Power Dynamics in Global Production Networks

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Abstract: In this paper we argue that the structural characteristics of global economic networks allow for an alternative understanding of the power relations between capital and labor, as expressed by the functional income distribution patterns. In particular, we utilize the concept of *positionality*, found in the literatures of Labor Sociology, Economic Geography and Network Theory, in order to reflect the structural advantages of economic sectors, due to their position in a global inter-dependent economy. Empirically, we build on the World Input-Output Database and the OECD Inter-Country Input-Output Tables, in order to construct sector-specific measures of positionality, based on the concept of network centrality, and correlate them with the shares of each sector to the total value-added. The results show that more centralized country-specific economic sectors benefit from a 'network-effect' and gain higher profit-shares compared with less centralized.

Keywords: *economic power; global value chains; governance structure; input-output tables; bargaining power; centrality*

1. Introduction

Since the early 1990s *Global Commodity Chains* (GCC), *Global Value Chains* (GVC) and *Global Production Networks* (GPN) frameworks have dominated the analysis of world capitalism, focusing on the questions of governance and power in international supply chains. These relatively new conceptualizations of globalization highlight, on the one hand, the full range of activities that firms, and workers perform in order to produce and distribute commodities into the final market and, on the other, the development paths that economic, social and institutional actors pave for their respective national and regional economies. Central in their analysis is the ability of powerful firms to dominate in value chains or production networks, shape the governance structures that regulate the army of spatially dispersed suppliers and consequently capture the highest possible amounts of value-added (Coe & Yeung, 2015; Gereffi, 1994; Gereffi, Humphrey, & Sturgeon, 2005; Hopkins & Wallerstein, 1994; H. W. Yeung & Coe, 2015).

The causation mechanism the aforementioned approaches employ lacks, however, the appropriate analytical depth for a thorough and meaningful analysis of globalization dynamics. In their view, when it comes to the distribution of value and the developmental paths paved by globalization, it is simply the most powerful actor (usually a big firm) that will have the capacity to shape global production processes, in such ways as to maximize the value-added captured vis-à-vis its suppliers and labor. In the GCC approach, for instance, it is the powerful firms belonging to *Producer-Driven* and *Buyer-Driven* commodity chains that have the ability to determine the structures of global production and reap the benefits of globalization (Gereffi, 1994). Likewise, in the much more advanced framework of GVC, in which the producer-driven and buyer-driven commodity chains have been transformed into five types of differential degree of power asymmetry between suppliers and buyers, the powerful actors of global value chains shape the structural characteristics of global value production and regulate the distribution of value along the actors of productions (Gereffi et al., 2005). Similarly, in the GPN literature, actors that manage to excel in the three "structural competitive dynamics" of a) cost to production capabilities ratio optimization, b) market development and c) financial discipline, will be able to 'rule the game' by altering the production networks configurations, in order to cope with the uncertain and risky conditions of the world economy (Coe & Yeung, 2015; Henderson, Dicken, Hess, Coe, & Wai-Chung Yeung, 2002; H. W. Yeung & Coe, 2015).

In our view, though, the above analytical paths do not pay the proper attention neither to the concept of power *per se*, nor to the nature and various dimensions of the concept, leaving the "analytical scope in which power operates and the precise determinants of power are underspecified in each" (Mahutga, 2014a, p. 158). Consequently, the most important contribution of the approaches of GCC, GVC and GPN to the analysis of globalization - the models of governance structures - seems to be ill-treated exactly on the basis of their subject matter, namely the concept of power. Important exception is the work of Mahutga (Mahutga, 2014b, 2014a) who borrows valuable insights from sociology and network theory to conceptualize power in terms of 'positionality', namely the particular positions actors hold in economic and production networks, filling, in that way, the analytical gap between governance structures and power. In particular, Mahutga produces a global, network-based, bargaining power concept, building on the work of sociologists concentrating on the theory of power-dependency (Emerson, 1962) and labor bargaining power (Wallace, Griffin, & Rubin, 1989), as well as, network theory, in order to examine the structures of international exchange-trade networks, at the country-level.

In this paper we follow a research path similar to Mahutga by arguing that the structural and statistical properties of the network relationships emerged in a global economy, have the ability to express patterns of governance structures, allowing us to conclude on the power asymmetries between economic actors. More specifically, we build upon network theory's notion of *'node centrality'* and the work of Erik Ohlin Wright (Wright, 2000) on the multidimensionality of labor bargaining power, in order to capture the positional dimension of the power of economic sectors in global production networks, given that centrality is related to power and influence, due to the topological properties of particular nodes in a network. In other words, since GCC, GVC and GPN literatures envision global economy in the form of a global economic network, and network theory utilized the concept of node centrality as a proxy of the influence and power that particular nodes exert upon all the other nodes in a network, it is evident to link the two approaches on the ground of positional power of economic sectors in an economic network. We demonstrate that this is the case by checking the correlations (Pearson, Spearman and Kendall) between different measures of node centrality in different economic sectors in a global economy and their respective shares of the Total Value-Added. We are able to calculate this by using two different Global Input-Output Databases, the World Input-Output Database (Timmer, Dietzenbacher, Los, Stehrer, & de Vries, 2015) and the Organization of Economic Cooperation and Development (OECD) Inter-Country Input-Output (ICIO) Tables, with different country, sectors and time coverage (see *Appendix A* for data details).

The contribution of our paper lies on different levels: First of all, we provide a general theoretical contribution regarding the connection of the literatures of globalization in economic geography, on the grounds of governance structures and power. By exploring the sociological discussion on power and bargaining power, and synthesizing it with insights from network theory, we highlight the importance of 'network configuration' discussed in the literature of GPN 2.0. More specifically, we overcome the "methodological constraints of GPNs vis-à-vis GVCs" (G. Yeung, 2016, p. 268) and provide the basis for a quantitative analysis of global production networks. Secondly, our work can be viewed as a methodological contribution to Input-Output Analysis with the use of network theory's tools and particularly that of node centralities, since this is the first time that the structural properties of an economic/production network have been linked to the functional income distribution. Lastly, the empirical findings of our work regarding the positional dimensionality of power in global production networks, find many applications in the respective empirical literatures focusing on the effects of international trade and offshoring on labor markets and functional income distribution (Berman, Bound, & Griliches, 1994; Feenstra, 1998; Guerriero & Kunal, 2012; Milberg & Winkler, 2013).

The structure of the paper is as follows. *Section 2* paves the theoretical ground of our main argument, which is inspired by the work of labor sociology regarding the multidimensionality of the concept of labor bargaining power, as well as, the discussion of power and governance structures found in the literatures of GCC, GVC and GPN. In *Section 3*, we explore the input-output characteristics of the global economy and how these are related to the notion of 'node centrality' in economic networks. *Section 4* outlines the methodological steps that we take in our paper, regarding the use of world input-output data, from two different datasets for various year, sectors and countries coverages, while in *Section 5* we highlight the empirical conclusions of our work.

2. Positional Power in Global Production Networks

In order to understand the concept of positional power in global production networks, we firstly need a proper economic understanding of the concept of power, *per se*. Many economists, from different schools of thought, have come to the conclusion that the concept of *'power'* has been only partially investigated and superficially incorporated in the analytical corpus of economics, even though it has been heavily used in the discipline. The term is commonly used at the micro-level analysis, and particularly in *Microeconomics* and *Industrial Organization*, to describe the oligopoly power of the firm in imperfectly competitive markets, as well as, to illustrate the interaction between employees and employers in the labor market, through bargaining power (Carlton & Perloff, 2004; Dunlop & Higgins, 1942; Tirole, 1988). However, these two instances of power are quite restrictive, not only in the sense of defining the subject matter (i.e., power), but also in their capacity to provide the concept of power the proper analytical strength to effectively describe the dynamic and conflictual nature of economic phenomena in contemporary capitalism.

Whilst economics has left the notion of power analytically undeveloped, scholars coming from different scientific backgrounds, like sociology, have produced a variety of definitions and research agendas and offer a more developed discussion of power relations. It is quite common in sociology and political science to distinguish between various dimensions of power (Bachrach & Baratz, 1962; Dahl, 2007; Emerson, 1962; Lukes, 2005). This is more evident in labor sociology, which tends to differentiate workers' bargaining power according to the specific social and economic positions and functions workers hold and engage with, respectively (Arrighi, 1982; Arrighi & Silver, 1984; Perrone, Wright, & Griffin, 1984; Silver, 2003; Wallace et al., 1989; Wallace, Leicht, & Grant, 1993; Wright, 2000).

The most common distinction of labor bargaining power comes from the work of Erik Olin Wright (Wright, 2000) and Beverly Silver (Silver, 2003). Wright distinguishes between two dimensions of labor bargaining power, *Associational Power* and *Structural Power*. With associational power he defines the collective power of the working class emerging from representative institutions and labor organizations. The density of unionization, the coverage of the collective agreements or the participation of labor collectives in firm and non-firm decision making, are some of the attributes of associational power. Structural power, on the other hand, represents the "power of workers as individuals that results directly from tight labor markets or from the *strategic location* of a particular group of workers within a key industrial sector" (Wright, 2000, p. 962) and their capacity to interrupt the normal functioning of the production process, and in that way pressure employers for concessions. Silver extensively builds on Wright's work, as well as, previous work conducted by herself and Giovanni Arrighi (Arrighi, 1982; Arrighi & Silver, 1984), and divides structural power into *Structural Marketplace Bargaining Power*, stemming from the "tight labor markets" and *Structural Workplace Bargaining Power*, generated by the "strategic location" of labor in the production process.

The starting point, however, of the multidimensionality of labor bargaining power, is to be found in the independent research works of Perrone (Perrone et al., 1984), Arrighi (Arrighi, 1982) and Arrighi and Silver (Arrighi & Silver, 1984), who provided interesting approaches regarding the forms of labor bargaining power, analytically connecting the latter with globalization and the fundamental dynamics of capitalist development. More specifically, Arrighi and Silver were the first scholars who attempted a formal distinction of the dimensionality of labor bargaining power, distinguishing between marketplace and workplace power. *Marketplace Bargaining Power (MBP)* relates to the bargaining power of labor when workers sell their labor-power to the capitalist, and thus puts emphasis on the specific characteristics of labor's skills and the degree of subjection to capital's authority. On the other hand, *Workplace Bargaining Power (WBP)* denotes the power of labor stemming from the vulnerability of capital to workers' resistance, due to increased concentration and centralization of labor in large production units and the "connectedness of work roles" (Arrighi, 1982). According to them, capitalist accumulation constantly transforms industrial organization and the labor process, in such a way as to weaken MBP, through the deskilling and homogenization of labor, and at the same time strengthen WBP via the concentration of greater volumes of living labor in the same production unit, paving the way for "their association in a struggle against their common exploitation" (Arrighi, 1982, p. 84).

Around the same time Arrighi and Silver developed their conceptualizations of bargaining power, *Luca Perrone* (Perrone et al., 1984) becomes the first sociologist who explicitly links the position of labor in the production process of complex interdependent economic systems, with the *"disruptive potential"* or potential damage labor unrest inflicts to the capitalist. He formally defines the "disruptive potential of workers which is derived from their varying positions within the system of economic interdependencies" (Perrone et al., 1984, p. 414), as the *'structural power'* of labor, a term that we will find in the work of Erik Olin Wright, 16 years later. However, the most important novelty of Perrone's work is his attempt to *'operationalize'* and empirically measure the structural power of labor. His empirical approach was based on the utilization of Input-Output Tables (IOTs) and the assumption that the structural power of labor in a particular industry, results from the power of the latter due to its position in the inter-dependent economic system. In other words, simply by measuring the positional power of economic sectors with the number of linkages connecting the supplying to demanding sectors of an economy, Perrone managed to measure the positional or structural power of labor or what he calls in his paper, the *"disruptive potential"* of the labor class.

Perrone's 1984 paper was edited by Erik Olin Wright and published in the American Sociological Review after his unexpected death. Unfortunately, Perrone didn't have the chance to incorporate any of the assessments and criticisms made by his reviewers. However, the postscripts written by Wright and Griffin at the end of Perrone's paper, are extremely useful for a reconceptualization of labor's structural and positional power. Responding to those critical assessments, *Wallace, Griffin and Rubin* (Wallace et al., 1989) refined Perrone's conceptualization and extended the understanding of positional power to account for the disruptive potential of labor employed, not only in the supplying-sectors, but also in the demanding-sectors (buyers). This path significantly broadened the analytical depth of the concept of positional/structural power of labor, since embodied cases of disruptive potentials for the economic system as a whole and not only for the damage threat directed from input supplying, *upstream*, firms/industries to receiving, *downstream* sectors.

Mahutga, as we have seen in the introduction, makes the first attempt to connect the GVC and GPN literatures on the ground of the "conceptualization of inter-firm power that is latent in the two literatures, and by sketching an empirical framework to advance basic research on the link between globally networked forms of economic organization and national economic development" (Mahutga, 2014a, p. 158). Following the analytical and empirical work of Wallace, *et al*. (1989), he estimates the positional power of firms as the "network position of resident firms on a large sample of countries in both the garment and transportation equipment industries" (Mahutga, 2014a, p. 167), by employing trade data from UNCOMTRADE in order to construct of World Trade Network, for the respective industries. In other words, he constructs two distinct trade networks, one for the garment and one for the automobile industries, and measures the most influential nodes, as the import share of exports, across counties.

All the approaches discussed above, explicitly conclude that the positional dimension of power in economic networks (national or international) can be conceptualized and expressed by the topological characteristic of the respective networks. For instance, Perrone (1984) and Wallace, et al. (1989), assume that a national economy, based on the Input-Output Tables, can take the form of an economic network, with each node denoting an economic sector and each link expressing the transactions between them. Taking into account the properties of the network structure and particularly the centrality of each node-sector, they are able to estimate their own measurements of positional power for each industry and consequently for the labor that produces in it. Likewise, in the trade network of Mahutga, in which each node represents a country in the garment or automobile industry, and each link a value analogous to the import-to-export ratio of the respective country, the position of each country in the trade-network, measured by its centrality, allows for validation tests regarding the correspondence "with what we know of the role countries play in the two industries from case studies" (Mahutga, 2014a, p. 168).

However, in our view, the attempt made by Mahutga to fill the analytical and conceptual gaps of GCC, GVC and GPN literatures and connect their respective theories of governance structures on the ground of a reconceptualized power concept, is not complete, for two reasons: First of all, Mahutga only goes half-way in the incorporation of network theory's toolkit, since he uses one measure of node centrality, which simply counts the number of out-going and in-coming trade-links. There is an extensive and growing literature on the analysis of the network characteristics of economic systems focusing on more sophisticated statistical and structural measures, which have the ability to reveal the full complexity of the transactions relationships between social actors in an economy (Cerina, Zhu, Chessa, & Riccaboni, 2015; Fagiolo, Reyes, & Schiavo, 2009; Foerster & Choi, 2017; McNerney, Fath, & Silverberg, 2013; Tsekeris, 2017; Xu, Allenby, & Crittenden, 2011). Secondly, he limits the scope of analysis to the trade relations between countries, assuming that country-level measurements simply reflect industry-specific dynamics. In this paper, we continue the research agenda initiated by Mahutga and we try to enhance the GPN literature by introducing more sophisticated measurements of actor centrality in order to capture more complex characteristics of inter-firm and capital-labor relationships, as well as, extend the scope of analysis from cross-country trade relations to cross-sector and cross-country production relations, with the use of global input-output databases. In the next Section we will explore the input-output characteristics of the global economy and how these are related to the notion of node centrality in economic networks.

3. Centrality and Production

Input-Output Analysis (IOA) provides the analytical framework for the exposition and exploration of the interdependent nature of inter-industry relations in an economy. Developed by Wassily Leontief in the 1930s, the fundamental framework of an Input-Output model consists of all the basic information regarding the production (output) and consumption (inputs) of goods and services in a specific geographic unit, for example, a region, a national economy or the whole world. This information composes the *Input-Output Table* (IOT), which distinguish between the economic transactions in an economy between uses and sources (Miller & Blair, 2009).

Each row of an IOT shows the amount of goods and services produced by each sector in an economy and how much of these commodities has been used, either as an input for the production of other goods and services or as final products for consumption. Likewise, each column of an IOT expresses the amount of inputs demanded from all the other sectors of an economy, as well as, the amount of labor and capital used for the production of goods/services. Consequently, we can envision an IOT as the combination of four sub-tables of sub-matrices: the *Intermediate Demand Matrix (Z)*, which consists of the inter-industry transactions between sectors, the *Final Demand Matrix (FD)*; which records the sales of products and services to final markets, breaking the respective amounts into the final demand components of Consumption, Investment, Government Expenses and Net Exports; the *Value-Added Matrix (VA)*, which accounts for the non-industrial inputs of the production process; and the *Gross Output Vector (GO)*, which expresses the total output of the economy, produced and consumed, in gross terms. Schematically, we can express an IOT as in *Figure 1*.

Figure 1 - An Input-Output Table

<table>
<tr><td></td><td>Supply/Demand</td><td>Agriculture</td><td>Mining</td><td>Construction</td><td>Manufacturing</td><td>Transportation</td><td>Services</td><td>Consumption</td><td>Investment</td><td>Government Expenditures</td><td>Net Exports</td><td>Gross Output</td></tr>
<tr><td rowspan="6">Producers</td><td>Agriculture</td><td colspan="6" rowspan="6">Intermediate Demand Matrix (Z)</td><td colspan="4" rowspan="6">Final Demand Matrix (FD)</td><td rowspan="10">Gross Output Matrix (GO)</td></tr>
<tr><td>Mining</td></tr>
<tr><td>Construction</td></tr>
<tr><td>Manufacturing</td></tr>
<tr><td>Transportation</td></tr>
<tr><td>Services</td></tr>
<tr><td rowspan="3">Value-Added</td><td>Wages</td><td colspan="6" rowspan="3">Value-Added Matrix (VA)</td><td colspan="4" rowspan="4"></td></tr>
<tr><td>Taxes</td></tr>
<tr><td>Profits</td></tr>
<tr><td></td><td>Gross Output</td><td colspan="6">Gross Output Matrix (GO)</td></tr>
</table>

Source: Own Illustration

The mathematical relations connecting the constituent sub-matrices are easy to follow and construct the foundations of input-output analysis. Denoting with *n* the number of economic sectors in an economy, *i* the rows of an IOT and *j* the columns, we have that the gross output can be expressed, row-wise, as the sum of industries' products supplied as inputs in the production process of other sectors, as well as, sold in the final market:

$$GO_i = \sum_{j=1}^{n} Z_{ij} + FD_i \tag{1}$$

Equally, we can define gross output, column wise, as the products demanded by sectors for the production process, as well as, the incomes generated for the primary inputs of labor and capital:

$$GO_j = \sum_{i=1}^{n} Z_{ij} + VA_i \tag{2}$$

For example, reading the IOT in Figure 1, row-wise, we can see the how much of the product of *Construction Sector* has been purchased and used in the production processes of all the other buyer-sectors in the hypothesized economy, and also how much of this product has been sold to the final market, either to private consumers (households and firms), to the government or exported to foreign markets. Likewise, if we read the IOT column-wise, we can see how much of inputs, each production process demands from the seller-sectors, and how much of value, the primary inputs have been added to the final product.

From the above discussion becomes evident to conclude that the foundations of input-output analysis provide with the appropriate analytical framework for the exploration of the industrial interdependency in an economy, as well as, the investigation of the complexities of buyer-seller relationships. In order to do that properly, though, we will need to rest upon the analytical tools of network theory, which is the mathematical branch that investigates the abstract notion of *'structure'* found in natural and social interdependent systems is network theory.

As a network we formally define "a collection of points joined together in pairs by lines" (Newman, 2010, p. 1), where each point (also known as a *node* or a *vertex*) represents an object of interest, like for example a social subject or a biological unit or a physical object, while each line (also known as a *link* or an *edge*) expresses the relationship that 'joins together' the respective points. In an economic setting it is obvious to assume that nodes represent economic actors, usually firms and workers, and links express the economic relationships or transactions between them. So, if we want to envision a national economy as an economic network, the nodes of such a network must represent productive units (at the firm, sector or country levels) and the links/edges the financial transactions between them.

