver			.0481	.00034***	.0487	0.00035***
Log_distance					-.4419	0.0170***
Number of iterations	13		29		35	
Log-likelihood	-2.063e+05 on 3 df		-1.776e+05 on 7 df		-1.764e+05 on 9 df	

Signif. Codes 0*** 0.001** 0.01* 0.05’

Table 6. Results of the binomial regression

The model with mass only performs quite well in terms of predictive ability of counts of weblinks: it identifies 64% of the non-zero dyads and, when it predicts a count higher than 0, it is correct in 78% of the cases. Furthermore, the predictive ability of the model is rather similar for the countries considered, except for Norway where the model identifies only 20% of the non-zero counts. As expected, the coefficients of sender and receiver mass are almost identical. The model, including the log of distance, is statistically superior but only slightly increases the predictive ability. As a matter of fact, the mass only model provides a largely equivalent result to a full model, separately including all organizational and geographical variables showing that the measure of mass captures almost all organizational effects on interlinking.

Estimates of the predicted probability of interlinking and of the expected counts help to disentangle the interaction between mass and distance (Figure 3).

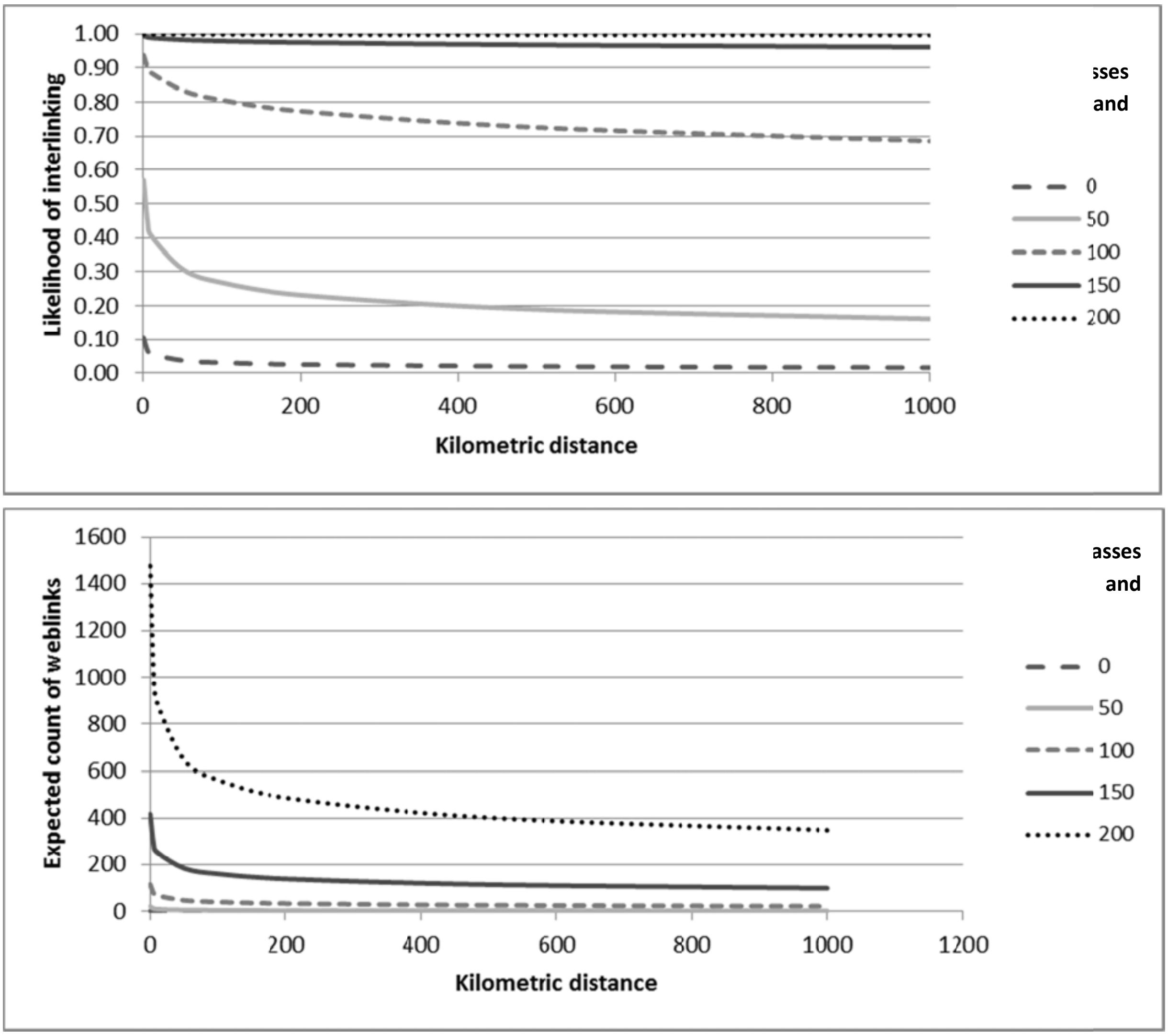

Figure 3. Predicted values of weblinks depending on sum of masses and distance
Top: probability of interlinking; bottom: expected counts as generated by the model

These results are consistent with descriptive analysis. The probability of interlinking remains consistently high when the sum of masses is sufficiently large: core HEIs will be connected independent of distance, whereas the most peripheral HEIs will be connected only if they are very near (below a scale of about 50 km). For core-periphery connections (mass between 100 and 150), the likelihood of linking decreases with distance but remains relatively high at the largest distance found in the countries considered. Thus, core HEIs function as national attractors independent of distance.

Second, the impact on counts of links is large only at a very small distance (below 50 km) and is generally less strong than the one of mass: two HEIs with total mass 200 and 500 km apart are expected to have the same of number of links as two HEIs of total mass 150 located in the same city. Dyads with high mass and low distance are rather rare since large HEIs tend to be distributed across a country in order to respond to the demand for students – only 20% of the dyads in our dataset with total mass above 150 have distance below 100 km. This implies that dyads with large counts will tend to be distributed at a national level and thus distance will not have a strong impact on the core/periphery structure (while influencing individual counts when two large HEIs are very near).

This analysis suggests that geography is likely to have a stronger impact on network structure when there is a small number of regional clusters comprising at least one of the largest HEIs (in terms of relational mass) and many smaller HEIs, while the geographical size of the clusters is much smaller than the distance between them. Under that condition, connections between large HEIs will remain distributed to the whole country, whereas peripheral HEIs are expected to display larger levels of connectivity thanks to geographical proximity, thus leading to a hub and spoke structure.

