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Theodore Tsekeris

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Theodore Tsekeris
Centre of Planning and Economic Research (KEPE), Athens, Greece
E-mail: tsek@kepe.gr

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Network analysis of inter-sectoral relationships and key economic sectors

Theodore Tsekeris

Centre of Planning and Economic Research (KEPE)

11 Amerikis, 10672 Athens, Greece

E-mail: tsek@kepe.gr

Abstract

The rapidly growing theories of networks and complex systems have been recently adopted to interpret the efficiency and robustness of various economic markets. Based on these theoretical underpinnings, the present paper describes a structural input-output analysis of the inter-sectoral linkages and main activity clusters of the Greek economy, which is modeled as a complex network. Such an analysis employs suitable network analytic metrics to measure the centrality and influence of each sector on the other ones, and the possibilities for clustering of related (groups of) activities. Key sectors related to the production of tradable goods and services are identified, in terms of their marginal ability to pull the total economic activity. Critical sectors are also determined in terms of their ability to retain the interconnectivity and strengthen the stability of the whole economic system. More synergies among the activity clusters, through the creation of integrated value chains, would allow better coordination of policies, more efficient allocation of resources and enhanced diffusion of knowledge.

JEL classification: C02, C67, D85, O11.

Keywords: Input-output tables, network analysis, key sectors, clusters, development.

Note: Some of the author's results presented in this paper have been included in an earlier form in the study of KEPE titled "The Growth Vision for Greece in 2020" on behalf of the Ministry of Development and Competitiveness, 2014.

Ανάλυση δικτύου των διακλαδικών σχέσεων και των κλάδων κλειδιών της ελληνικής οικονομίας

Θεόδωρος Τσέκερης

Περίληψη

Ο καθορισμός των κλάδων-κλειδιών και των κύριων ομάδων κλαδικών δραστηριοτήτων στην οικονομία μιας χώρας αποτελεί μια ιδιαίτερα χρήσιμη διαδικασία για τον προσδιορισμό των στόχων και των πολιτικών κατανομής πόρων στο στρατηγικό σχέδιο ανάπτυξής της. Οι ραγδαία εξελισσόμενες θεωρίες των δικτύων και των πολύπλοκων συστημάτων μπορούν να εφαρμοστούν κατάλληλα για την υποστήριξη της προαναφερόμενης διαδικασίας σχεδιασμού, επιτρέποντας την κατανόηση και την ερμηνεία των πηγών αποτελεσματικότητας και ευρωστίας μιας οικονομίας ή μιας επιμέρους αγοράς. Με βάση αυτές τις θεωρητικές και μεθοδολογικές εξελίξεις, η παρούσα εργασία παρέχει μια δομική ανάλυση των διακλαδικών σχέσεων, των κλάδων-κλειδιών, των κρίσιμων για την ευρωστία κλάδων, και των κύριων ομάδων δραστηριοτήτων της ελληνικής οικονομίας, η οποία αναπαριστάται ως ένα πολύπλοκο δίκτυο. Η ανάλυση δείχνει τις βασικές σχέσεις των μακροσκοπικών μεγεθών του συγκεκριμένου δικτύου, όπως εκφράζονται μέσω επιλεγμένων δεικτών κεντρικότητας κάθε οικονομικής δραστηριότητας. Οι δείκτες κεντρικότητας περιγράφουν τη σχετική θέση και επιρροή κάθε κλάδου στο σύνολο της οικονομίας, ανάλογα με τις άμεσες και έμμεσες συνδέσεις ή εγγύτητά τους με τους υπόλοιπους κλάδους. Σε συνέπεια με τις αναλύσεις για άλλες χώρες, τα αποτελέσματα δείχνουν ότι το δίκτυο της ελληνικής οικονομίας αυτό-οργανώνεται σε έναν μικρό αριθμό (έξι) ομάδων συναφών οικονομικών δραστηριοτήτων, που σχετίζονται με: (α) το εμπόριο και τις λοιπές υπηρεσίες, (β) τις κατασκευές, (γ) την γεωργία, τα τρόφιμα και τον τουρισμό, (δ) τα χημικά, τα φάρμακα και την υγεία, (ε) τις μεταφορές, και (στ) την ενέργεια. Η αύξηση της πυκνότητας των διακλαδικών συνδέσεων εντός κάθε ομάδας και μεταξύ των ομάδων μπορεί να αυξήσει την αποδοτικότητα και την ευρωστία του δικτύου της ελληνικής οικονομίας, με τη δημιουργία συνεργειών και ολοκληρωμένων (καθετοποιημένων) αλυσίδων δραστηριοτήτων μεγαλύτερης αξίας και υψηλότερης ποιότητας.