Mathematically, a network can be expressed through its *Adjacency Matrix*. An adjacency matrix is defined as the square matrix that takes the value of 1, whenever a link exists that connects node *i* with node *j*, and the value 0, otherwise:

$$A_{ij} = \begin{cases} 1 \; if \; there \; is \; a \; link \; between \; i \; and \; j, \\ 0, otherwise \end{cases} \tag{3}$$

In the case of an economy, though, we are interested not only on the existence of linkages between buyers and sellers, but also on the relative strength of those links and their respective direction. That is why in the analysis of the network characteristics of an economy, we usually take into account the weighted and directed adjacency matrix, each element of which represents the value and direction of value transactions between the sectors of an economy:

$$weighted\ A_{ij} = \begin{cases} w_{ij}\ if\ there\ is\ a\ transfer\ of\ value\ from\ i\ to\ j, \\ 0, otherwise \end{cases} \qquad (4)$$

where, w_{ij} is the weight of the adjacency matrix, representing the exchange relation that transfer an economic value w from sector/node i to sector/node j. Since we are dealing within an economic context, it is evident to establish a conceptual and analytical correspondence between the workings of an adjacency matrix and that of an intermediate demand sub-matrix. Both of them are the mathematical representation of the relationships established between the actors of the system under question and hence we will use the intermediate demand sub-matrix in order to define the adjacency matrix of an economic network.

Additional to the adjacency matrix, which is an analytical tool for network representation, network theory offers a multitude of empirical tools for the analysis of the structural properties of social systems that take the form of a network. One of the most important empirical tools that network theory offers is 'node centrality', which "quantifies how important vertices (or edges) are in a networked system" (Newman, 2010, p. 9). Network centrality is a critical concept in the analysis and understanding of the structural characteristics of a network. Each centrality measure sheds light on "different aspects of the position that a node has, which can be useful when working with information flows, bargaining power, infection transmission, influence and other sorts of important behaviors on a network" (Jackson. 2008, p. 62). Network centrality enhances our understanding of both capital-labor relations in an economy and the positional power that economic actors hold in production networks. We believe that the centrality measures in networks theory applied to IOTs are the straightforward way of identifying the positional power.

For the purposes of our paper we concentrate on two families of centrality measures: the *Degree/Strength* centralities, which focus on number and relative power of the links connecting the nodes/actors in a network and the so-called *Influence* centralities, which underline the relative importance of a node's neighbors (Freeman, 1978; Jackson, 2008; Newman, 2010).

A node's degree centrality is defined as the number of links a node has established with all the other nodes in a network system. In our context, this translates into the number of direct linkages one sector forms with all the sectors in our economy, that is with how many other sectors is conducting business with. This measure is called *Total-Degree* centrality. If we differentiate between the buying and selling directions of the economic transactions in an economy, then we have the *In-Degree* and *Out-Degree* centralities, which count the number of links that represent purchasing and selling transactions, respectively. Denoting as deg_i, the degree centrality of node/sector i, and A_{ij} the intermediate demand sub-matrix acting as the adjacency matrix of the economic network, we have the formal definitions of in-degree, out-degree and total-degree centralities, as follows:

$$deg_i^{in} = \sum_{j=1}^{n} A_{ij} \qquad (5)$$

$$deg_i^{in} = \sum_{j=1}^{n} A_{ij} \tag{6}$$

$$deg_j^{out} = \sum_{i=1}^{n} A_{ij} \tag{7}$$

The above degree centralities measure the number of linkages connecting each pair of nodes in a network. By doing so, they treat the adjacency matrix in a binary way, without taking into account the weights of the matrix that represent the economic value of the transaction relationships between economic sectors. On the contrary, In-Strength, Out-Strength and Total-Strength centralities do take into account the weights and directions of the adjacency matrix, by adding, instead of the number of connections, their respective value.

$$str_i^{in} = \sum_{j=1}^{n} weightedA_{ij} \tag{8}$$

$$str_j^{out} = \sum_{i=1}^{n} A_{ij} \tag{9}$$

$$str_i^{total} = k_i^{in} + k_j^{out} \tag{10}$$

Another family of centrality measures, the influence measures, focus on "the premise that a node's importance is determined by how important its neighbors are" (Jackson, 2008, p.65). The logic behind these measures is simple. They calculate the centrality of node based on the number or strength of the linkages connecting that node with the whole network and then they add a component that reflects the relative importance of the neighbors of the initial node. The most commonly used influence measure is *Eigenvector* centrality. Assuming an adjacency matrix and a node/sector *i*, in an economy, we define eigenvector centrality as:

$$x_i = \sum_j A_{ij} x_j \tag{11}$$

where, x_i is the eigenvector centrality of node i, x_j the sum of centralities of node j, and A, is the adjacency matrix. Thus, node i, will gain more weight in terms of centrality, if it is connected to more connected nodes, which themselves have higher centralities. In matrix notation, the eigenvector centrality takes the form $\boldsymbol{x'} = \boldsymbol{Ax}$, where $\boldsymbol{x}$ is a vector with elements x_i and $\boldsymbol{A}$ is the adjacency matrix in a matrix form. When eigenvector centrality is expressed in this form, we are dealing with a usual eigenvalue-eigenvector problem with many different eigenvectors corresponding to different eigenvalues. However, since the adjacency matrix is by definition a non-negative matrix, the *Perron-Frobenius Theorem* applies and guarantees that the maximum eigenvalue corresponds to a unique and positive eigenvector, which results to the desired eigenvector centrality measure, first proposed by Bonacich (Bonacich, 1987).

Another variant of the influence measures is *PageRank* centrality, which takes into account the strength of the neighbors of node i, normalized by their out-degree, adding a β, usually equal to 1, in order to account for nodes having zero in-degree. The formal definition of the PageRank centrality, then becomes:

$$x_i = \sum\nolimits_j A_{ij} \frac{x_j}{deg_j^{out}} + \beta \tag{12}$$

where, x_i is PageRank centrality of node i, x_j the sum of centralities of node j, *A* the adjacency matrix, deg_j^{out}, the out-degree centrality of node j.

The last centrality measure that we will take into account is Kleinberg's *Authorities* and *Hubs* centralities. Kleinberg thought of the problem of measuring node centralities in terms of the directional characteristics of the links in a network. For that reason, he distinguished between authority and hub centralities, which measure how much incoming links originate from nodes having many outgoing links (suppliers) and how much outgoing links originate from nodes having many ingoing links (buyers), respectively (Kleinberg, 1999; Tsekeris, 2017). Formally, we define authority centrality xi and hubs centrality yi, with α and β being some constants, as:

$$x_i = a \sum\nolimits_j A_{ij} y_j \tag{13}$$

$$y_i = a \sum\nolimits_j A_{ij} x_j \tag{14}$$

A meaningful question on economic networks is: Which are the most central, the most important nodes/sectors in an economy? For answering that, we have to empirically apply the aforementioned centrality measures on a real economic network configuration, constructed by utilizing two different input-output databases and then check whether they are correlated with the shares of each sector's profits to total value-added.

4. Empirical Results

As we have underlined above, the scope of the analysis of an input-output table can be changed accordingly. In this paper we focus on the global dimension of input-output analysis and thus we will use databases that contain transactions data for the global economy, representing the outputs and inputs relationships of country-specific industrial sectors. In particular, we make use of two different global input-output databases, one from the *World Input-Output Database* (Timmer et al., 2015) and the other from the *Organization of Economic Co-operation and Development (OECD) Inter-Country Input-Output (ICIO)* Tables. Both databases come into two industrial classifications versions, ISIC rev.3 and ISIC rev.4, for similar years, but with different numbers of countries and economic sectors (*see* Appendix A for details).

The first version of the WIOD (2013 release, 1995-2011) consists of input-output data for 41 countries including a proxy for the Rest of the World, at the ISIC rev.3 industrial classification system, for 35 economic sectors, while the second version (2016 release, 2000-2014) contains data for 44 countries (plus Rest of the World), at the ISIC rev.4 industrial classification system, for 56 economic sectors. On the other hand, the first version (1995-2011) of the OECD-ICIO Tables, consist of 64 countries (plus Rest of the World) and 34 sectors, while, the second version (2005-2015) 65 countries and 36 economic sectors. The use of global IOTs provides some considerable analytical strength, especially for the conduct of a global analysis, since: a) it provides data for the global production structure, b) overcomes data unavailability problems found in National IOTs, and, c) allows for a global production network (sector- and country-specific) analysis.

The structural composition of the global IOTs follow the usual structure of the national IOTs, with some important additions. Schematically, a global IOT looks like the one in Figure 2, with the four distinct, but interconnected sub-matrices of Intermediate Demand, Final Demand, Value-Added and Total Output. For the purposes of our paper we focus on the intermediate demand matrix, which presents the productive interdependent relationships developed among countries and sectors in a world economy will be used for the construction of the respective adjacency matrices.

Figure 2 - Hypothesized two-economy, two-sector, Global Input-Output Table

Supply/Demand		Economy 1		Economy 2		Final Demand		Total Output
		Ind. 1	*Ind. 2*	*Ind. 1*	*Ind. 2*	*Economy 1*	*Economy 2*	
Economy 1	*Ind. 1*	**Intermediate Demand**				**Final Demand**		
	Ind. 2							
Economy 2	*Ind. 1*							
	Ind. 2							
Value Added	*Wages*	**Value-Added**						
	Taxes							
	Profits							
Total Output								

Source: Own Illustration

For the calculation of the centrality measures we will need to have the appropriate adjacency matrix. Since we have four sequences of input-output tables, we will construct four adjacency matrices and then calculate the respective centrality measures. According to the literature of economic networks, the statistical distributions of centrality measures are far from normal and usually follow some type of power-law or fat-tailed distribution[5]. We present all the Empirical Cumulative Distribution Function plots for all the databases for three indicative year in *Appendix B*.

Regarding the calculation of the Profit-Shares we take into account the auxiliary variable sets that both databases provide for the value-added components. We define the profit-share of each sector-economy, as the ratio of *Gross Operating Surplus* (GOS) to *Total Annual Value-Added*. However, due to the fact that each database provides different variables of value-added components, we had to recompute the profit component. In particular, for the WIOD, we estimate the GOS as the difference between *Gross Value Added* and *Employees Compensation*. Hopefully, OECD-ICIO database provides data for GOS and thus we directly constructed our profit-share estimates. The distribution of the profit-shares exhibits the same fat-tail characteristics as the distributions of the centrality measures (*see* Appendix B).

[5] A power-law distribution takes the form of $p(x) = C\,x^{-a}$.

In order to investigate the relationship between the various measures of node centralities, which express the positional power of country-specific industries in the context of the global economic network, and their respective profit-shares, we calculate three types of correlation coefficients, the Pearson's linear correlation *r*, and the rank correlations of Spearman (*ρ*), and Kendall (*τ*). In *Table 1*, we present the correlation coefficients for four different years, for all the databases. The full set of correlation coefficients and corresponding scatterplots are presented in Appendix B. Since the distributions of both variables (profit-shares and centralities) seem to follow some type of fat-tail distribution, it is evident to log-transform the data.

Table 1 - Correlations of Centrality measures and Profit-Shares, log-transformed

	WIOD (1995)			WIOD (2000)			OECD (2002)			OECD (2015)		
	r	**ρ**	**τ**	**r**	**ρ**	**τ**	**r**	**ρ**	**τ**	**r**	**ρ**	**τ**
Total-Degree	-0.01	0.14	0.10	-0.04	0.15	0.11	0.59	0.58	0.41	0.14	0.41	0.28
In-Degree	0.28	0.28	0.20	0.24	0.25	0.17	0.70	0.71	0.53	0.35	0.36	0.25
Out-Degree	-0.05	0.03	0.02	-0.07	-0.03	-0.02	0.28	0.45	0.31	0.03	0.17	0.13
Total-Strength	0.89	0.89	0.71	0.92	0.92	0.76	0.90	0.89	0.71	0.92	0.91	0.75
In-Strength	0.88	0.87	0.69	0.91	0.91	0.74	0.88	0.87	0.69	0.92	0.90	0.74
Out-Strength	0.85	0.86	0.68	0.89	0.90	0.73	0.85	0.86	0.68	0.87	0.86	0.69
Eigenvector	0.79	0.76	0.57	0.84	0.85	0.86	0.82	0.82	0.63	0.85	0.85	0.66
PageRank	0.70	0.72	0.53	0.71	0.72	0.53	0.74	0.75	0.56	0.79	0.81	0.62
Authority	0.78	0.75	0.56	0.84	0.85	0.66	0.83	0.83	0.64	0.85	0.85	0.66
Hubs	0.58	0.56	0.40	0.73	0.72	0.53	0.63	0.62	0.44	0.70	0.67	0.49

From Table 1 we can observe that all centrality measures, for both WIOD and OECD economic networks, exhibit a significant and positive linear correlation with Profit-Shares, except for Degree centralities. In particular, for the Degree (Total, In and Out) centralities, the only database that shows a moderately high linear correlation, is the OECD IOT for 2002. All the others exhibit low correlations and even negative in the case of WIOD for 1995 and 2000. On the contrary, the rank correlations of degree centralities and profit-share are moderately positive for OECD 2002 and 2015. For the 'influence centralities' of eigenvector, PageRank and Authority-Hubs and Total/In/Out Strength centralities, we observe high positive correlations with profit-shares, for both linear and rank correlations measures.

The above results allow us to conclude that the positional power of sectors in a global economic network, measured by the notion of node centrality, have the analytical and empirical force to relate with the observed pattern of functional income distribution and especially with the share of profits on value-added. Having said that, we believe that there is space for the utilization of a network theorization of macroeconomic phenomena and structures, on the grounds of exploring the special 'network effects' that characterize the complex and interdependent nature of the global economy.

5. Conclusions

In this paper we have argued that the structural characteristics of global economic networks allow for an alternative understanding of the power relations between capital and labor, as expressed by the functional income distribution patterns. In particular, we combined insights from the literatures of Labor Sociology, Economic Geography and Network Theory, regarding the relationship between the notion of positionality and power, in order to conceptually and empirically express the structural advantages of economic sectors, due to their position in a global inter-dependent economy.

Building on the input-output analysis, we have found that the observed profit-shares of country-specific industries exhibit positive correlations with their positional power measures by the node centralities of the respective economic networks. This result can be utilized in the future for the enhancement of macroeconomic econometric models that analyze the effects of globalization and spatial disintegration of production on functional income distribution.

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Appendix 1: Details of the Global Input-Output Databases

In this paper we use two Global Input-Output Databases, both of them coming into two versions with different country, sectors and time coverages. The first database is the World Input-Output Database, with two versions, the first for 1995-2011 time period and the second for 2000-2015 time period. The 1995-2011 WIOD consists of 41 countries, along with a proxy for the Rest of the World (ROW) and covers 35 economic sectors at the International Standard Industrial Classification (ISIC) revision 3 system. The 2000-2015 WIOD consists of 44 countries (plus ROW) and covers 56 economic sectors at the ISIC rev.4 system. The 1995-2011 OECD-ICIO database consists of 64 countries (plus ROW) and 34 ISIC rev.3 economic sectors, while the 2005-2015 OECD-ICIO database of 65 (plus ROW) and 36 ISIC rev.4 economic sectors. For details regarding the calculations of the Profit-Shares, see Appendix 2. The data for those calculations has been obtained by the complementary datasets for value-added components, found in the WIOD Socio-Economic Matrices and the OECD Input-Output Tables related data on Value-Added Components.

List of 1995-2011 WIOD Economic Sectors (ISIC rev3)

1. Agriculture, Hunting, Forestry and Fishing
2. Mining and Quarrying
3. Food, Beverages and Tobacco
4. Textiles and Textile Products
5. Leather, Leather and Footwear
6. Wood and Products of Wood and Cork
7. Pulp, Paper, Paper, Printing and Publishing
8. Coke, Refined Petroleum and Nuclear Fuel
9. Chemicals and Chemical Products
10. Rubber and Plastics
11. Other, Non-Metallic Mineral
12. Basic Metals and Fabricated Metal
13. Machinery, Nec
14. Electrical and Optical Equipment
15. Transport Equipment

16. Manufacturing, Nec; Recycling
17. Electricity, Gas and Water Supply
18. Construction
19. Sale, Maintenance and Repair of Motor Vehicles and Motorcycles; Retail Sale of Fuel
20. Wholesale Trade and Commission Trade, Except of Motor Vehicles and Motorcycles
21. Retail Trade, Except of Motor Vehicles and Motorcycles; Repair of Household Goods
22. Hotels and Restaurants
23. Inland Transport
24. Water Transport
25. Air Transport
26. Other Supporting and Auxiliary Transport Activities; Activities of Travel Agencies
27. Post and Telecommunications
28. Financial Intermediation
29. Real Estate Activities
30. Renting of M&Eq and Other Business Activities
31. Public Admin and Defence; Compulsory Social Security
32. Education
33. Health and Social Work
34. Other Community, Social and Personal Services
35. Private Households with Employed Persons

List of 1995-2011 WIOD Countries

Austria	Belgium	Cyprus	Estonia	Finland
France	Germany	Greece	Ireland	Italy
Luxembourg	Malta	Netherlands	Portugal	Slovakia
Slovenia	Spain	Bulgaria	Czech Rep	Denmark
Hungary	Latvia	Lithuania	Poland	Romania
Sweden	UK	Canada	Mexico	USA
China	Japan	South Korea	Taiwan	Australia
Brazil	India	Indonesia	Russia	Turkey
Rest of World				

List of 2000-2014 WIOD Economic Sectors (ISIC rev4)

1. Crop and animal production, hunting and related service activities
2. Forestry and logging
3. Fishing and aquaculture
4. Mining and quarrying
5. Manufacture of food products, beverages and tobacco products
6. Manufacture of textiles, wearing apparel and leather products
7. Manufacture of textiles, wearing apparel and leather products
8. Manufacture of wood and of products of wood and cork, except furniture; manufacture of articles of straw and plaiting materials
9. Manufacture of paper and paper products
10. Printing and reproduction of recorded media
11. Manufacture of coke and refined petroleum products
12. Manufacture of chemicals and chemical products
13. Manufacture of basic pharmaceutical products and pharmaceutical preparations
14. Manufacture of rubber and plastic products

15. Manufacture of other non-metallic mineral products
16. Manufacture of basic metals
17. Manufacture of fabricated metal products, except machinery and equipment
18. Manufacture of computer, electronic and optical products
19. Manufacture of electrical equipment
20. Manufacture of machinery and equipment n.e.c.
21. Manufacture of motor vehicles, trailers and semi-trailers
22. Manufacture of other transport equipment
23. Manufacture of furniture; other manufacturing
24. Repair and installation of machinery and equipment
25. Electricity, gas, steam and air conditioning supply
26. Water collection, treatment and supply
27. Sewerage; waste collection, treatment and disposal activities; materials recovery; remediation activities and other waste management services
28. Construction
29. Wholesale and retail trade and repair of motor vehicles and motorcycles
30. Wholesale trade, except of motor vehicles and motorcycles
31. Retail trade, except of motor vehicles and motorcycles
32. Land transport and transport via pipelines
33. Water transport
34. Air transport
35. Warehousing and support activities for transportation
36. Postal and courier activities
37. Accommodation and food service activities
38. Publishing activities
39. Motion picture, video and television programme production, sound recording and music publishing activities; programming and broadcasting activities
40. Telecommunications
41. Computer programming, consultancy and related activities; information service activities
42. Financial service activities, except insurance and pension funding
43. Insurance, reinsurance and pension funding, except compulsory social security
44. Activities auxiliary to financial services and insurance activities
45. Real estate activities
46. Legal and accounting activities; activities of head offices; management consultancy activities
47. Architectural and engineering activities; technical testing and analysis
48. Scientific research and development
49. Advertising and market research
50. Other professional, scientific and technical activities; veterinary activities
51. Administrative and support service activities
52. Public administration and defense; compulsory social security
53. Education
54. Human health and social work activities
55. Other service activities
56. Activities of households as employers; undifferentiated goods- and services-producing activities of households for own use

List of 2000-2014 WIOD Countries

Austria	Belgium	Cyprus	Estonia	Finland
France	Germany	Greece	Ireland	Italy
Luxembourg	Malta	Netherlands	Portugal	Slovakia
Slovenia	Spain	Bulgaria	Czech Rep	Denmark
Hungary	Latvia	Lithuania	Poland	Romania
Sweden	UK	Canada	Mexico	USA
China	Japan	South Korea	Taiwan	Australia
Brazil	India	Indonesia	Russia	Turkey
Croatia	Switzerland	Norway	Rest of the World	

List of 1995-2011 OECD-ICIO Economic Sectors (ISIC rev3)