In Norway there are only four large attractors (the historical universities in Oslo, Bergen, NIST Trondheim and Tromsø) whose average distance approaches 1000 km, clustering many smaller HEIs (15 out of the 38 remaining HEIs are located in one of these cities). Our model provides evidence that this geographical structure accounts for the characteristics of the Norwegian network, with the lower fit to the core/periphery and a flat distribution of coreness despite inequality in the repartition of resources. Moreover, a closer investigation shows that some large deviations from the model are explained by specific institutional characteristics, like the presence of institutional cooperation between HEIs in the same town (the colleges in Lillehammer and Gjøvik in Norway or EPFL and UNIL in Switzerland) or sharing a common regional and cultural focus (University of Tromsø and the Sami college). Expectedly, these regional factors are more important in a country like Norway where regions are very far apart.

5 Discussion and conclusion

Findings can be interpreted at two levels, a technical one on the structure of HE interlinking networks, and an organizational one concerning the structuring of social relationships in HE fields.

Results go beyond existing studies, which mainly analyze the determinants of interlinking between HEIs, to analyze the structural characteristics of the network emerging from connectivity and to which extent they generate regularities in the network structure; this kind of investigations have been common for publication and citation networks, but to our knowledge are not frequently adopted for relational patterns between HEIs.

Our results show that a *common* core/periphery model explains a large part of the observed network structure in the considered countries, with the partial exception of Norway. This means that a) national networks are organized around a single center and that b) the number of weblinks between two HEIs can be predicted with high precision solely from their individual level of coreness. Importantly, these are not straightforward assumptions, as most social networks are organized around social mechanisms like the distinction between types of organizations or spatial structures, or those generated by endogenous network mechanisms like social closure and the formation of cliques.

Furthermore, centrality turns out to be closely associated to organizational characteristics and, for small HEIs, it depends essentially on size, whereas for the largest ones depends on international reputation. This implies a well-defined repartition of HEIs in the network, with the center occupied by the largest research universities, the middle range by other universities, as well as large non-university HEIs, and the periphery by smaller HEIs in the country. These relationships are basically the same for the countries considered, despite differences in national policies and in the types of HEIs. In our opinion, this hints to the fact that there are deep mechanisms generating weblinks, related to organizational activities and characteristics of HEIs. Thus, the basic structure of HEI interlinking networks is determined by the distribution of resources and reputation among organizations – independent of political, social and geographical characteristics of the considered countries.