1. Introduction

Input-output tables constitute a valuable tool for supporting the analysis of the structural relationships among sectors in a national or regional economy. These tables depict the intermediate and final transactions; namely, they describe the supply and use of goods and services that are directly consumed or used up as inputs in the production process of the whole economic system. They can be utilized both in the planning and evaluation of public investment programs. Specifically, they can provide useful insight into the size of industries, development strategies with respect to different production structures, and the potential effect of the expansion of one sector on other ones (Rasmussen, 1957; Hirschman, 1958; Jones, 1976).

Typical analysis of input-output tables (Leontief, 1951; Rasmussen, 1957) employs the input or technical coefficients, calculated by dividing each sector's column of inputs by the total national production, to calculate the inverse Leontief matrix and multiplier effects. Nonetheless, this analysis relies on the absolute or relative magnitude of sectors, without accounting for heterogeneous characteristics such as their particular role in the interconnectivity and stability of the whole economic system. Moreover, it assumes the existence of constant returns to scale and concentrates on the average (rather than marginal) effects of a change in one sector's demand on the others and the national economy.

The adoption of methods and metrics from graph theory and network science can address some of those problems, through considering issues of centrality and clustering effects. In particular, the national economic system is modeled as a network, taking as nodes the sectors and edges (directed links) the transactions (sales/purchases) between them, weighted by the amount (monetary flow) of each transaction, as described in the input-output matrix. The proposed approach can suitably represent multi-sectoral interdependencies and the potential influence of one sector on other, significant sectors and/or groups of sectors, beyond the standard analysis of the pair-wise relationships between sectors. Besides, it can help to identify critical sectors associated with the robustness of the whole economic system. In this way, some intrinsic features pertaining to the complexity of the economic network are taken into account, as it is recognized that the outcome at the macro level cannot be inferred from an individual outcome on its own, but from varying interactions among several (groups of) sectors at different network scales.

The present paper provides a complex network analysis of the inter-sectoral relationships and the key sectors of the Greek economy. Based on the use of network analysis tools, the main objectives of the paper are: (a) to identify main sectoral clusters, which accumulate interrelated economic activities, (b) to determine key sectors, which can potentially contribute to the restructuring of economy, by favoring the production of internationally tradable goods and services, and (c) to determine critical sectors, which can mostly ensure the stability and resilience of the whole economic system. Especially, knowledge of key sectors (or industries) is crucial to design policies for economic recovery, since the expansion of activities of those sectors would lead to general increase in economic activity of all or most of the other sectors (Rasmussen, 1957). Furthermore, knowledge about the formation of activity clusters may allow better coordination of policies and more efficient allocation of resources and utilization of infrastructure, information and business practices, in order to promote innovation and knowledge transfer among sectors.

The current study utilizes the input-output matrix of the intermediate transactions among the sectors[1] of the Greek economy for 2010, the last year with available data from the Hellenic Statistical Authority (EL.STAT.). It is noted that input-output matrices require large amount of data, which cannot be frequently (typically, within less than 2-3 years) updated, while technological change does not occur rapidly in most sectors, which implies that the structure of the economy has generally remained stable over time. Thus, the results of the current analysis may be considered as providing reasonable description of and useful insights into the key sectors and critical sectors of the economy as well as the main activity clusters and sectoral group interactions.