1. Agriculture, hunting, forestry and fishing
2. Mining and quarrying
3. Food products, beverages and tobacco
4. Textiles, textile products, leather and footwear
5. Wood and products of wood and cork
6. Pulp, paper, paper products, printing and publishing
7. Coke, refined petroleum products and nuclear fuel
8. Chemicals and chemical products
9. Rubber and plastics products
10. Other non-metallic mineral products
11. Basic metals
12. Fabricated metal products
13. Machinery and equipment, nec
14. Computer, Electronic and optical equipment
15. Electrical machinery and apparatus, nec
16. Motor vehicles, trailers and semi-trailers
17. Other transport equipment
18. Manufacturing nec; recycling
19. Electricity, gas and water supply
20. Construction
21. Wholesale and retail trade; repairs
22. Hotels and restaurants
23. Transport and storage
24. Post and telecommunications
25. Financial intermediation
26. Real estate activities
27. Renting of machinery and equipment
28. Computer and related activities
29. R&D and other business activities
30. Public admin. and defence; compulsory social security
31. Education
32. Health and social work
33. Other community, social and personal services
34. Private households with employed persons

List of 1995-2011 OECD-ICIO Countries

Australia	Austria	Belgium	Canada	Chile
Czech Republic	Denmark	Estonia	Finland	France
Germany	Greece	Hungary	Iceland	Ireland
Israel	Italy	Japan	Korea	Latvia
Luxembourg	Mexico	Netherlands	New Zealand	Norway
Poland	Portugal	Slovakia	Slovenia	Spain
Sweden	Switzerland	Turkey	United Kingdom	United States
Argentina	Brazil	Brunei	Bulgaria	Cambodia
China	Chinese Taipei	Colombia	Costa Rica	Croatia
Cyprus	Hong Kong	India	Indonesia	Lithuania
Malaysia	Malta	Morocco	Peru	Philippines
Romania	Russia	Saudi Arabia	Singapore	South Africa
Thailand	Tunisia	Viet Nam	Rest of the world	

List of 2005-2015 OECD-ICIO Economic Sectors (ISIC rev4)

1. Agriculture, forestry and fishing
2. Mining and extraction of energy producing products
3. Mining and quarrying of non-energy producing products
4. Mining support service activities
5. Food products, beverages and tobacco
6. Textiles, wearing apparel, leather and related products
7. Wood and products of wood and cork
8. Paper products and printing
9. Coke and refined petroleum products
10. Chemicals and pharmaceutical products
11. Rubber and plastic products
12. Other non-metallic mineral products
13. Basic metals
14. Fabricated metal products
15. Computer, electronic and optical products
16. Electrical equipment
17. Machinery and equipment, nec
18. Motor vehicles, trailers and semi-trailers
19. Other transport equipment
20. Other manufacturing; repair and installation of machinery and equipment
21. Electricity, gas, water supply, sewerage, waste and remediation services
22. Construction
23. Wholesale and retail trade; repair of motor vehicles
24. Transportation and storage
25. Accommodation and food services
26. Publishing, audiovisual and broadcasting activities
27. Telecommunications
28. IT and other information services
29. Financial and insurance activities
30. Real estate activities
31. Other business sector services
32. Public admin. and defense; compulsory social security

33. Education
34. Human health and social work
35. Arts, entertainment, recreation and other service activities
36. Private households with employed persons

List of 2005-2015 OECD-ICIO Countries

Australia	Austria	Belgium	Canada	Chile
Czech Republic	Denmark	Estonia	Finland	France
Germany	Greece	Hungary	Iceland	Ireland
Israel	Italy	Japan	Korea	Latvia
Lithuania	Luxembourg	Mexico	Netherlands	New Zealand
Norway	Poland	Portugal	Slovakia	Slovenia
Spain	Sweden	Switzerland	Turkey	United Kingdom
United States	Mexico	Viet Nam	Argentina	Brazil
Brunei	Bulgaria	Cambodia	China	Colombia
Costa Rica	Croatia	Cyprus	India	Indonesia
Hong Kong	Kazakhstan	Malaysia	Malta	Morocco
Peru	Philippines	Romania	Russia	Saudi Arabia
Singapore	South Africa	Chinese Taipei	Thailand	Tunisia
	Rest of the World			

Appendix B: Distributions of Centralities and Scatterplots (Profit-Shares ~ Centralities) for WIOD and OECD databases