The models we developed also explain why, in the countries considered, geography does not affect the network structure, despite having an impact on connectivity and we do not observe regional clustering. The case of Norway, where departures are observed, suggests that large heterogeneities in the distribution of HEIs, with clearly defined regional clusters, are likely to have a stronger influence on network structure.

These results are consistent with the assumption that weblinks are not just connections between documents published on the web, but rather markers of underlying social relationships between HEIs, as related to their activities. Weblinks are systematically related to resources and status, and have different distributional properties than citation networks – total degree displays a loglinear distribution rather than a power law distribution.

While the focus of this paper was on understanding the core-periphery structure, our results suggest a few factors which might nevertheless influence the network structure and which deserve further investigation; these include the presence of institutional collaboration between two HEIs, specific regional structures related to geography, language and culture, and finally, network effects like reciprocation and the creation of cliques.

In a broader context, our results have important implications for the structure of HE fields. Despite different policy narratives and governance settings, the HE systems considered have developed a very similar status hierarchy, where binary systems display an even steeper hierarchy than the unitary ones. This conforms to widespread expectations that integration into a unique system is leading to a process of hierarchization, as different types of HEIs provide similar offerings (like bachelor and master studies), while hierarchy allows audiences to make choices (Bleiklie 2003). In this perspective, the main difference between unitary and binary systems is not structural (as functional differentiation theories suggest); rather, the establishment of a binary divide can be regarded as a policy instrument alternative to competition in order to concentrate research activities and resources in the system's core.

These results are consistent with expectations from economic sociology and institutional theory, that status hierarchy and relational structures coevolve over time and that differential access to resources determined by the core/periphery structure is a central element to ensuring the long-term stability of the status layering of national HE systems which has been observed by previous studies (Webster 1992, Burris 2004). This also suggests that the role of policies in shaping the HE system structure might be more limited than often assumed and they tend to be largely endogenous to existing system's hierarchy rather than to determine it.

While our investigation has been focused on the structure of the national HE network, a central issue for future research is represented by the relationships between national networks and the structuring of international and European networks. Previous studies have shown that HE interlinking networks are based on a country structure (Ortega, Aguillo, Cothey and Scharnhorst 2008), but there is evidence that internationally reputed HEIs are connected at the European (Seeber, Lepori, Lomi, Aguillo and Barberio 2012) and possibly at the world level (Lee and Park 2012). Several questions arise in this respect, like the relationships between international and national cores, the identification of HEIs acting as gatekeepers between them (and possibly, between countries with similar culture or language), and the different importance of size vs. reputation in determining international and national network centrality. Lasting processes of internationalization of HE systems, as well as the introduction of European-level governance and funding instruments would suggest that international relationships are becoming more important and, possibly, a more connected European core is emerging; longitudinal studies exploiting interlinking data from different years would be at place here.

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7 References

Abbasi, A., Hossain, L. & Leydesdorff, L. (2012). Betwenenness centrality as a driver of preferential attachment in the evolution of research collaboration networks. *Journal of Informetrics, 6(3)*, 403-412.

Adams, J., Faust, K. & Lovasi, G. (2012). Capturing context: Integrating spatial and social network analyses. *Social Networks, 34(1)(1-5)*.

Aguillo, I., Granadino, B., Ortega, J. L. & Prieto, J. A. (2006). Scientific research activity and communication measured with cybermetric indicators. *Journal of the American Society for Information Science and Technology, 57(10)*, 1296-1302.

Bar-Ilan, J. (2009). Infometrics at the beginning of the 21st century - A review. *Journal of Infometrics, 2(1)*, 1-52.

Bar-Ilan, J. (2004). A microscopic link analysis of academic institutions within a country - the case of Israel. *Scientometrics, 59(3)*, 391-403.

Bleiklie, I. (2003). Hierarchy and Specialisation: on the institutional integration of higher education systems. *European Journal of Education, 38(4)*, 341-355.

Borgatti, S. P. & Everett, M. G. (1999). Models of core/periphery structures. *Social Networks, 21*, 375–395.

Borgatti, S. P., Everett & Freeman (2002). Ucinet 6 for Windows.

Boyd, J. P., Fitzgerald, W. J. & Beck, R. J. (2006). Computing core/periphery structures and permutation tests for social relations data. *Social Networks, 28(2)*, 165-178.