As far as the organization of the rest of the paper is concerned, Section 2 reviews the use of network analysis in economic systems in the existing literature. Section 3 presents the results of a procedure for identifying the main economic activity clusters of the country. Section 4 provides and discusses the results about the key sectors and critical sectors and links of the Greek economy network, and Section 5 summarizes and concludes.

[1] It is noted that the present analysis refers to 61 sectors (assuming that each one produces a single homogeneous good), as the following three sectors have been omitted due to negligible flows: ‘Employment services’, ‘Services of households as employers and undifferentiated goods and services produced by households for own use’ and ‘Services provided by extraterritorial organisations and bodies’.

2. The use of network analysis in economic systems

In the context of economic networks, several approaches from the graph theory and network science have been used in the last two decades to represent and interpret the systemic complexity pertaining to the structure of sectoral markets and regional or global economies. Specifically, these approaches can offer a new way of seeing the emergent processes of development in the national and international context. They can enhance the understanding of interrelationships and potential conflicts between individual interests (of sector, administrative or firm agents) and overall market efficiency; hence, they can facilitate the design of suitable policies that reduce risk of failure and make economic/financial networks more robust (Schweitzer et al., 2009; Faggini and Parziale, 2014). Complex network analysis has been primarily employed to demonstrate the importance of connectedness and density on the international trade and export performance of countries (Hidalgo et al., 2007; Barigozzi et al., 2011; De Benedictis and Tajoli, 2011; Squartini et al., 2011).

Similar to the significance of connectedness of a national economy in the global economic system, the connectedness of sectoral activities in the national economic system is regarded as crucial for their total performance. The introduction of graph-theoretic and network analytic metrics, most of which were originally implemented into the analysis of social networks, has significantly advanced the qualitative (or structural) input-output analysis of inter-sectoral linkages of national economies and contributed to uncover salient features of their structure. In particular, centrality measures can be used to identify the relative position of sectors within a national economy, their direct and indirect proximity with regard to each other, and, hence, identify the most influential and critical ones, exploiting information from input-output matrices (e.g., Cuello et al., 1992; Muñiz et al., 2008; Montresor and Marzetti, 2009).

Besides, it has been shown that the complexity of an economy, in terms of its graph density[2], and its intrinsic characteristics are vital for countries to explore combinations, to accumulate and to find new productive capabilities and develop

[2] The (graph) *density* of an economy can be defined as the ratio of the existing number of edges (inter-sectoral links) to the maximum number of (or total number of possible) edges. The maximum number of edges corresponds to the case where all sectors of the national economy network connect with each other. Hence, the density values range from 0 to 1.

more products (Hidalgo and Hausmann, 2009). Network analytic measures have also been employed to demonstrate the structural evolution or the emergence of production structures in national economies (Schnabl, 1994) and to offer useful insight into the stability and fluctuations of national aggregate economic measures (Acemoglu et al., 2012).

Network-analytic methods have been further employed to indicate the self-organization of national economies in sub-communities or groups of major sectors. It has been found that there are patterns of clustering among industries which are shared across economies of different countries (McNerney et al., 2013). These common groupings of sectors typically vary with the level (and rate) of development (Blöchl et al., 2011) and the involvement/intervention of government in economic markets. The emergence of clusters suggests increased interdependence of groups of intermediate goods, and it can be associated with multiplicative effects and complementarily issues along the added value chains of the economy. These synergistic forces are important for addressing distortions to the allocation of resources, which happen at the micro level and affect the whole economy, in the form of total factor productivity (Jones, 2011).

Based on the theoretical advancements mentioned before, the present analysis implements recent computational tools from network science to perform a multi-scale analysis of the Greek economy. The proposed methodological framework allows the identification of inter-sectoral clusters as well as group interactions between them. Moreover, it enables the identification and ranking of key sectors and critical sectors of the national economy. In turn, the results can provide useful insights into the formulation of a national growth plan to achieve long-term goals of economic development and stability.