Figure 3 - Total/In/Out Degree CDF plots for WIOD, 1995-2011

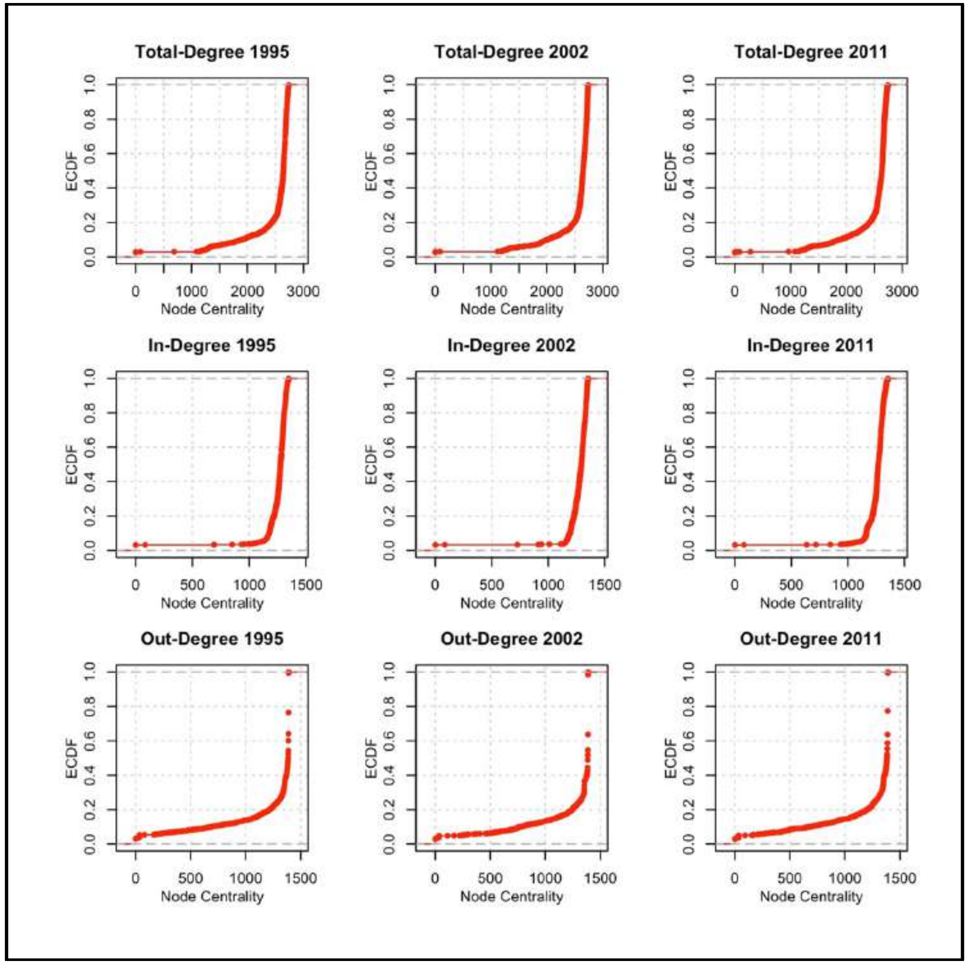

Figure 4 - Total/In/Out Strength CDF plots for WIOD, 1995-2011

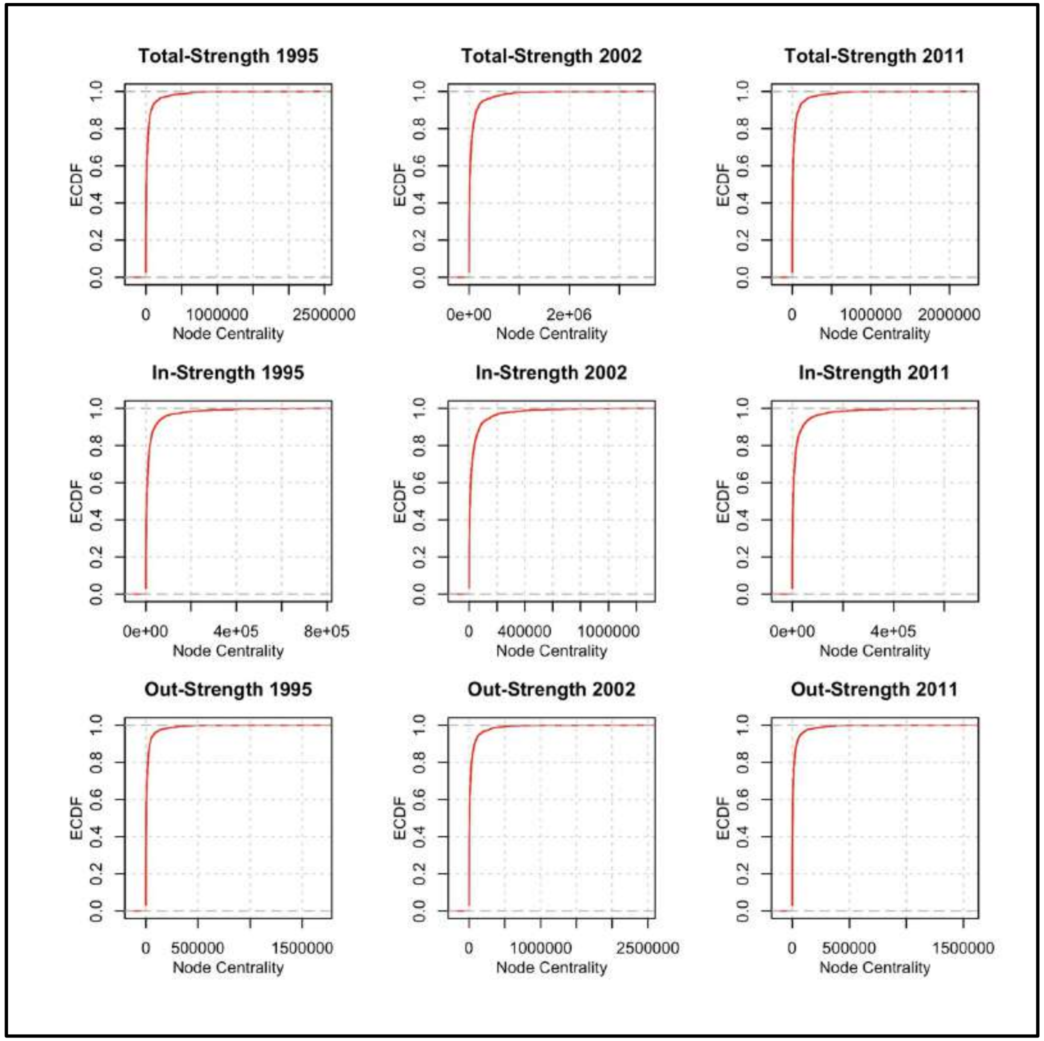

Figure 5 – Eigenvector, PageRank, Kleinberg's CDF plots for WIOD, 1995-2011

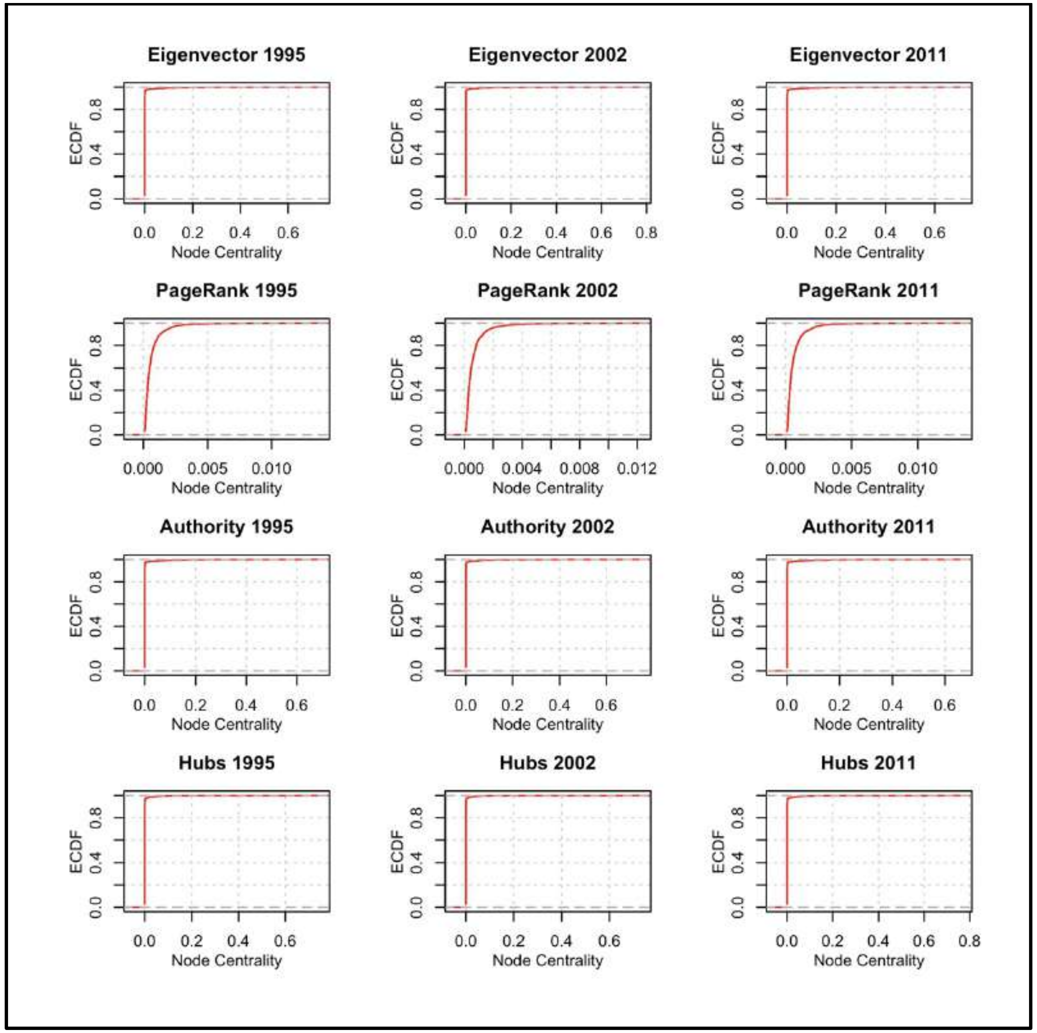

Figure 6 - Total/In/Out Degree CDF plots for WIOD, 2000-2014

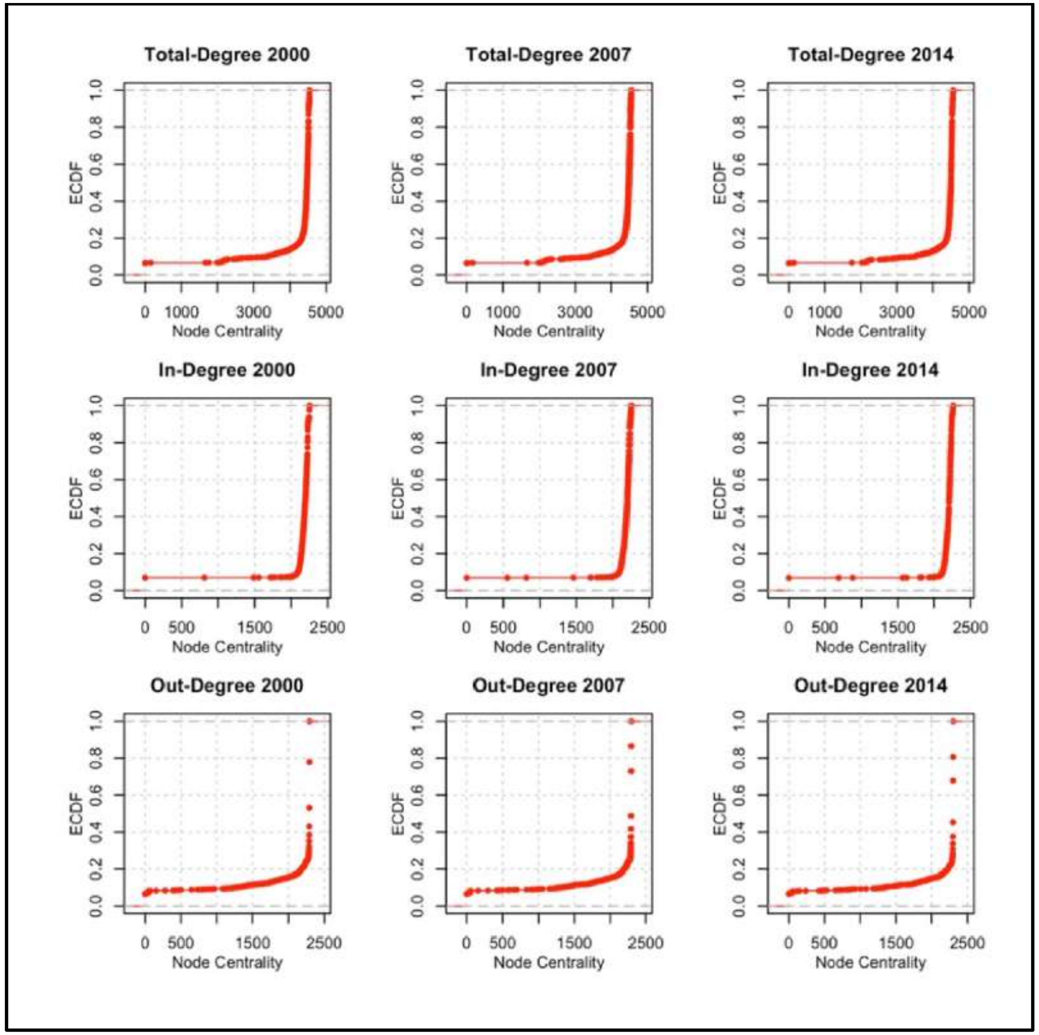

Figure 7 - Total/In/Out Strength CDF plots for WIOD, 2000-2014

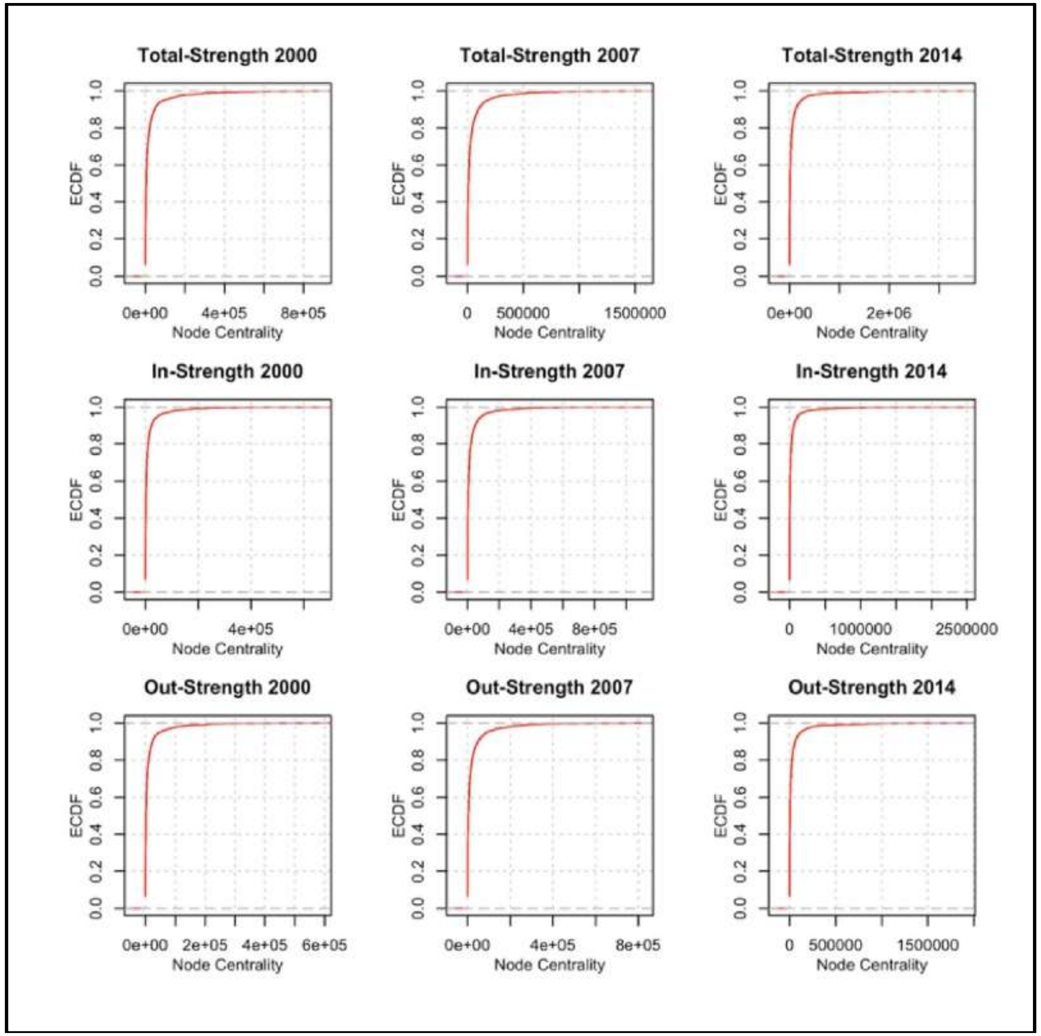

Figure 8 - Eigenvector, PageRank, Kleinberg's CDF plots for WIOD, 2000-2014

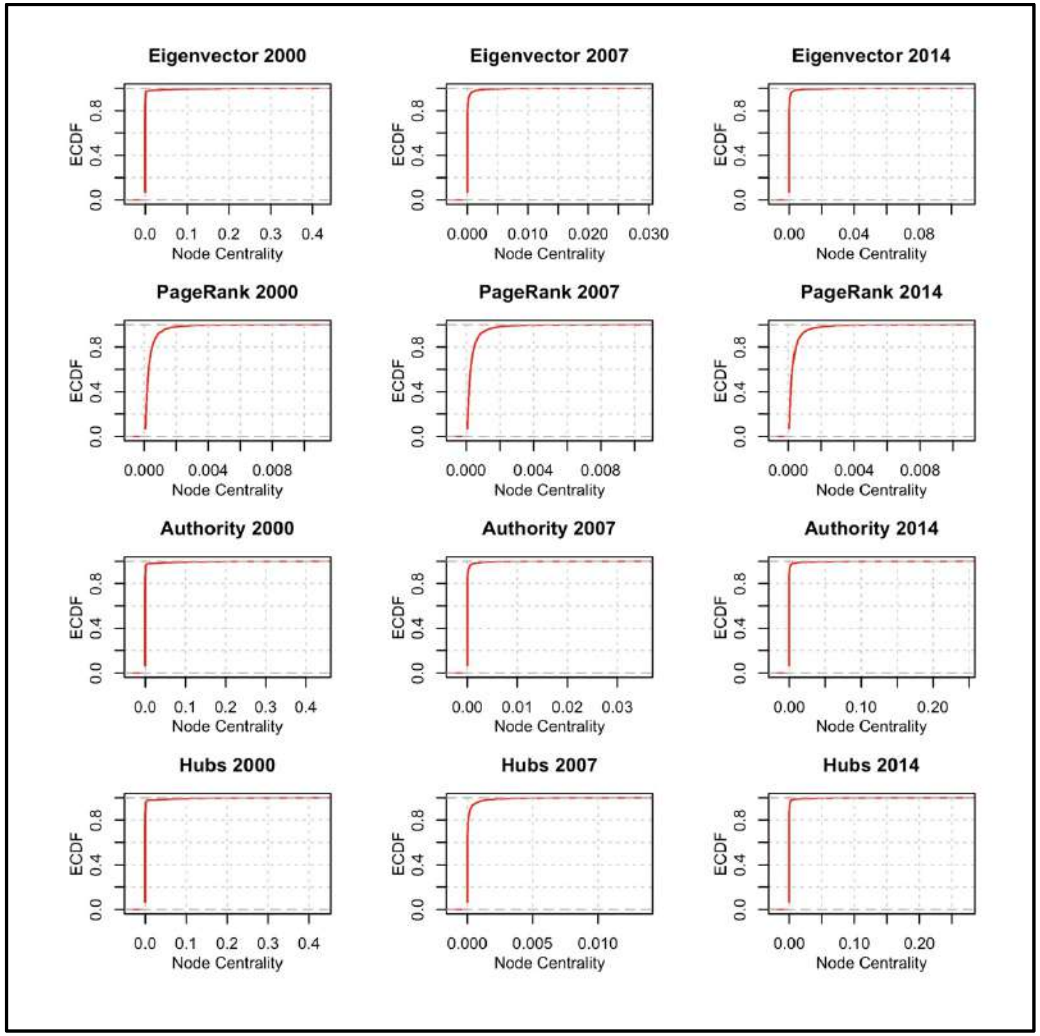

Figure 9 - Total/In/Out Degree CDF plots for OECD, 1995-2011

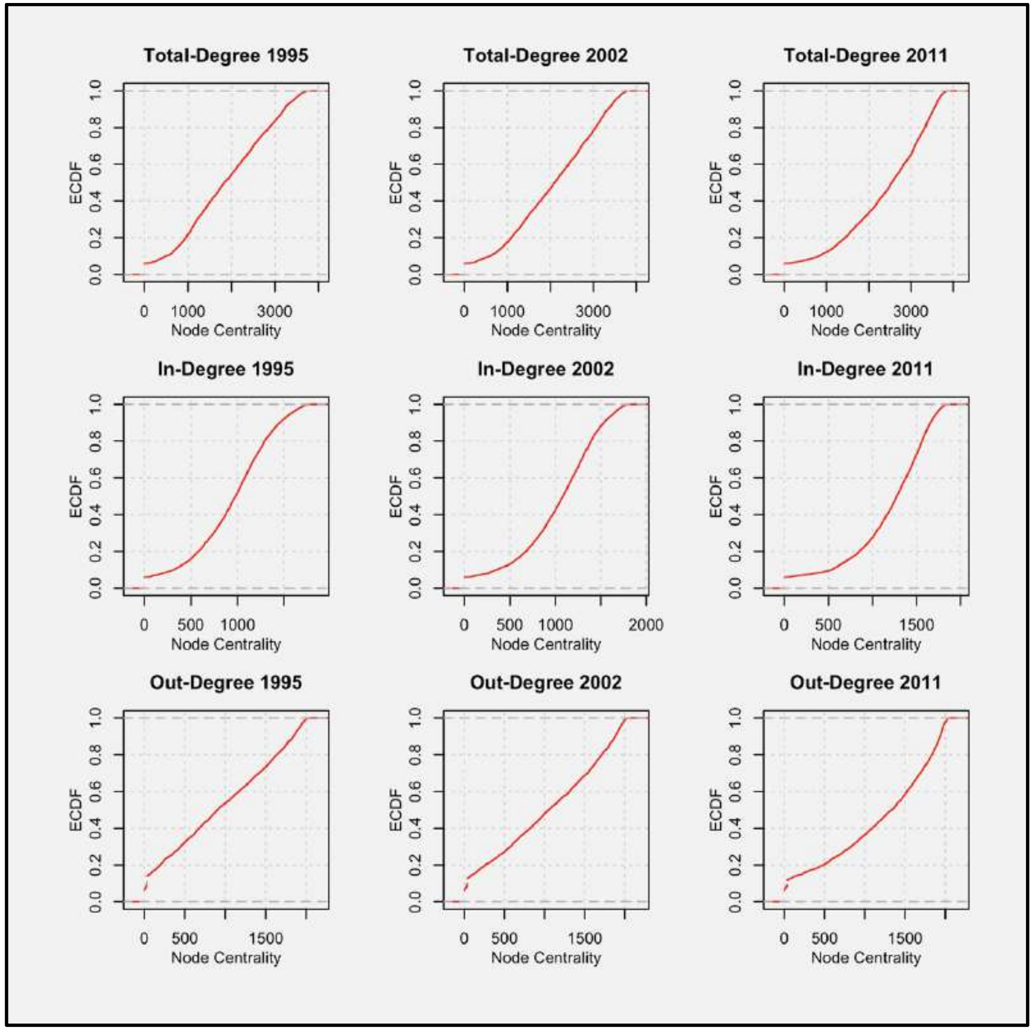

Figure 10 - Total/In/Out Strength CDF plots for OECD, 1995-2011

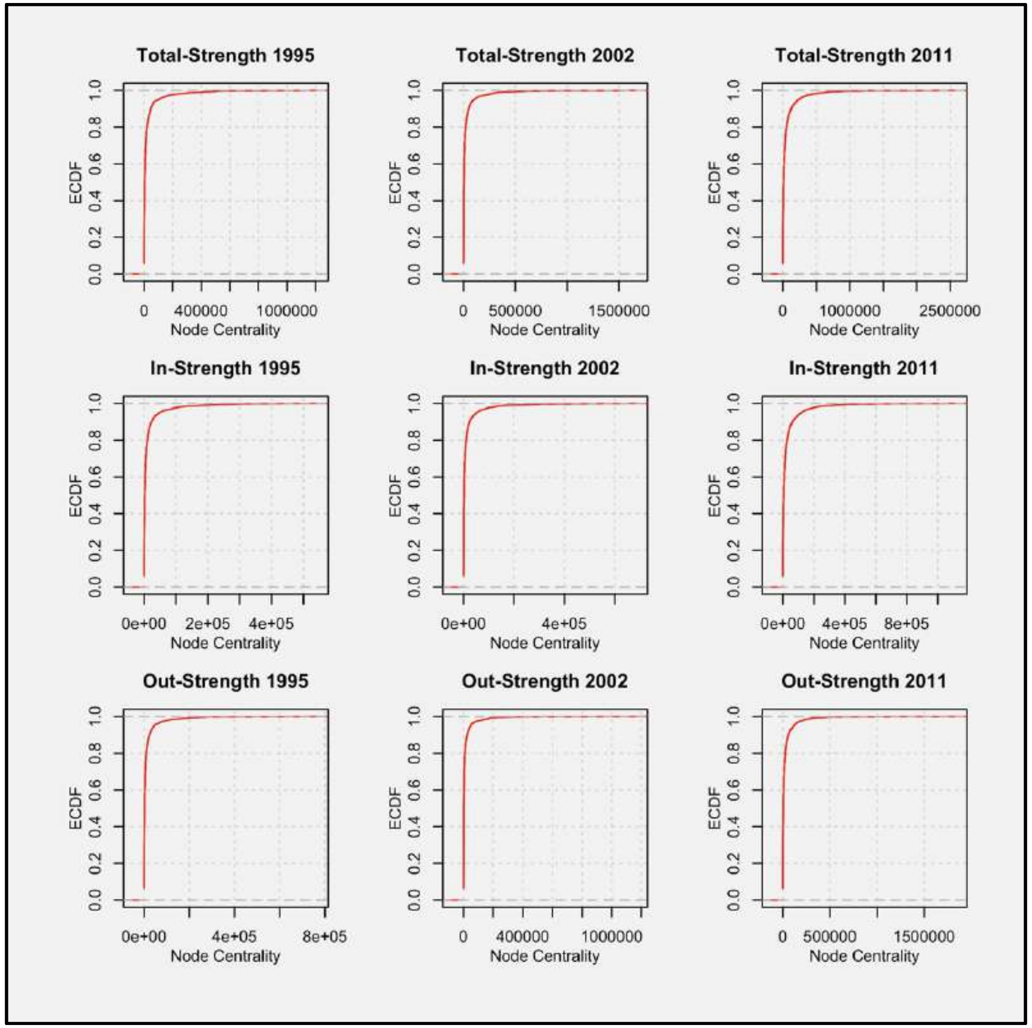

Figure 11 - Eigenvector, PageRank, Kleinberg's CDF plots for OECD, 1995-2011