Burris, V. (2004). The Academic Caste System: Prestige Hierarchies in PhD Exchange Networks. *American Sociological Review, 69(2)*, 239-264.

Burt, R. S. (1988). The Stability of American Markets. *American Journal of Sociology, 93*, 356–95.

Butts, C. T., Acton, R. M., Hipp, J. R. & Nagle, N. N. (2012). Geographical variability and network structure. *Social Networks, 34(1)*, 82-100.

Cattani, G., Ferriani, S., Negro, G. & Perretti, F. (2008). The Structure of Consensus: Network Ties, Legitimation, and Exit Rates of U.S. Feature Film Producer Organizations. *Administrative Science Quarterly, 53(1)*, 145-182.

Chinchilla-Rodriguéz, Z., Ferligoi, A., Miguel, S., Kronegger, L. & de Moya-Anegón, F. (2012). Blockmodeling of co-authorship networks in library and information science in Argentina: a case study. *Scientometrics, 93(3)*, 699-717.

Daraganova, G., Pattison, P., Koskinen, J., Mitchell, B., Bill, A., Watts, M. & Baum, S. (2012). Networks and geography: Modelling comunity network structures as the outcome of both spatial and network processes. *Social Networks, 34(1)*, 6-17.

Ferlie, E., Musselin & Andresani (2008). The steering of higher education systems: a public management perspective. *Higher Education, 56(3)*, 325-348.

Freeman, L. C. (1978/79.). Centrality in Social Networks. Conceptual Clarifications. *Social Networks, 1*, 215-239.

Glänzel, W. & Schubert, A. (2005). Analysing scientific networks through co-authorship. In H. F. Moed, W. Glänzel & U. Schmoch(Eds.) *Handbook of Quantitative Science and Technology Research* (pp. 257-276). Dordrecht: Kluwer Academic Publications.

Gonzalez-Bailon, S. (2009). Opening the black box of link formation: Social factors underlying the structure of the Web. *Social Networks, 31(4)*, 271-280.

Hazelkorn, E. (2009). Rankings and the battle for world-class excellence: institutional strategies and policy choices. *Higher Education Management and Policy, 21/1*.

Heller-Schuh, B., Barber, M., Henriques, L., Paier, M., Pontikakis, D., Scherngell, T., Veltri, G. A. & Weber, M. (2011). *Analysis of Networks in European Framework Programmes (1984-2006)* Luxembourg: Publications Office of the European Union.

Hoekman, J., Frenken, K. & Tijssen, R. (2010). Research collaboration at distance: Changing spatial patterns of scientific collaboration in Europe. *Research Policy, 39(5)*, 662-673.

Holmberg, K. & Thelwall, M. (2009). Local government websites in Finland: A geographic and webometric analysis. *Scientometrics, 1*, 157-169.

Holme, P. (2005). Core-periphery organization of complex networks. *Physical Review E, 72(4)*.

Jones, B. F., Wuchty, S. & Uzzi, B. (2008). Multi-University Research Teams: Shifting Impact, Geography, and Stratification in Science. *Science, 322(5905)*, 1259-1262.

Kronegger, L., Ferligoj, A. & Doreian, P. (2011). On the dynamics of national scientific systems. *Quality and Quantity, 45*, 989-1015.

Kyvik, S. (2004). Structural Changes in Higher Education Systems in Western Europe. *Higher Education in Europe, 29 (3)*, 393-409.

Kyvik, S. & Lepori, B. (2010). *Research in the non-university higher education sector in Europe* Dordrecht: Springer.

Laumann, E. O., Galaskiewicz, J. & Marsden, V. P. (1978). Community Structure as Interorganizational Linkages. *Annual Review of Sociology, 4*, 455-484.

Lee, M. & Park, H. W. (2012). Exploring the web visibility of world-class universities. *Scientometrics, 90*, 201-218.

Lepori, B. & Bonaccorsi, A. (2013). Towards an European census of higher education institutions. Design, methodological and comparability issues. *Minerva,* .

Lepori, B. & Kyvik, S. (2010). The research mission of Universities of Applied Science and the future configuration of Higher Education systems in Europe. *Higher Education Policy, 23*, 295-316.

Lepori, B. (2011). Coordination modes in public funding systems. *Research Policy, 40(3)*, 355-367.