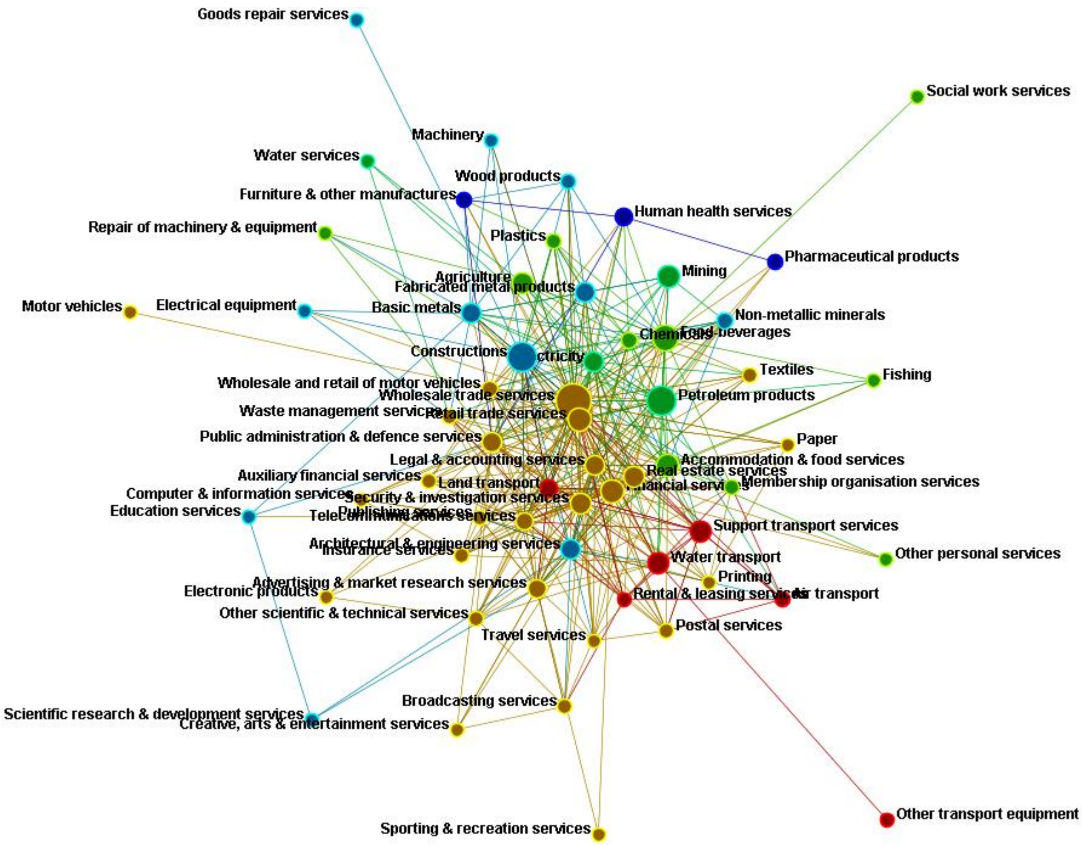
3. Identification of main sectoral clusters

Following the network representation of the Greek economy, based on the input-output matrix, the main activity clusters are identified. For this purpose, the statistical inference method of Newman's clustering (Clauset et al., 2004) is implemented for the accurate and efficient grouping of sectors into a small number of groups[3]. The method seeks to optimize the modularity Q, which is a metric of the quality of the

[3] The specific analysis of the network of the Greek economy is carried out with use of the ORA software.

grouping and it relies on the density of links inside communities as compared to links between communities. It is defined as $Q = (1/2m)\sum_{ij}\left[w_{ij} - (s_i s_j / 2m)\right]\delta(g_i, g_j)$, where w_{ij} represents the weight of the edge (i.e. amount of transaction) between sectors i and j, $s_i = \sum_j w_{ij}$ and $s_j = \sum_i w_{ij}$ are the sums of the edges attached to sectors i and j, respectively, g_i and g_j are the communities to which sectors i and j are assigned, δ function is 1 if $g_i = g_j$ and 0 otherwise, and $m = (1/2)\sum_{ij} w_{ij}$.