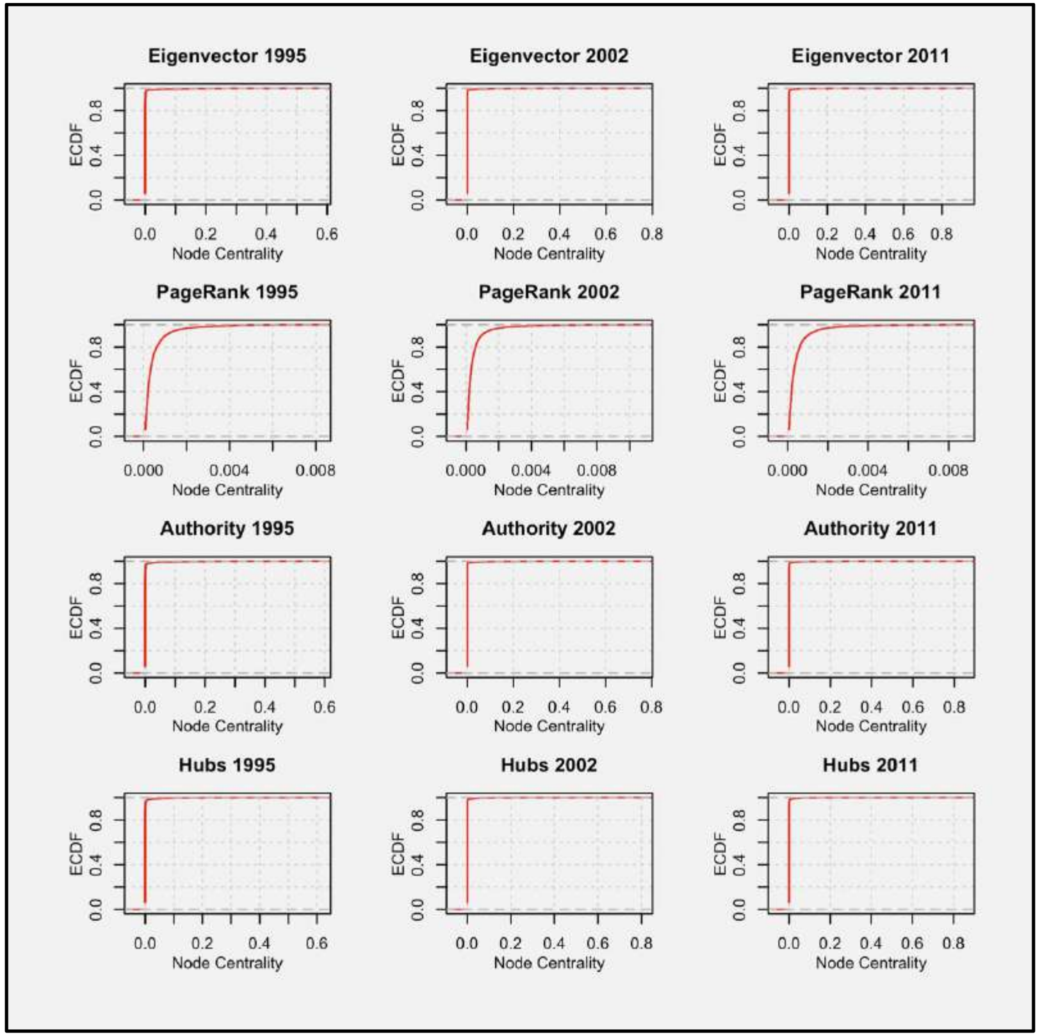

Figure 12 - Total/In/Out Degree CDF plots for OECD, 2005-2015

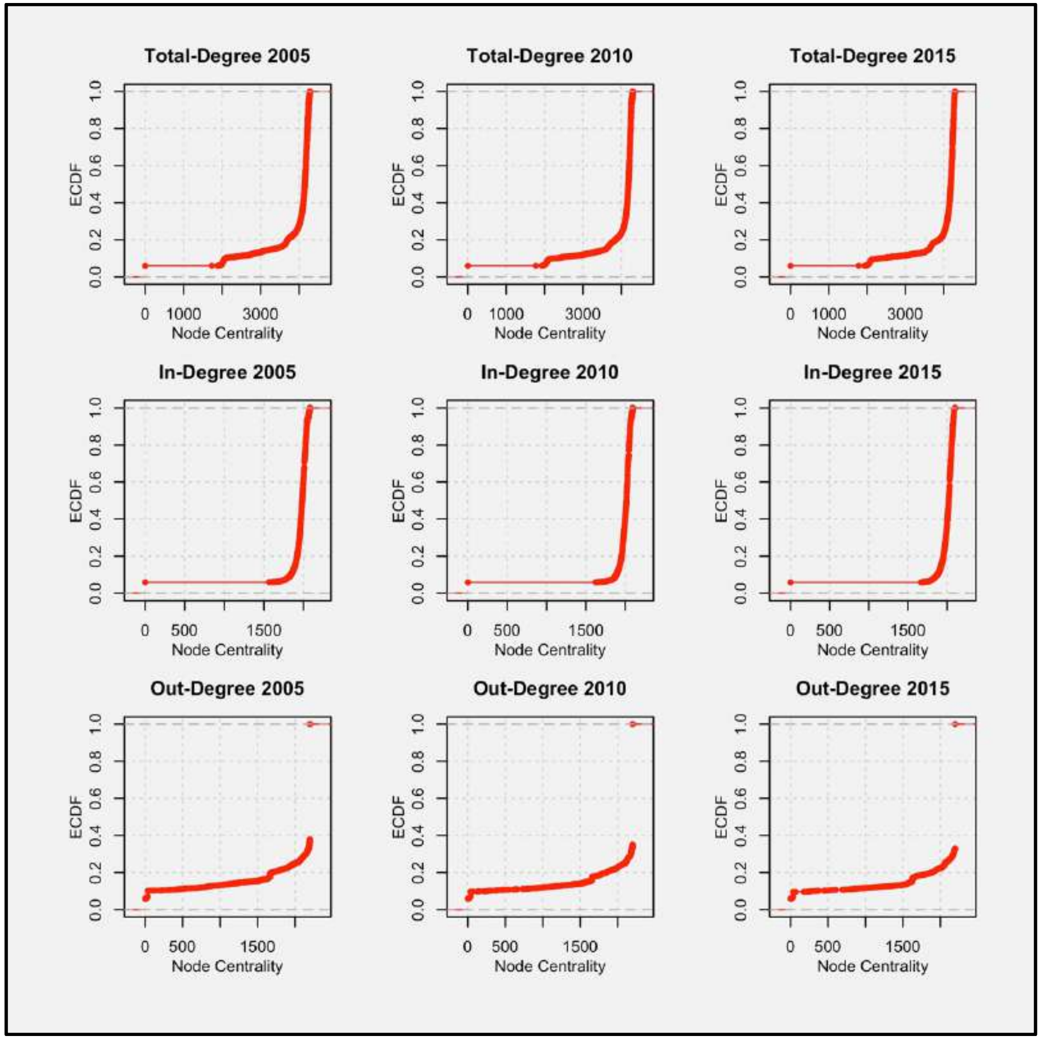

Figure 13 - Total/In/Out Strength CDF plots for OECD, 2005-2015

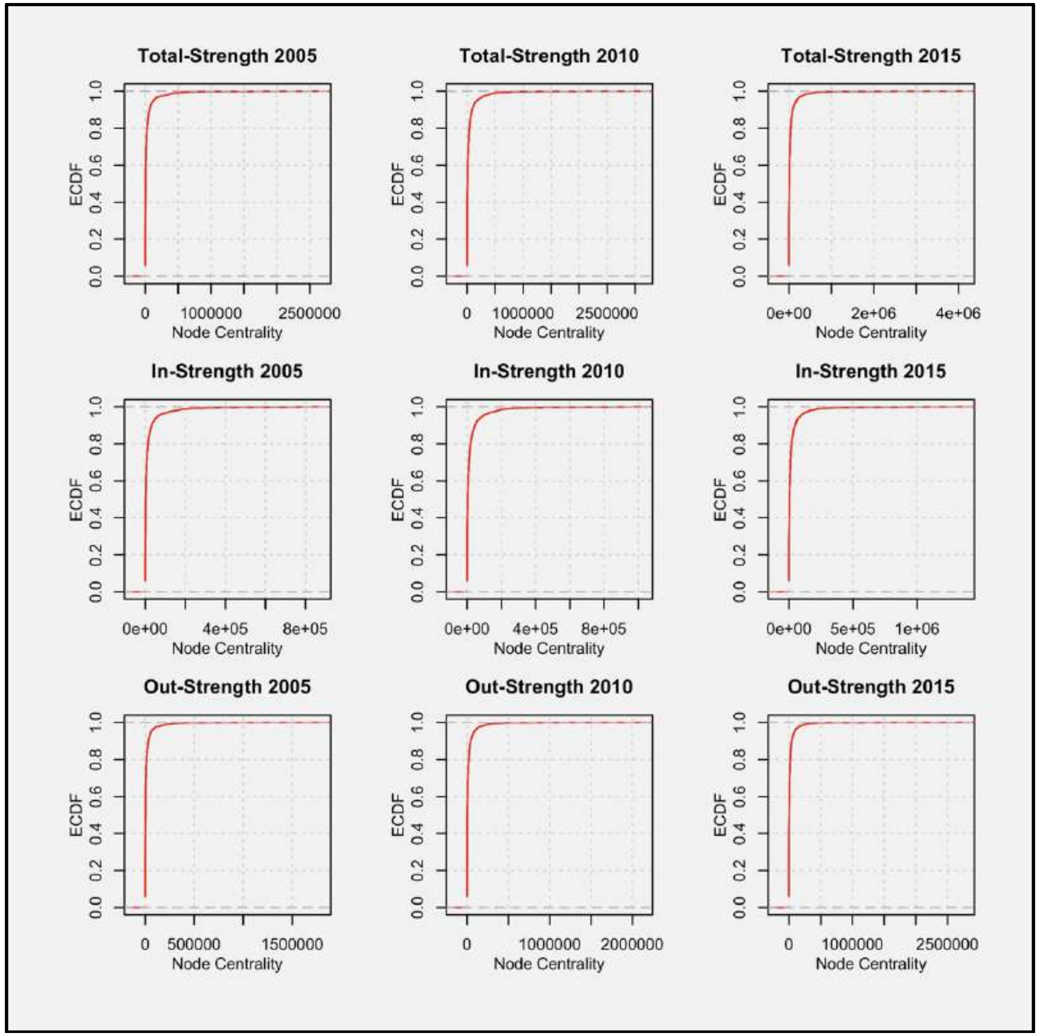

Figure 14 - Eigenvector, PageRank, Kleinberg's CDF plots for OECD, 2005-2015

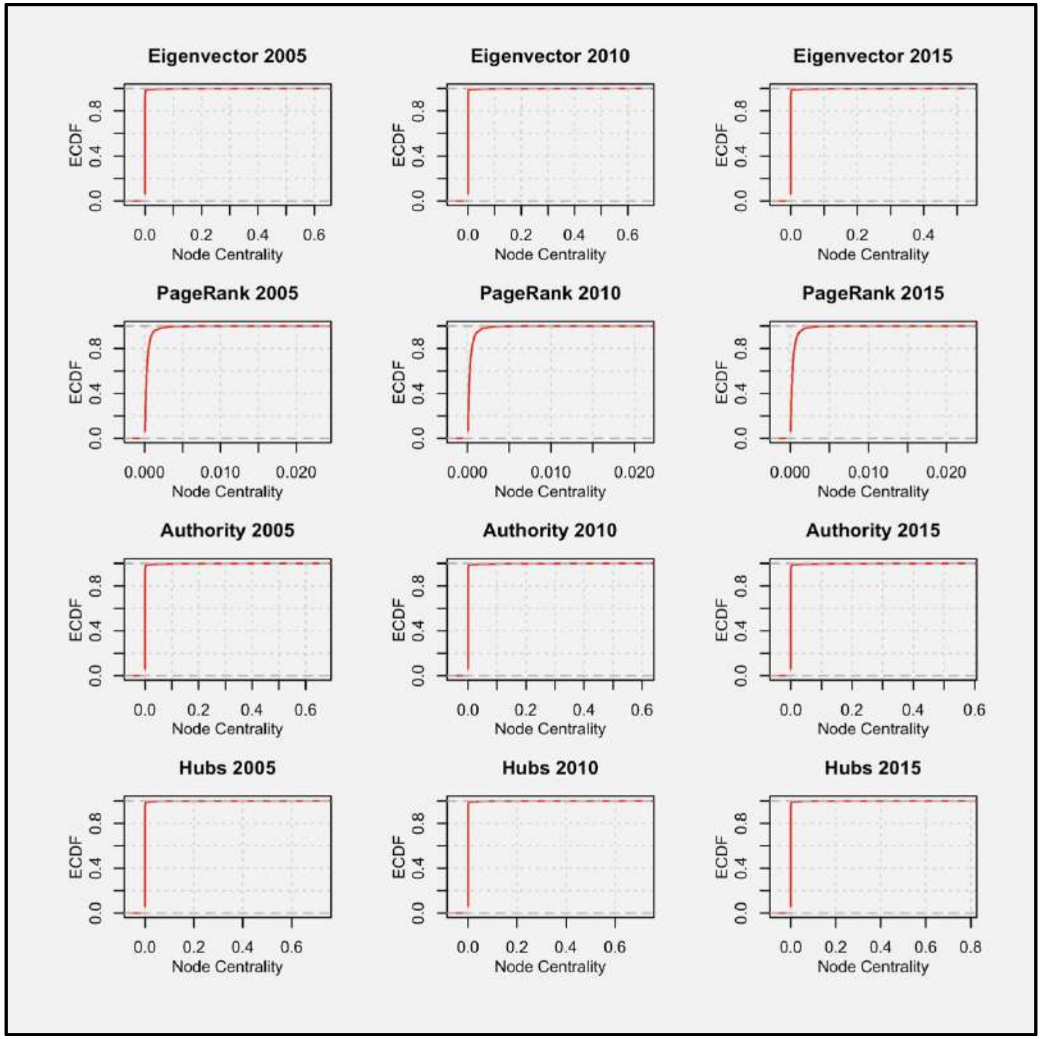

Figure 15 - Scatterplots of Profit-Shares and Centralities. WIOD (1995)

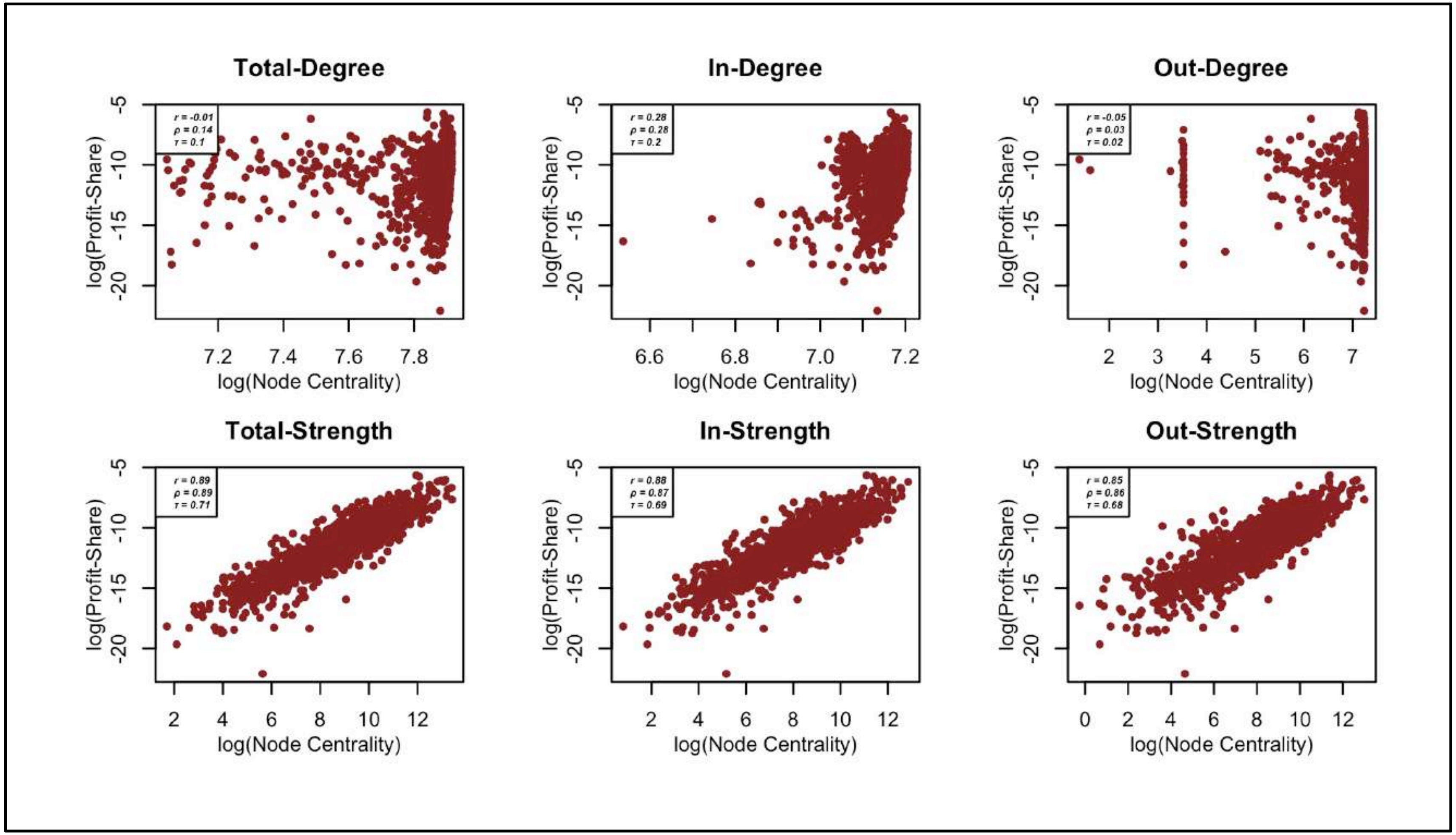

Figure 16 - Scatterplots of Profit-Shares and Centralities. WIOD (2002)

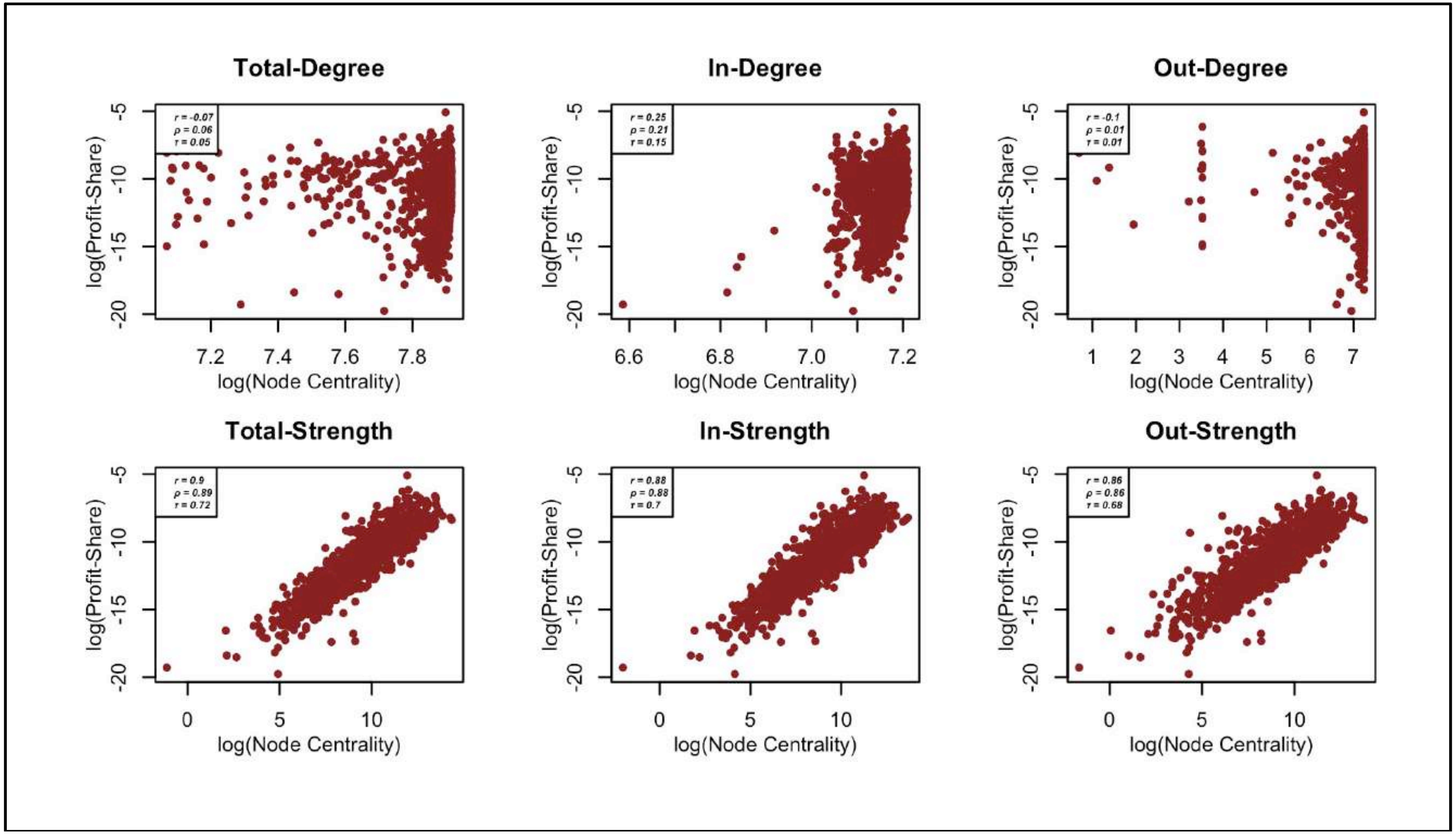

Figure 17 - Scatterplots of Profit-Shares and Centralities. WIOD 2011)

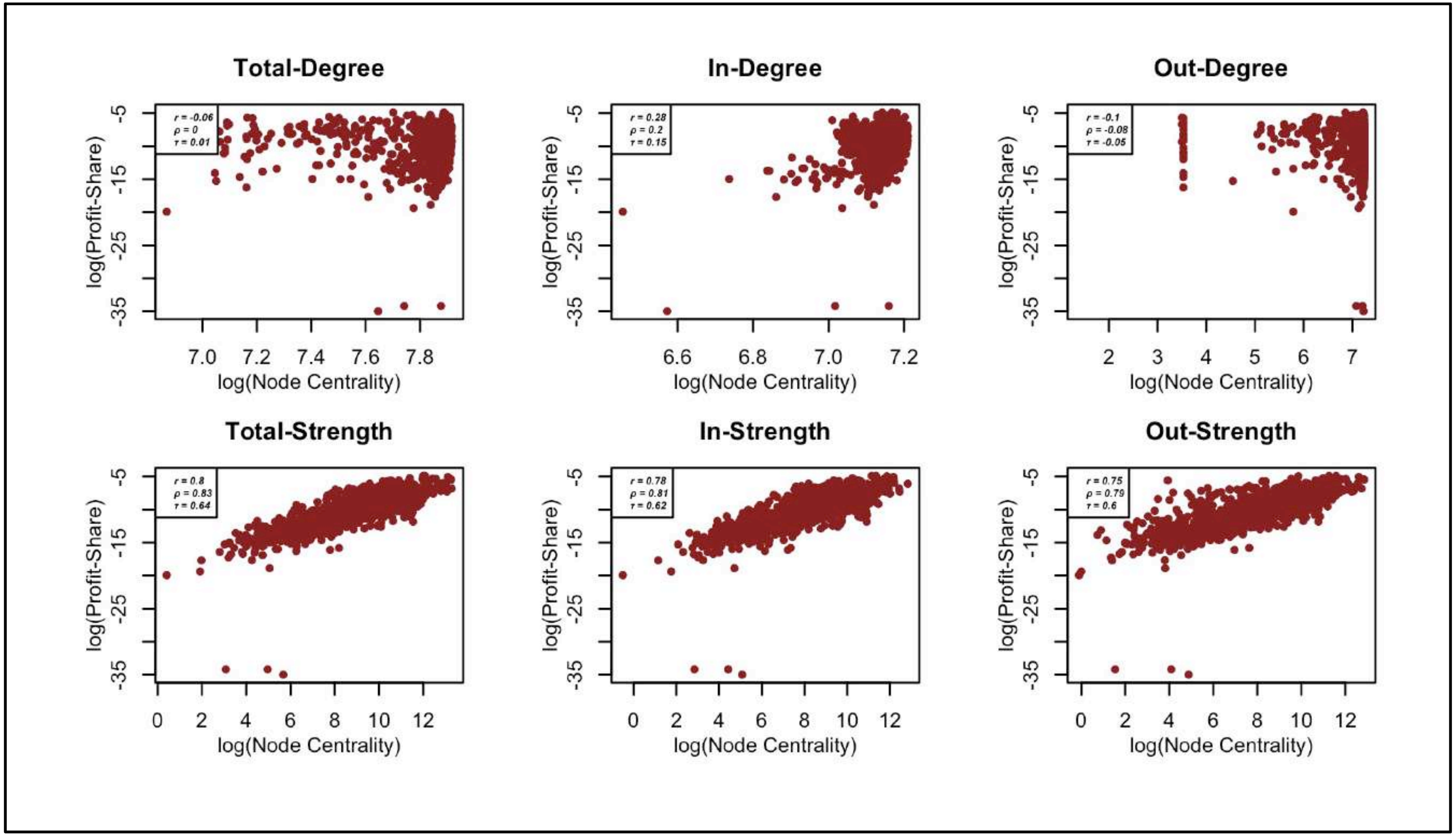

Figure 18 - Scatterplots of Profit-Shares and Centralities. WIOD (1995)

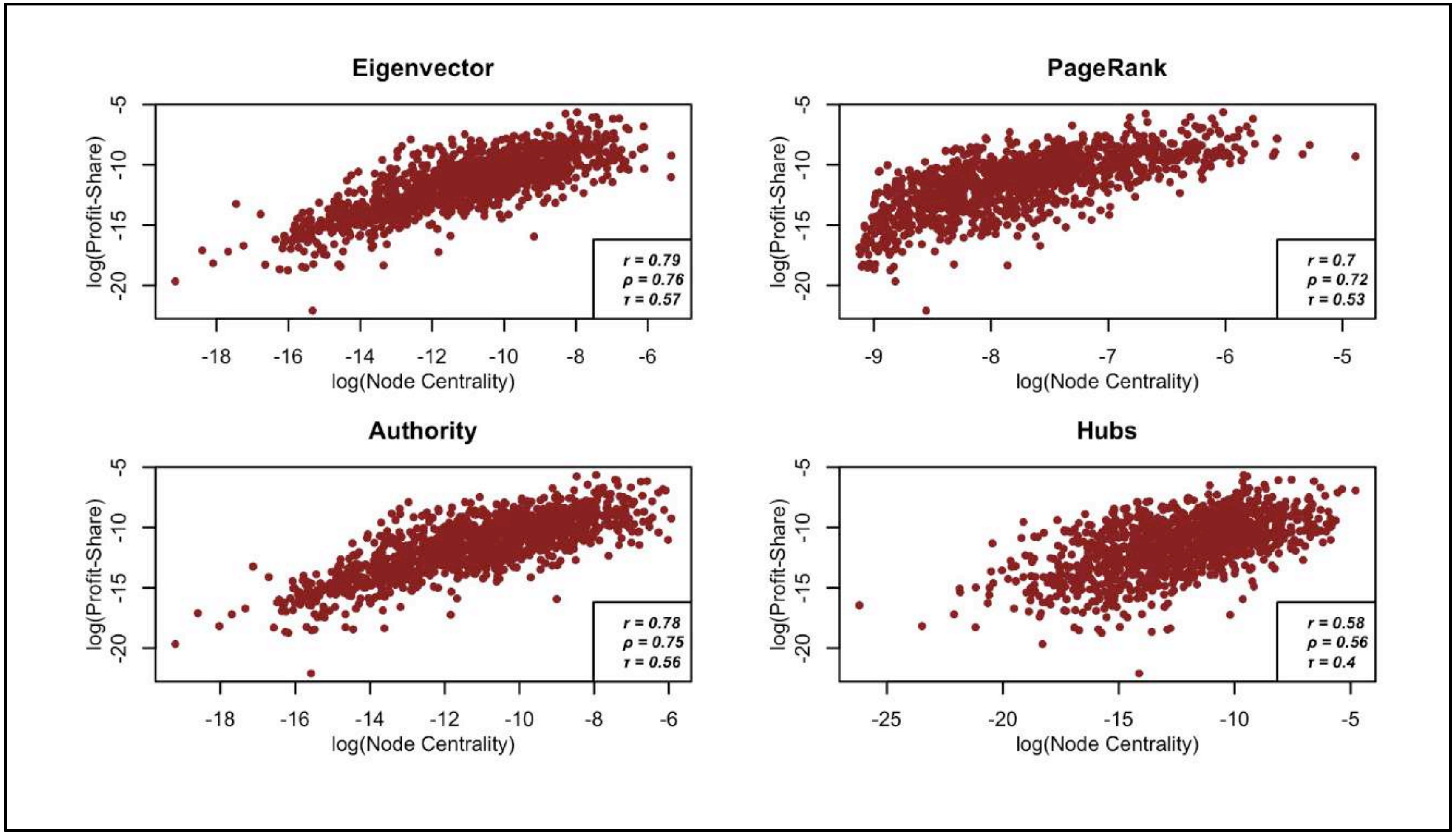

Figure 19 Scatterplots of Profit-Shares and Centralities. WIOD (2002)