Lepori, B., Benninghoff, M., Jongbloed, B., Salerno, C. & Slipersaeter, S. (2007). Changing models and patterns of higher education funding: Some empirical evidence. In A. Bonaccorsi & C. Daraio(Eds.) *Universities and Strategic Knowledge Creation. Specialization and Performance in Europe* (pp. 85-111). Bodmin, Cornwall: MPG Books Limited.

Marginson, S. (2006). Dynamics of national and global competition in higher education. *Higher Education, 52(1)*, 1-39.

Mullahy, J. (1986). Speci cation and Testing of Some Modified Count Data Models. *Journal of Econometrics, 33*, 341-365.

Nieminen, M. & Auranen, O. (2010). University research funding and publication performance - an international comparison. *39*, 822-834.

Ortega, J. L., Aguillo, I., Cothey, V. & Scharnhorst, A. (2008). Maps of the academic web in the European Higher Education Area - an exploration of visual web indicators. *Scientometrics, 74(2)*, 295-308.

Owen-Smith, J. & Powell, W. W. (2008). Networks and institutions. In R. Greenwood, C. Oliver, K. Shalin & R. Suddaby(Eds.) *The SAGE Handbook of Organizational Institutionalism* (pp. 594-621). London.

Paradeise, C., Reale, E., Bleiklie, I. & Ferlie, E. (2009). *University Governance. Western European Comparative Perspectives.*Dordrecht: Springer.

Rivera, M. T., Soderstrom, S. B. & Uzzi, B. (2010). Dynamics of Dyads in Social Networks: Assortative, Relational, and Proximity Mechanisms. *Annual Review of Sociology, 36(91-115)*.

Schofer, E., Meyer, J. (2005). The Worldwide Expansion of Higher Education in the Twentieth Century. *American Sociological Review, 70(6)*, 898-920.

Seeber, M., Lepori, B., Lomi, A., Aguillo, I. & Barberio, V. (2012). Factors affecting weblink connections between European higher education institutions. *Journal of Infometrics, 6(3)*, 435-447.

Snyder, D. & Kick, E. L. (1979). Structural Position in the World System and Economic Growth, 1955-1970: A Multiple-Network Analysis of Transnational Interactions. *American Journal of Sociology, 84(5)*, pp. 1096-1126.

Stiles, D. R. (2000). Higher Education Funding Patterns Since 1990: A New Perspective. *Public Money & Management, 20(4)*, 51-57.

Taylor, P. J. (2004). *World City Network: a Global Urban Analysis* London: Routledge.

Thelwall, M. (2002a). A research and institutional size based model for national university web site interlinking. *Journal of Documentation, 58(6)*, 683-694.

Thelwall, M. (2002b). Evidence for the existence of geographic trends in university web site interlinking. *Journal of Documentation, 58(5)*, 563-574.

Thelwall, M. & Sud, P. (2011). A comparison of methods for collecting web citation data for academic organizations. *Journal of the American Society for Information Science and Technology, 62(8)*, 1488-1497.

Thelwall, M., Tang, R. & Price, E. (2003). Linguistic patterns of academic web use in Western Europe. *Scientometrics, 56(3)*, 417-432.

Thelwall, M. & Zuccala, A. (2008). A university-centred European Union link analysis. *Scientometrics, 75(3)*, 407-420.

van Raan, A. F. J. (2007). Bibliometric statistical properties of the 100 largest European universities: prevalent scaling rules in the science system. *Eprint arXiv:0704.0889,* .

Volkwein, J. F. & Sweitzer, K. V. (2006). Institutional prestige and reputation among research universities and liberal arts colleges. *Research in Higher Education, 47(2)*.

Wagner, C. S. & Leydesdorff, L. (2005). Network Structure, Self Organization, and the Growth of International Collaboration in Science. *Research Policy, 34 (10)*, 1608-1618.

Webster, D. S. (1992). Reputational rankings of colleges, universities and individual disciplines and fields of study from their beginnings to the present. In C. S. John(Ed.) *Higher Education, Handbook of Theory and Research, vol. VIII* (pp. 234-304). New York: Agathon Press.

White, H., Boorman, S. & Breiger, R. (1976). Social Structure from Multiple Networks. I. Blockmodels of Roles and Positions. *The American Journal of Sociology, 81(4)*, 730.

White, H. C. (1981). Where Do Markets Come From? *American Journal of Sociology, 87*, 517–47.

Wilkinson, D., Harries, G., Thelwall, M. & Price, L. (2003). Motivations for academic web site interlinking: evidence for the Web as a novel source of information on informal scholarly communication. *Journal of Information Science, 29(1)*, 49-56.