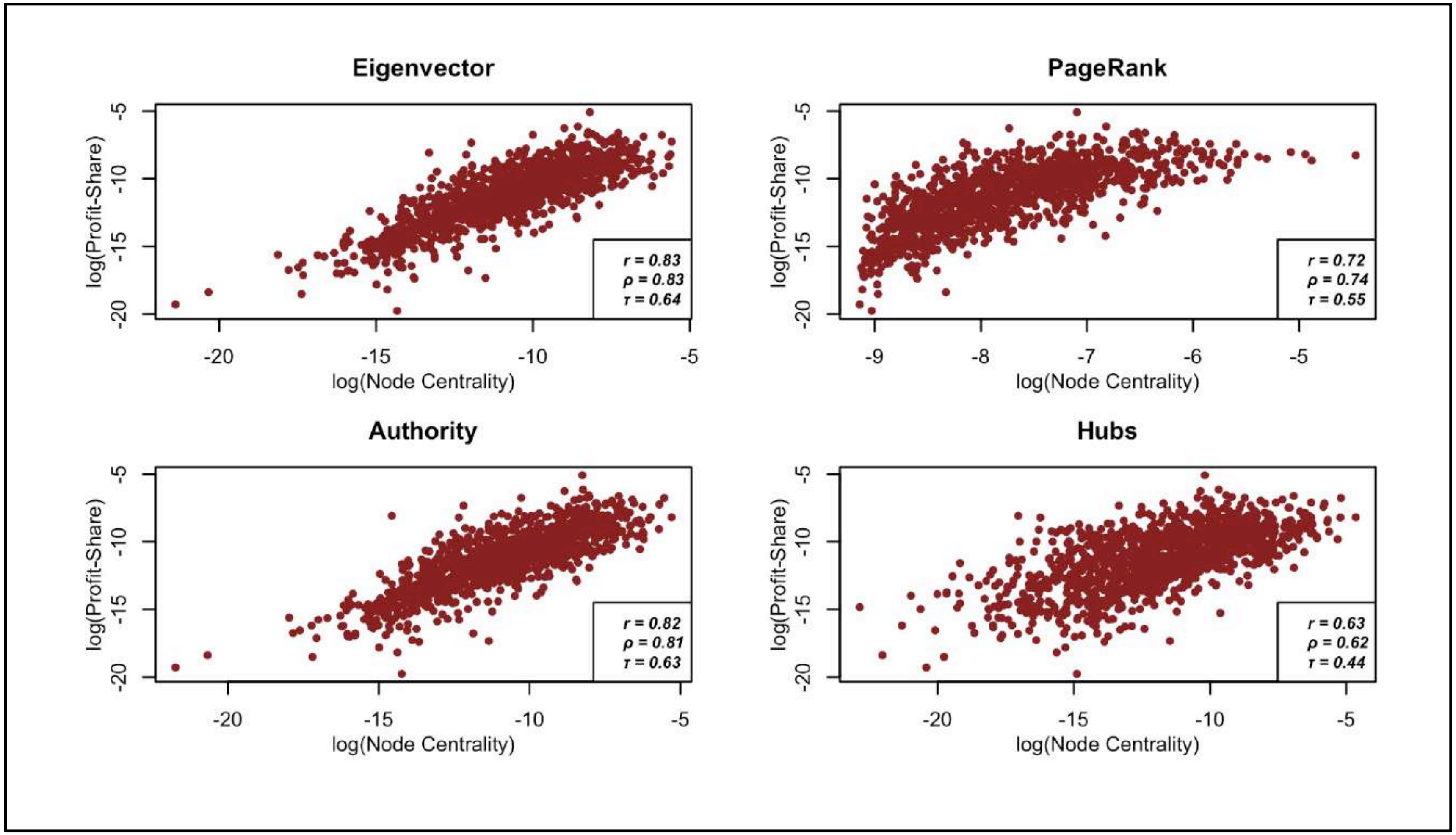

Figure 20 Scatterplots of Profit-Shares and Centralities. WIOD (2011)

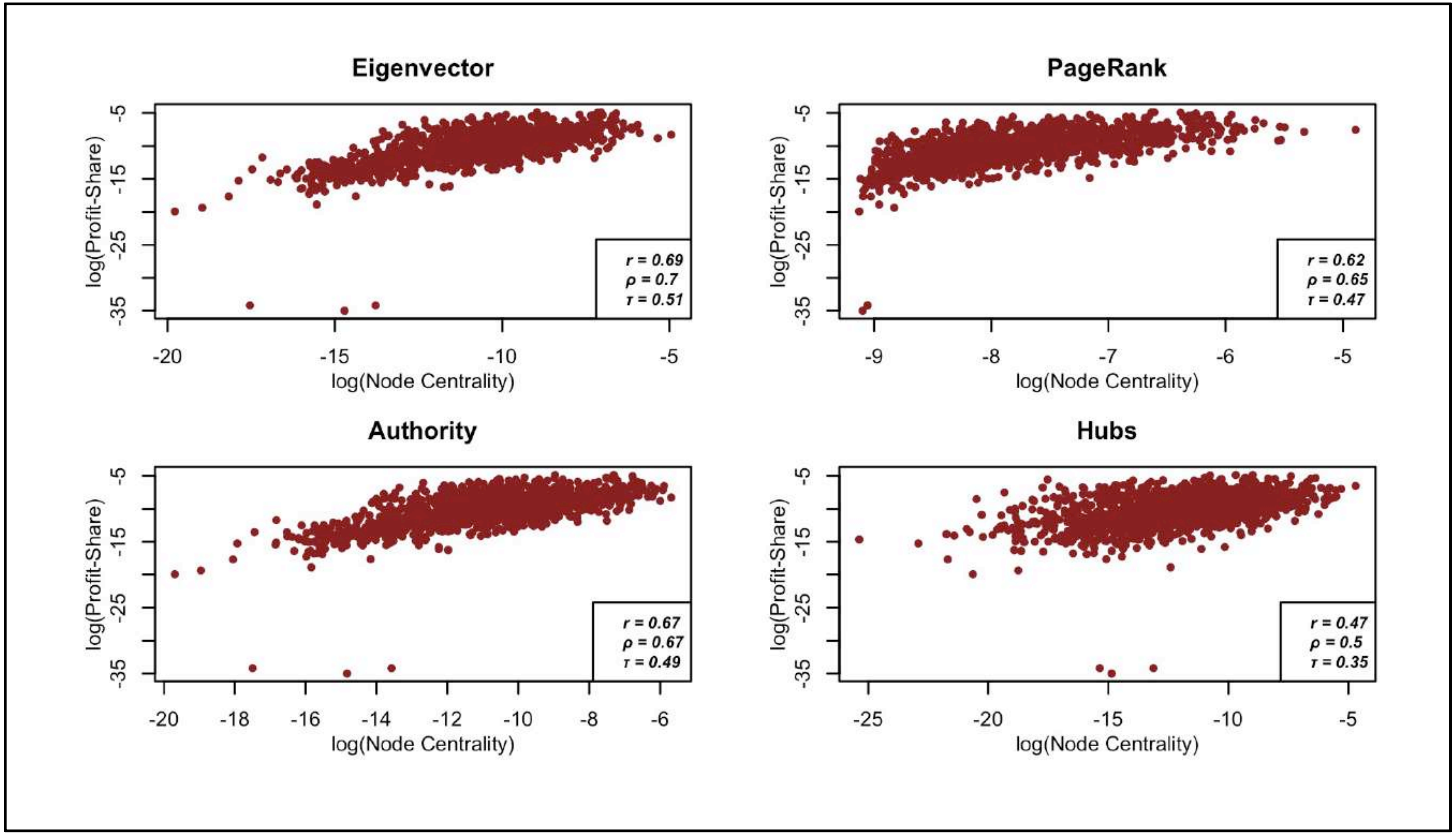

Figure 21 Scatterplots of Profit-Shares and Centralities. WIOD (2000)

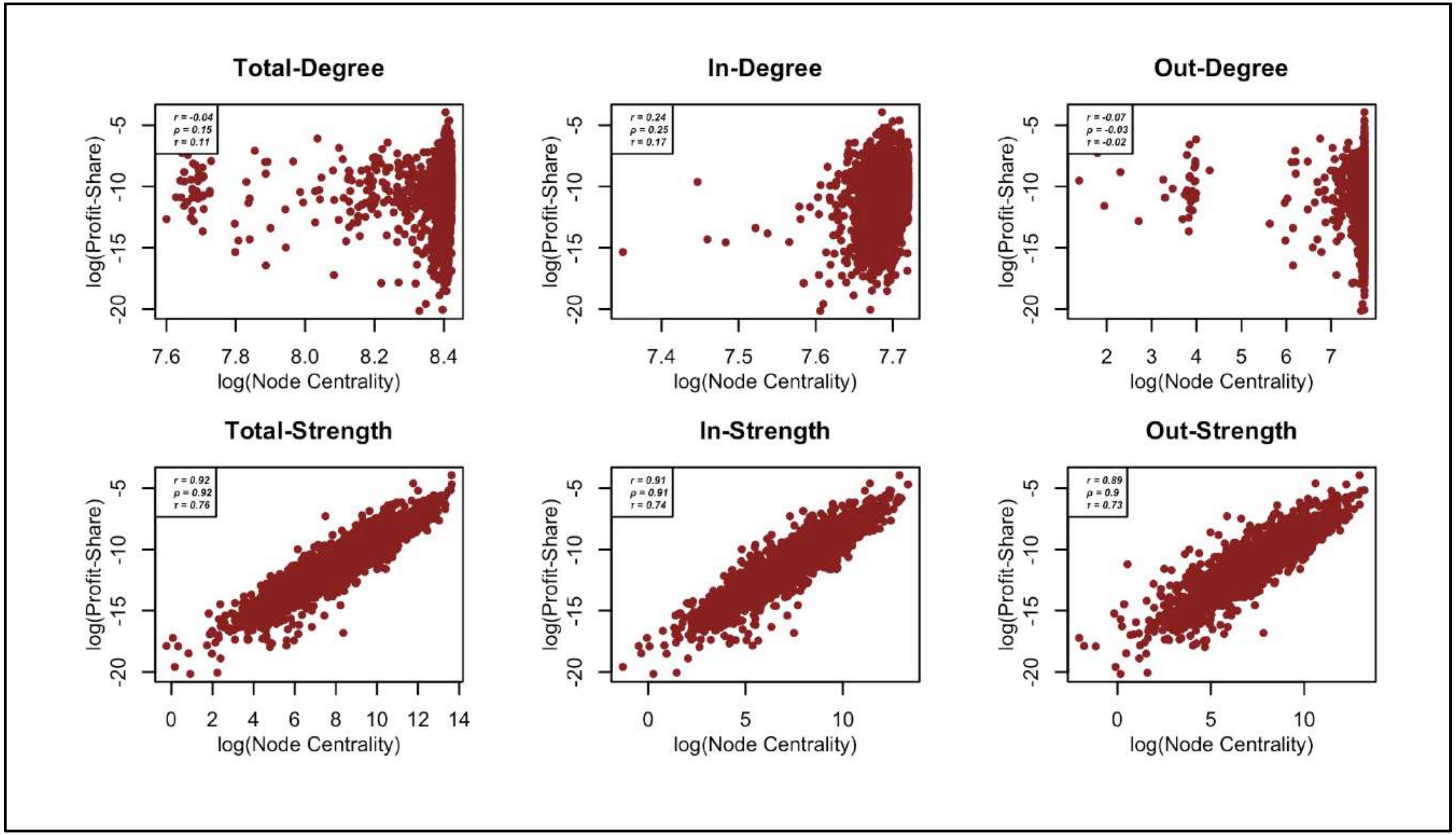

Figure 22 Scatterplots of Profit-Shares and Centralities. WIOD (2007)

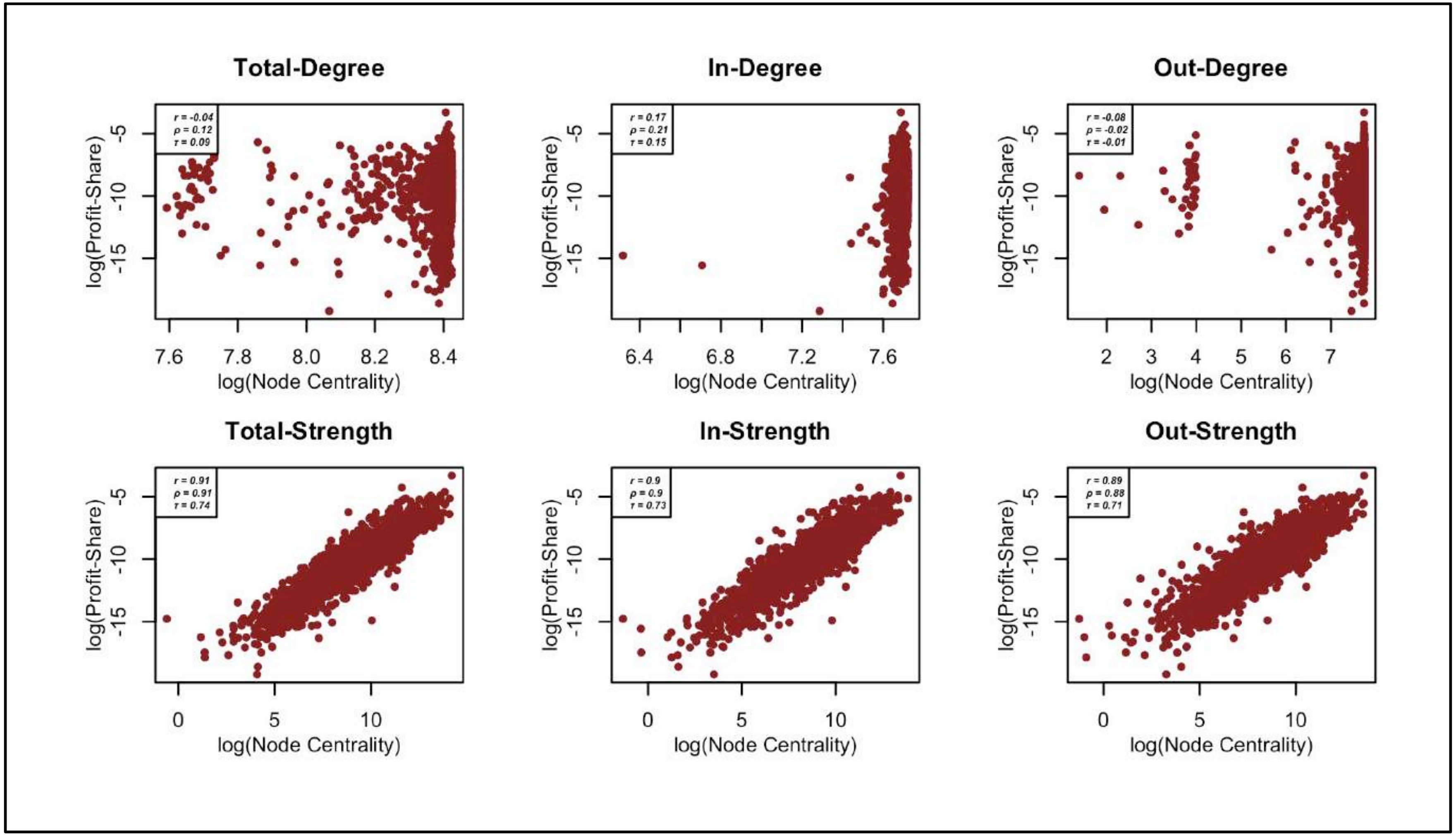

Figure 23 Scatterplots of Profit-Shares and Centralities. WIOD (2014)

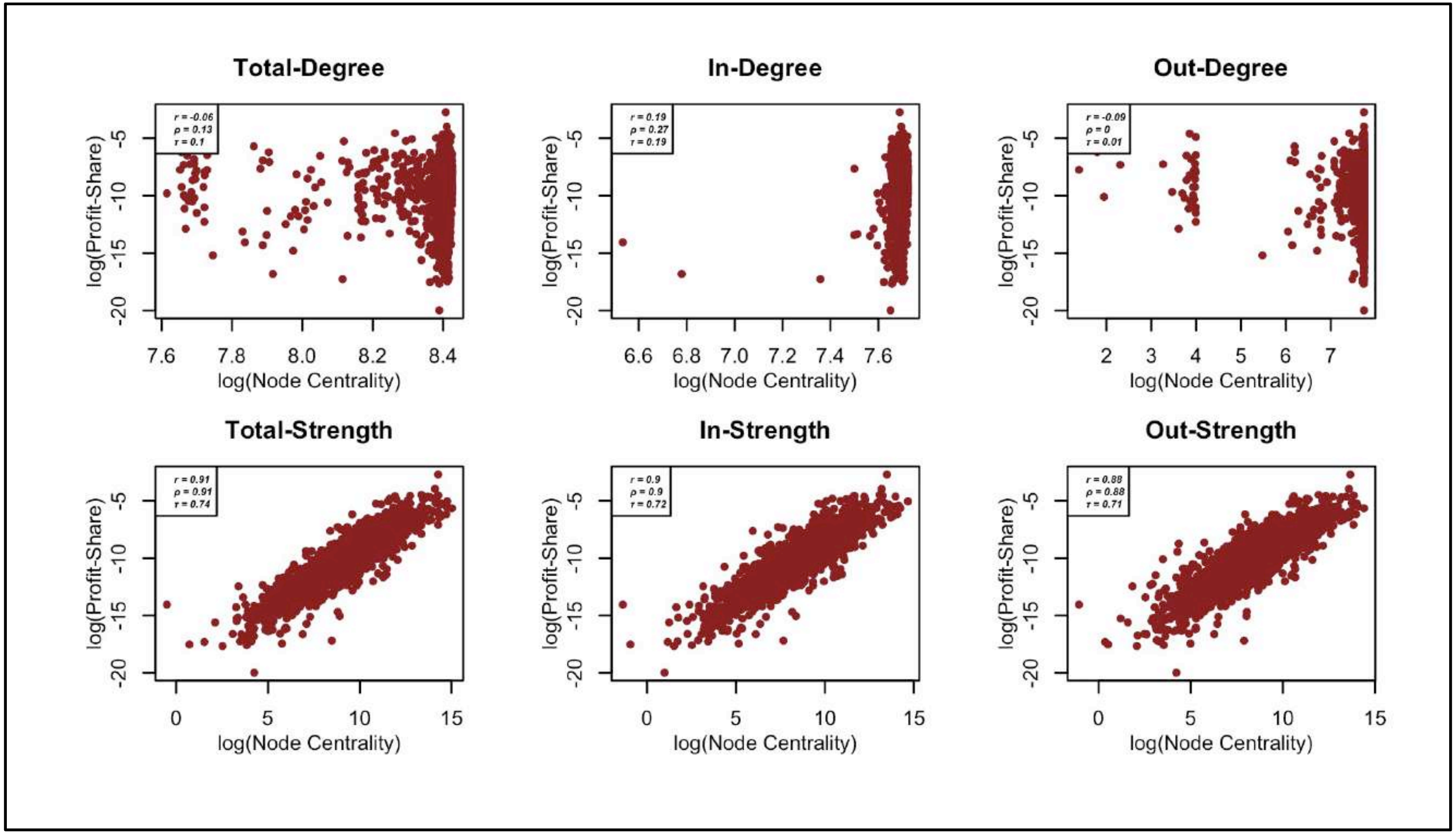

Figure 24 Scatterplots of Profit-Shares and Centralities. OECD (1995)

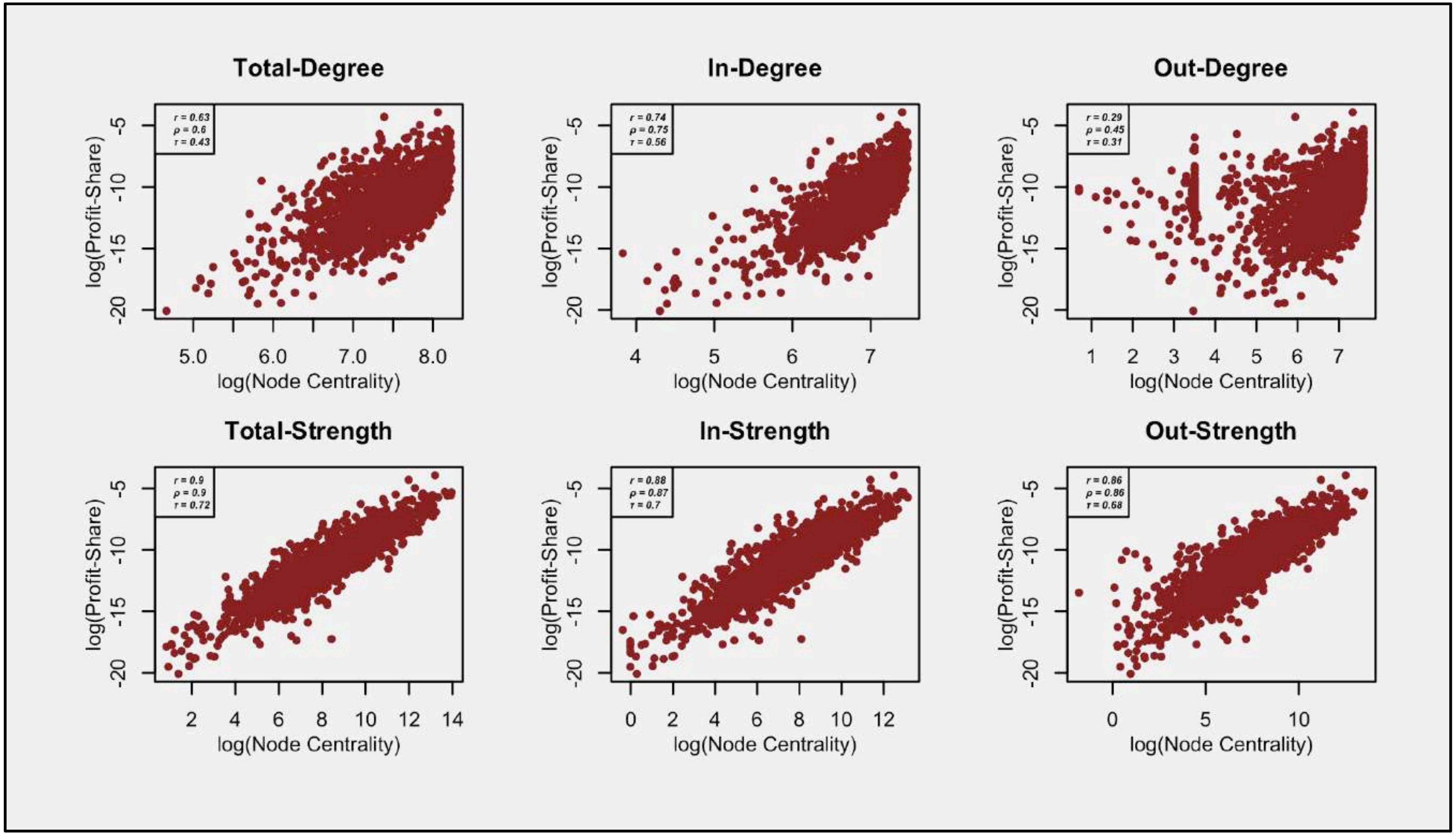

Figure 25 Scatterplots of Profit-Shares and Centralities. OECD (2002)

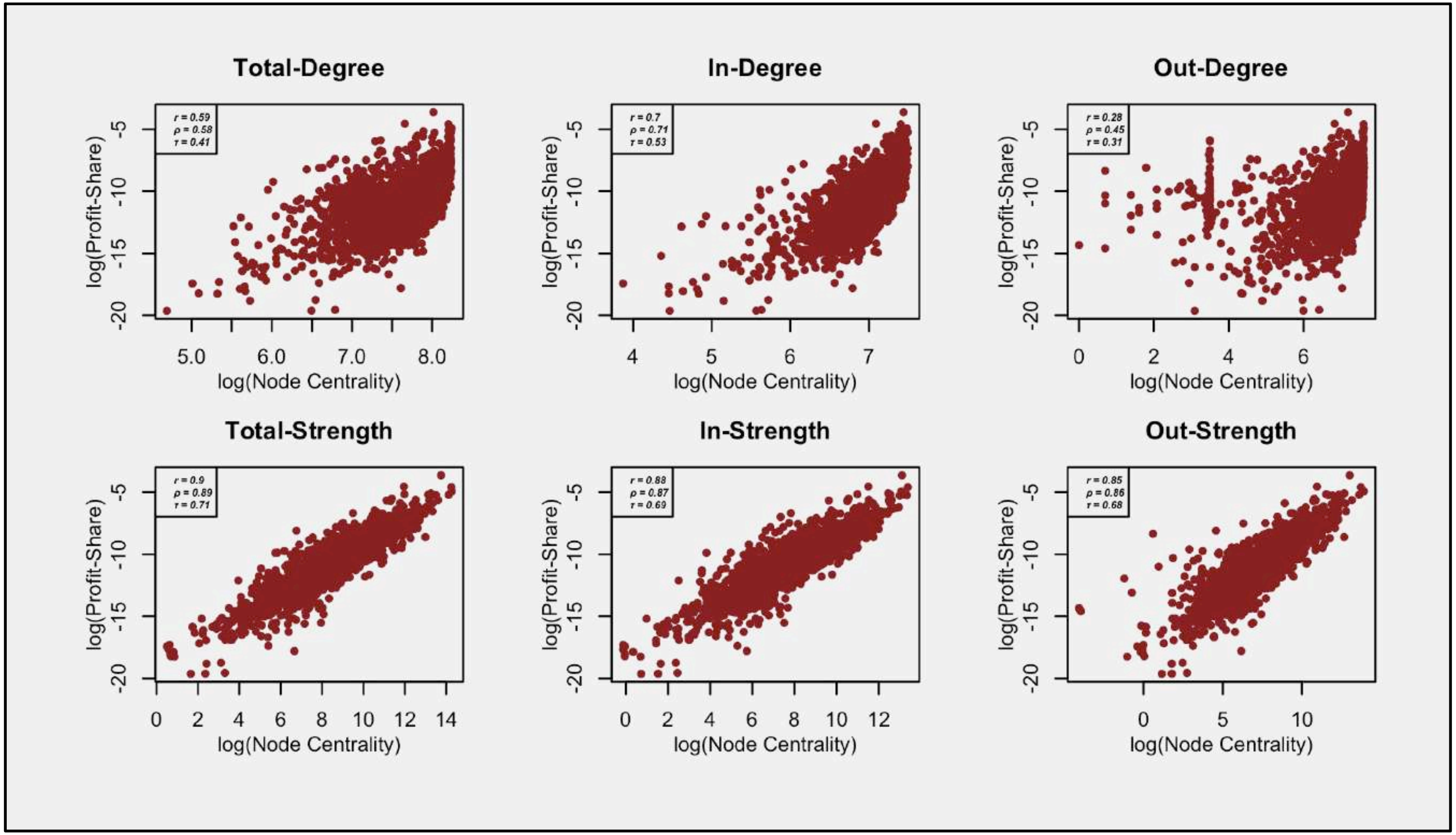

Figure 26 Scatterplots of Profit-Shares and Centralities. OECD (2011)

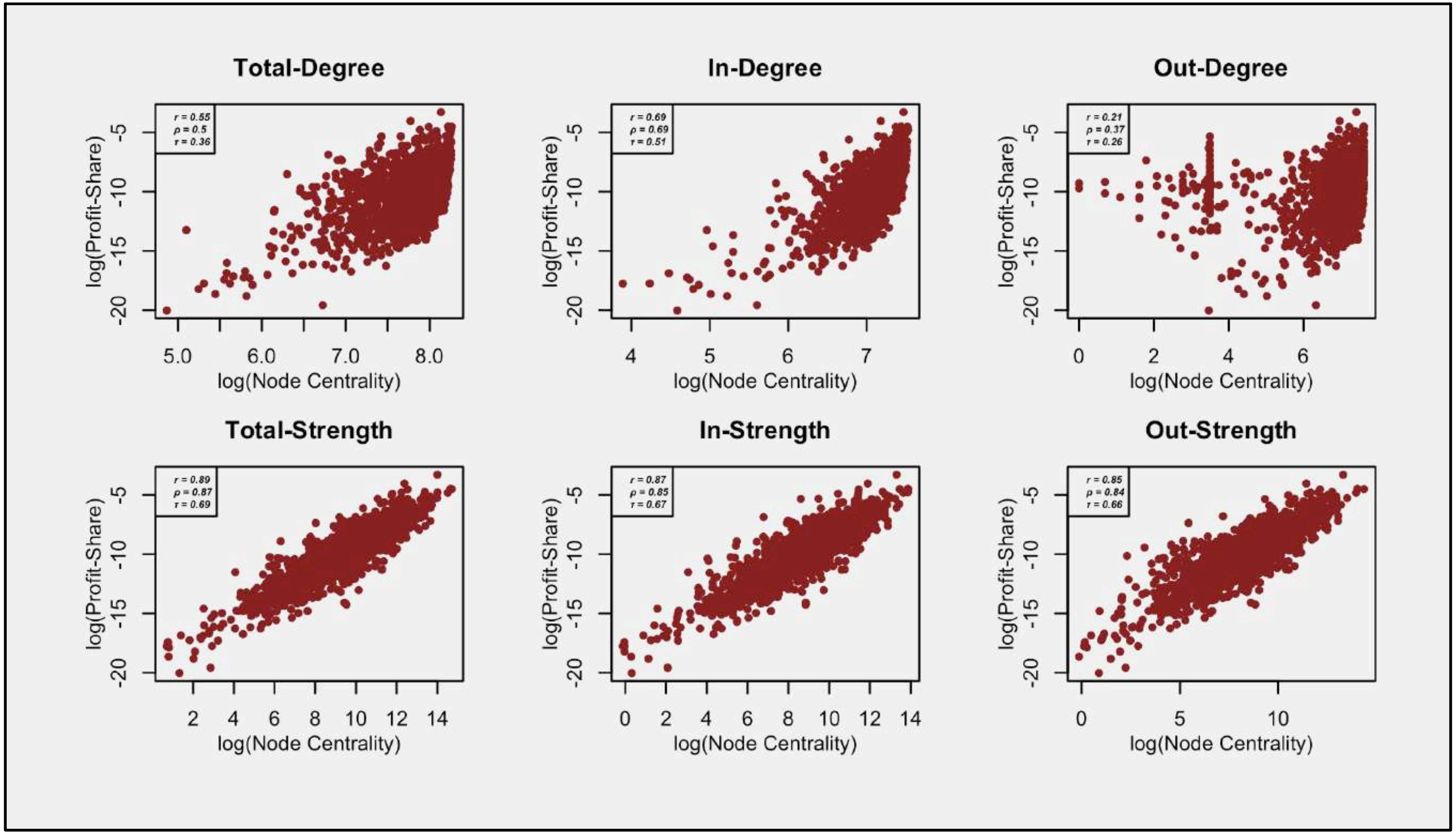

Figure 27 Scatterplots of Profit-Shares and Centralities. OECD (1995)

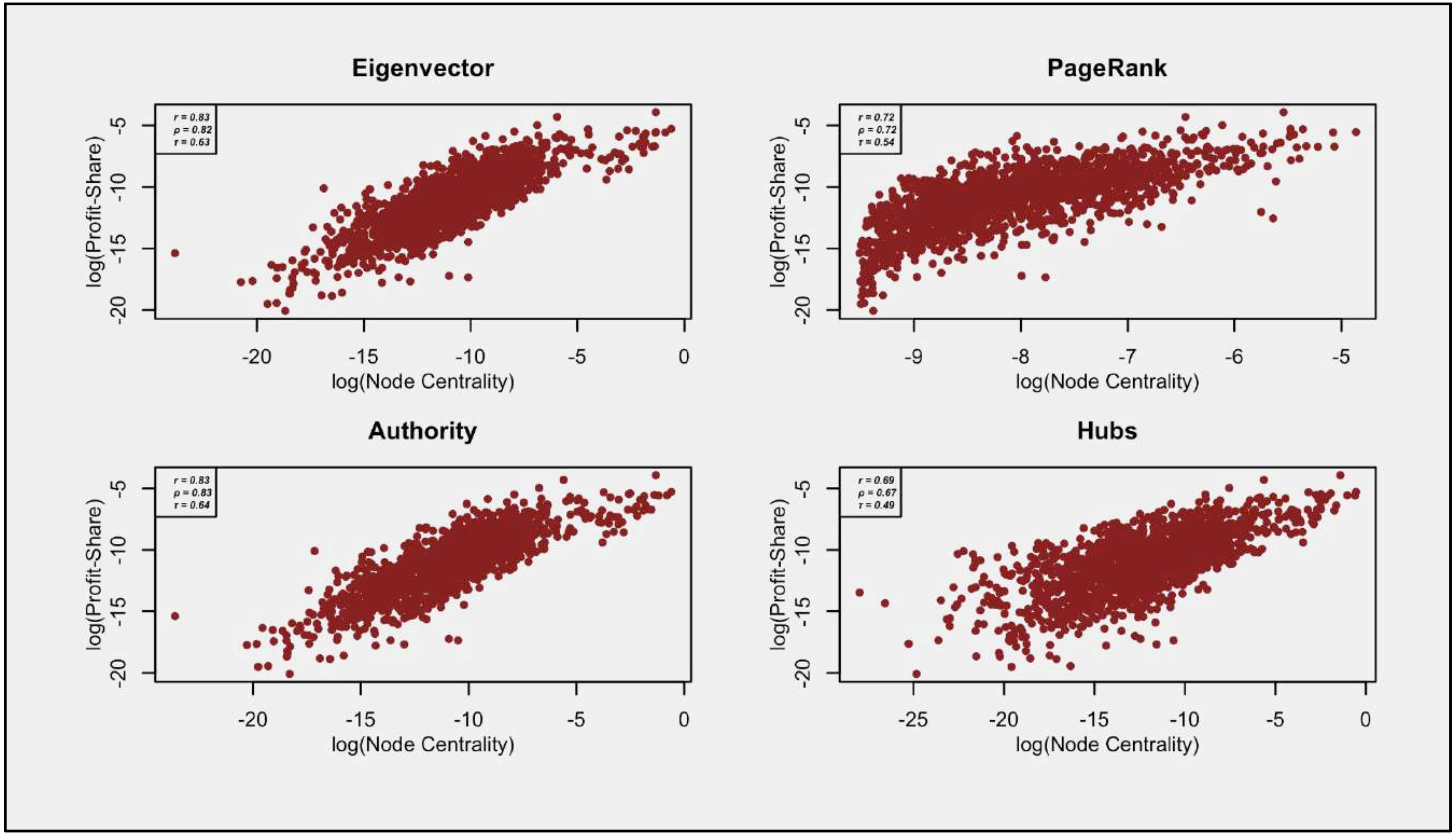

Figure 28 Scatterplots of Profit-Shares and Centralities. OECD (2002)

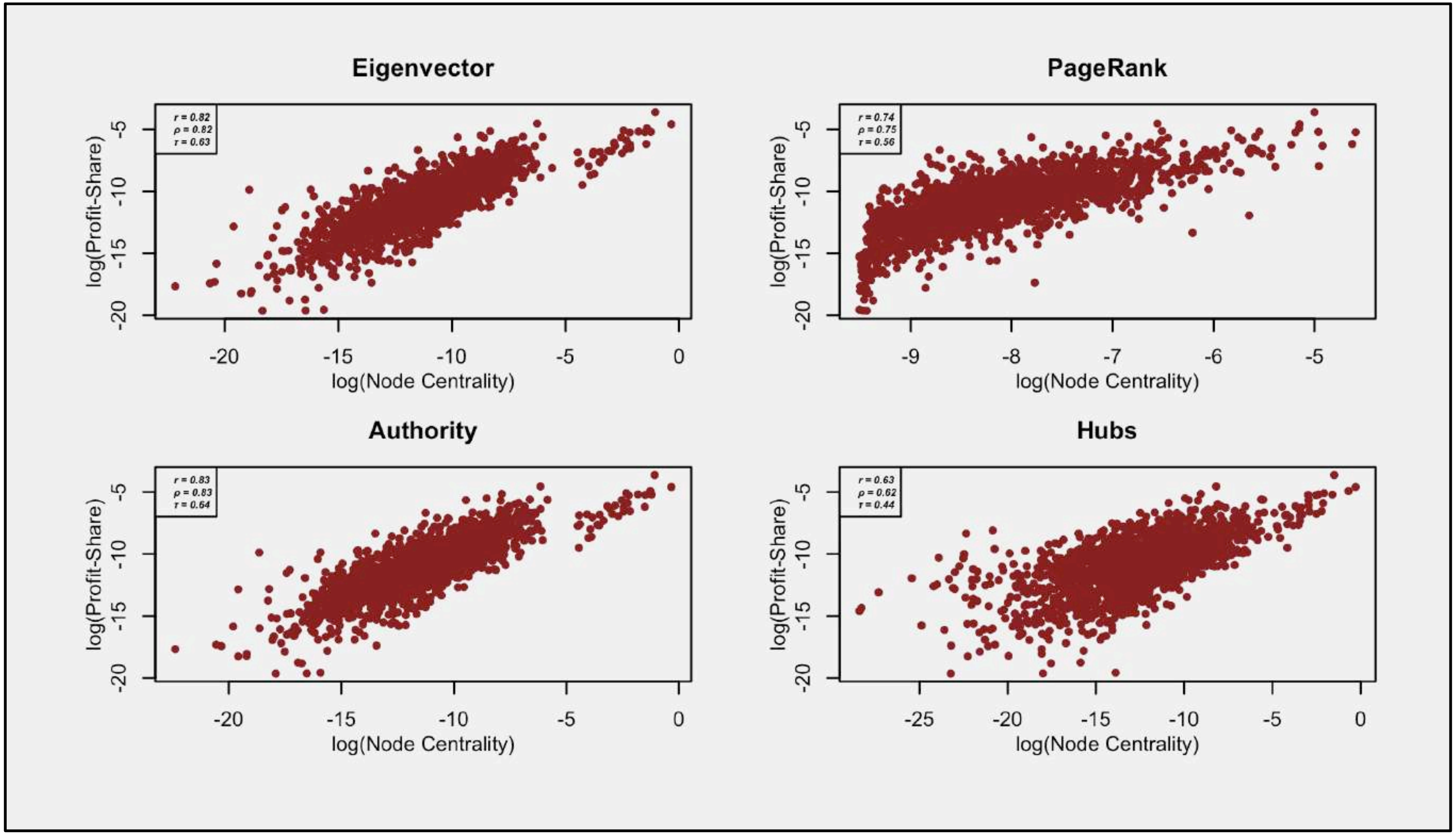

Figure 29 Scatterplots of Profit-Shares and Centralities. OECD (2011)

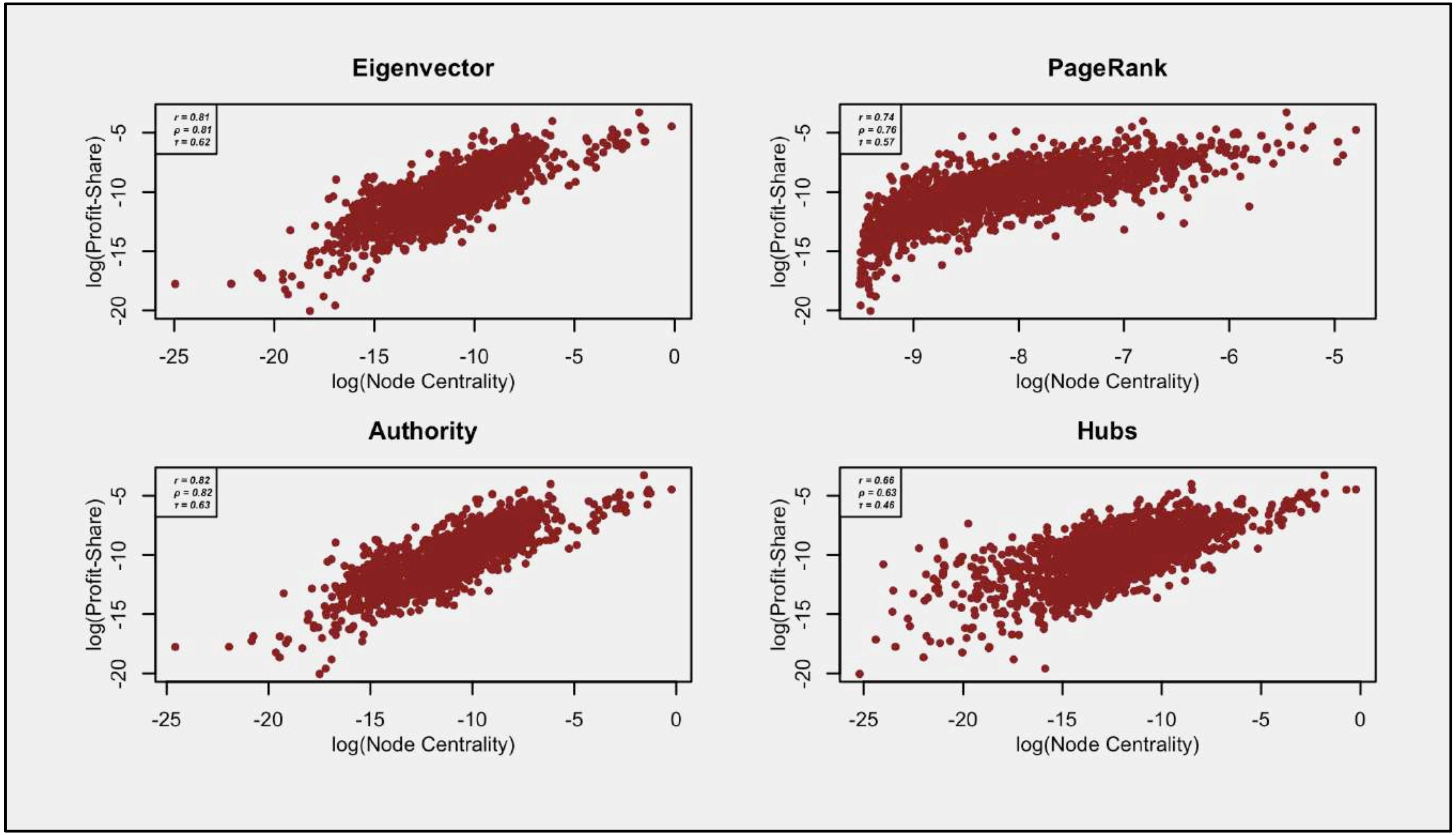

Figure 30 Scatterplots of Profit-Shares and Centralities. OECD (2005)

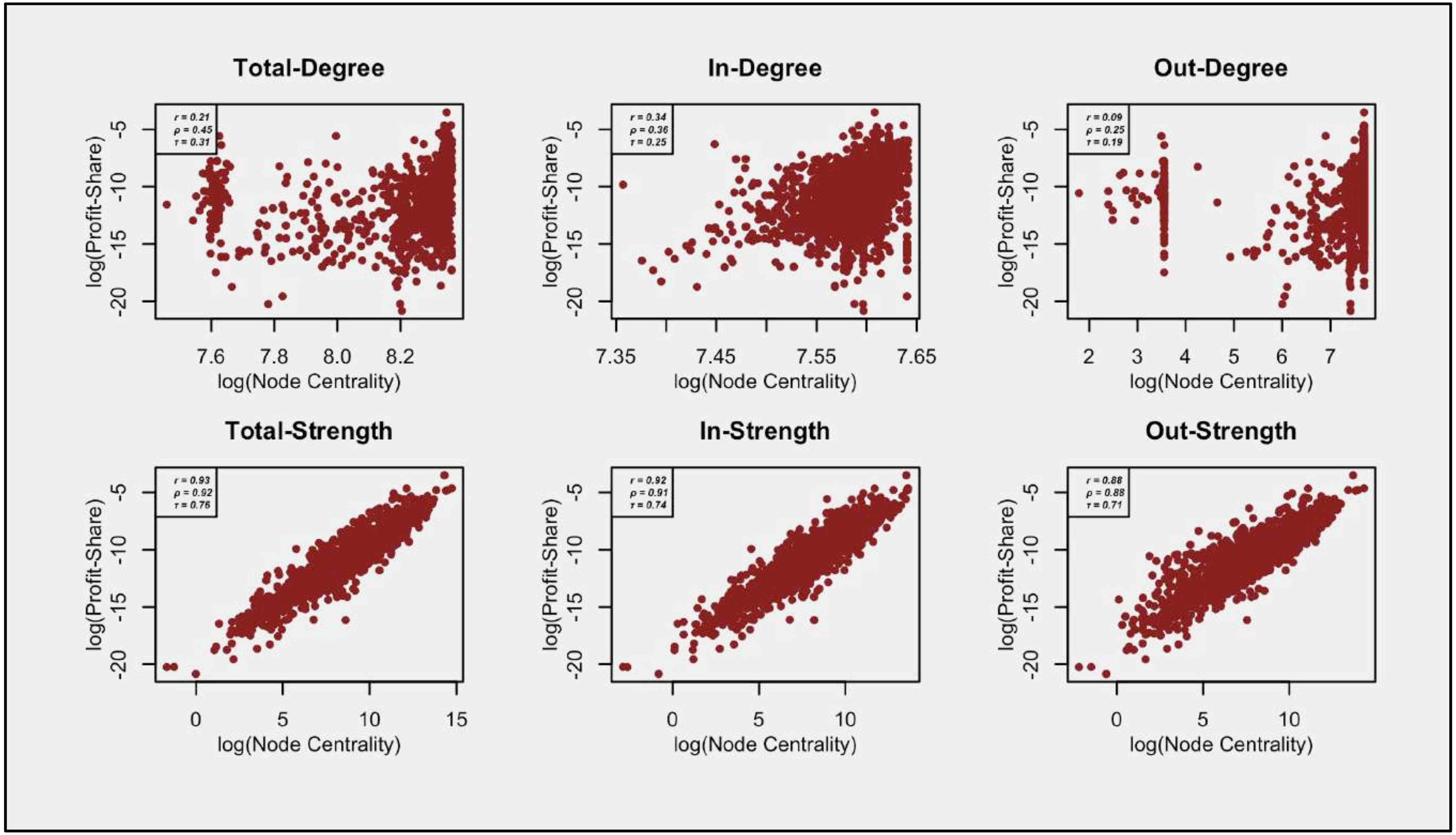

Figure 31 Scatterplots of Profit-Shares and Centralities. OECD (2010)

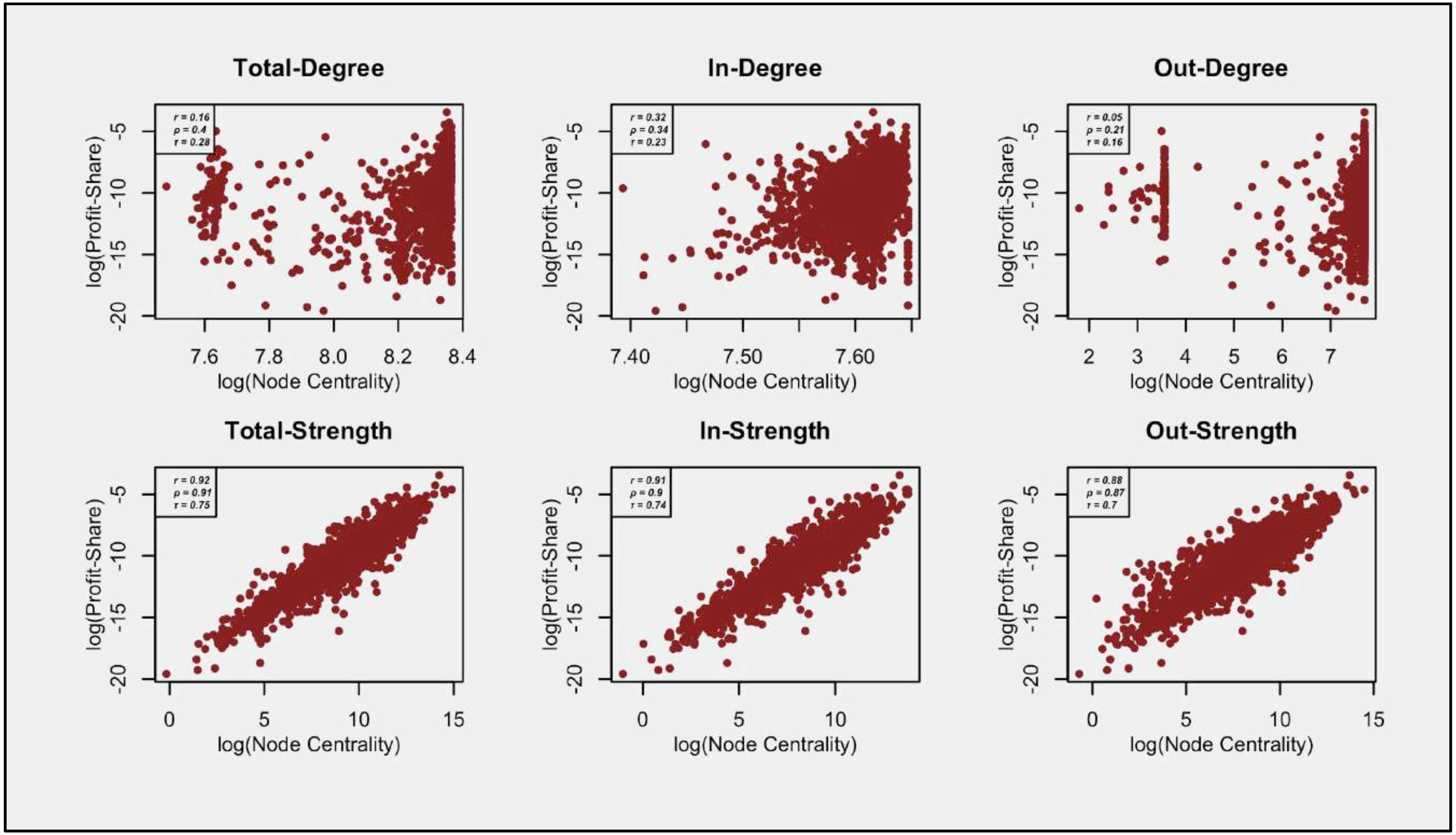

Figure 32 Scatterplots of Profit-Shares and Centralities. OECD (2015)

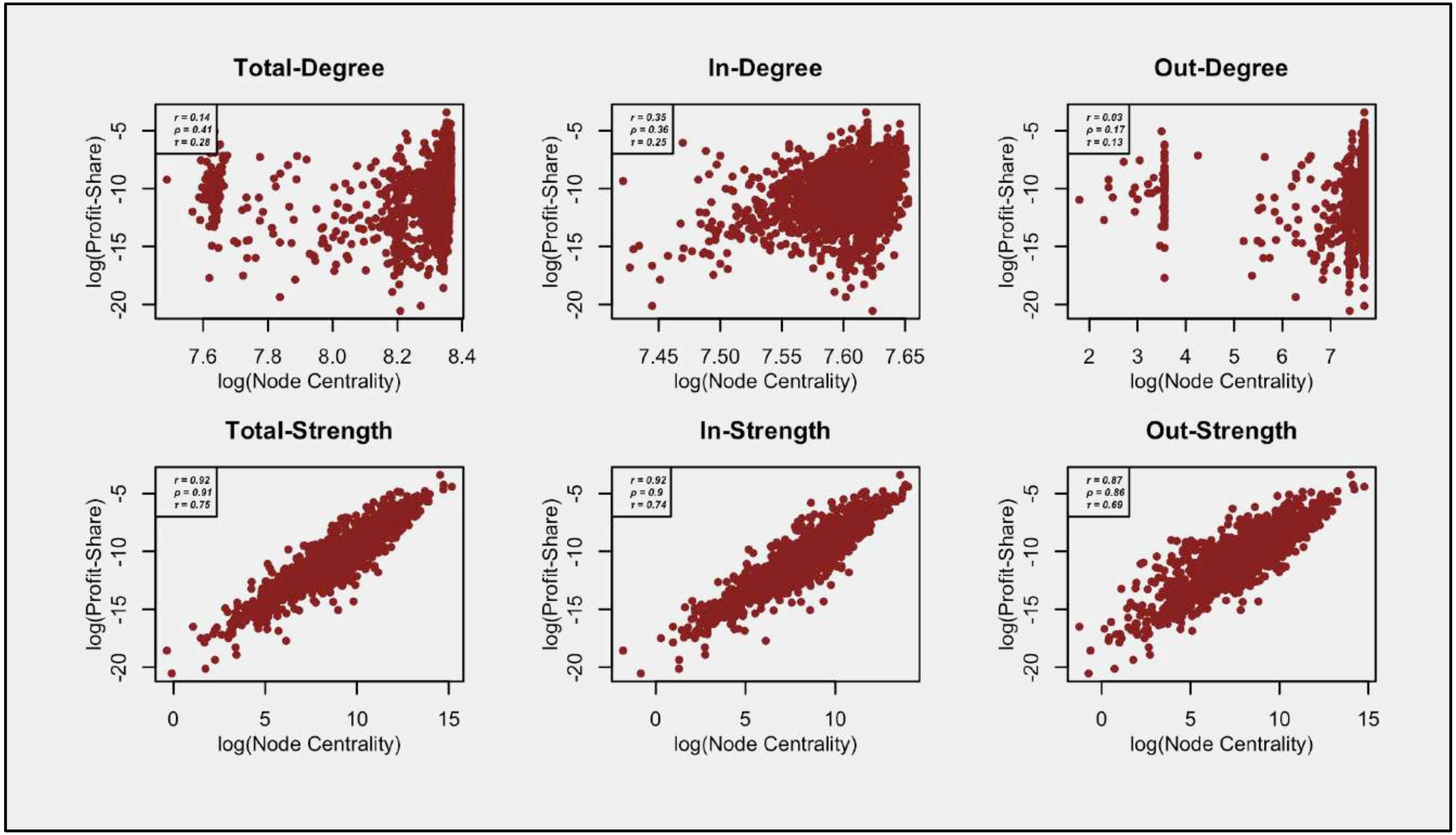

Figure 33 Scatterplots of Profit-Shares and Centralities. OECD (2005)

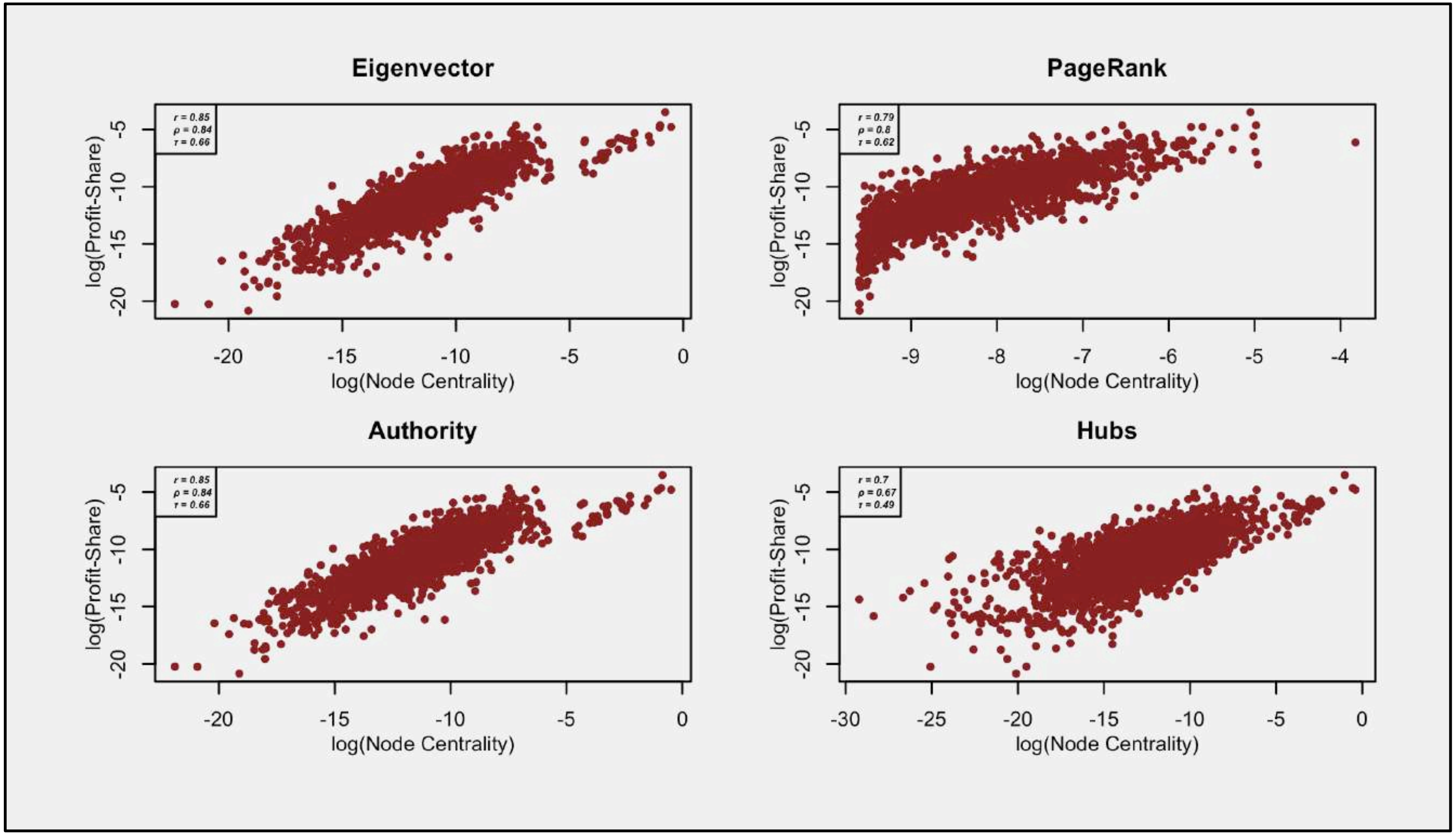

Figure 34 Scatterplots of Profit-Shares and Centralities. OECD (2010)

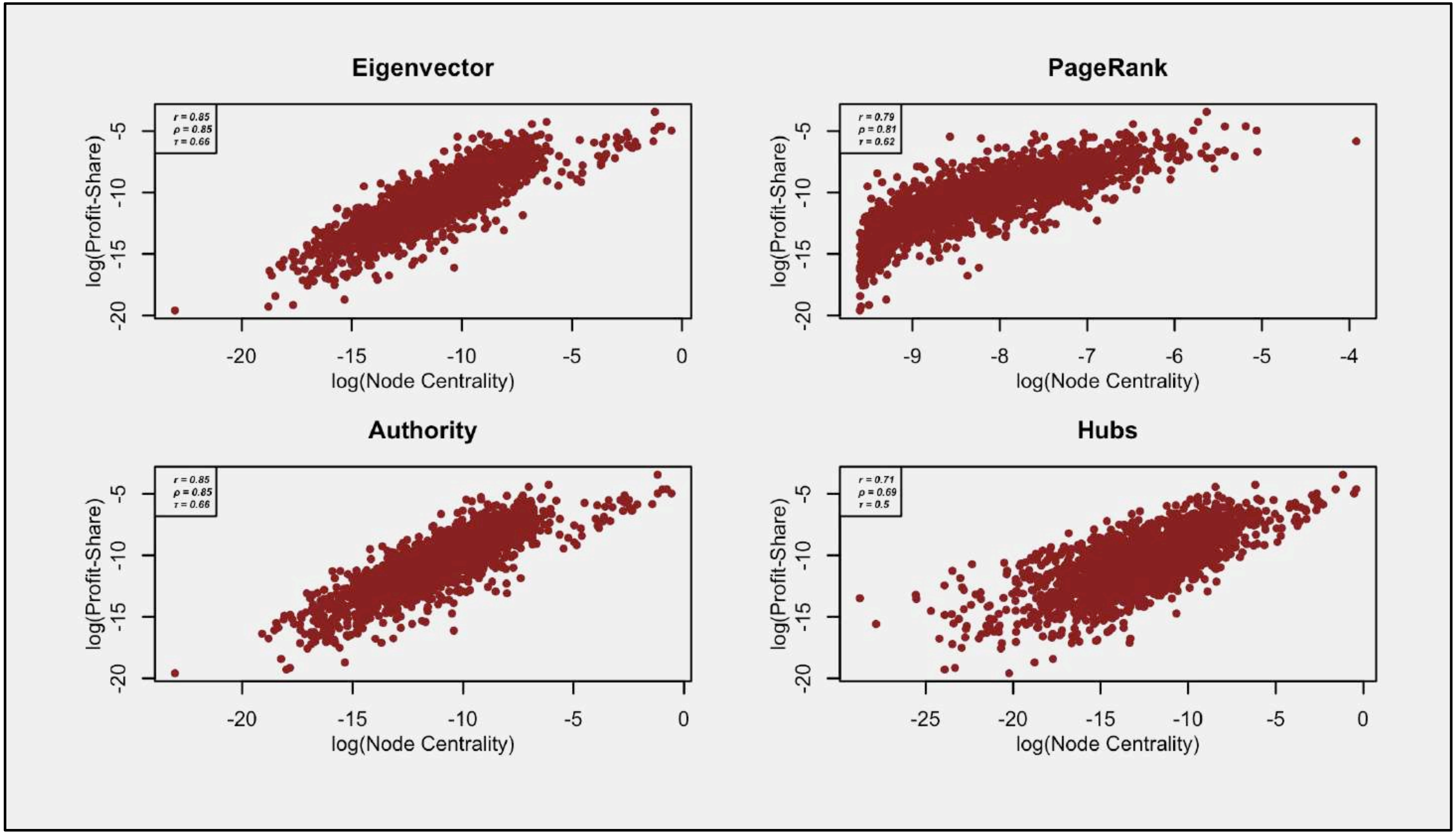

Figure 35 Scatterplots of Profit-Shares and Centralities. OECD (2015)