Figure 1: The network of inter-sectoral linkages and activity clusters of the Greek economy



Source: Own processing of the Greek input-output matrix for 2010, the last year with available data (ELSTAT), by use of ORA software. *Notes*: The size of nodes-sectors is proportional to their total degree. The coloring of nodes and their linkages is the same for each group of sectors, i.e. gold for trade and other services (Group 1), light blue for construction (Group 2), light green for agriculture, food and tourism (Group 3), turquoise for chemical and pharmaceutical industries and health services (Group 4), red for transport (Group 5), and deep blue for energy (Group 6). Flows larger than 1/5000 of the maximum flow are presented.

The results of the clustering analysis suggest the existence of six groups of sectors, which are illustrated with distinct colors in the national economy network shown in Figure 1. The identified groups are as follows: (i) trade and other services, which are not included in the other groups (*Group 1*), (ii) construction, including all relevant and supporting manufacturing sectors and services (*Group 2*), (iii) agriculture, food industry and tourism activities (*Group 3*), chemical and pharmaceutical industries and health services (*Group 4*), transport (*Group 5*) and energy (*Group 6*). These groups can be related to the particular and intrinsic characteristics pertaining to the network structure of the Greek economy. Similar to studies concerning other countries (Blöchl et al., 2011; McNerney et al., 2013), it is verified that inter-industry transactions in the Greek economy are tightly accumulated within a few groups of sectors.

Table 1 presents the six sectoral groups of the Greek economy and their main characteristics, in terms of density, connectivity and the external-internal (*EI*) link index. The connectivity index, whose values range from 0 to 1, offers an overall indication for the clustering of each group of sectors. It is measured through the global clustering coefficient (Luce and Perry, 1949; Wasserman and Faust, 1994; Watts and Strogatz, 1998), as it is further explained below. It depicts the average probability of future linkage between any two unconnected sectors, which are both connected with a third sector of the same group. The *EI* index, which takes values greater than 0 and lower than 1, signifies the openness of a group of sectors to the whole economic system, is defined for each group as the ratio:

$$\text{EI index} = \frac{\text{Number of external links} - \text{Number of internal links}}{\text{Total number of links}},$$

where the internal links join two sectors of the same group, while the external links join two sectors from different groups. As it is shown in Table 1, *Group 1* of trade and other services is the largest one, with respect to the number of constituent sectors (28). It composes also the most introverted group (*EI* index=0.23), in the sense that its constituent sectors mostly tend to be linked with each other, rather than with sectors of other groups. On the contrary, *Group 6* of activities related to energy is the smallest one (4 sectors), but also the most extroverted one (*EI* index=0.91), namely, it has the largest interconnection with sectors of other groups, relative to sectors of the same group.

Table 1: The sectoral groups of the Greek economy and their main characteristics

Group 1*: Sectors:* 28, *Density:* 0.475, *Connectivity:* 0.632, *EI:* 0.227
Textiles, Paper industry, Printing, Electronic products, Motor vehicles, Waste management services, Wholesale and retail of motor vehicles, Wholesale trade services, Retail trade services, Postal services, Publishing services, Broadcasting services, Telecommunications services, Computer & information services, Financial services, Insurance services, Auxiliary financial services, Real estate services, Legal & accounting services, Scientific research & development services, Advertising & market research services, Other scientific & technical services, Travel services, Security & investigation services, Public administration & defense services, Education services, Creative, arts & entertainment services, Sporting & recreation services
Group 2*: Sectors:* 10, *Density:* 0.356, *Connectivity:* 0.503, *EI:* 0.786
Forestry, Wood products, Non-metallic minerals, Basic metals, Fabricated metal products, Electrical equipment, Machinery, Constructions, Architectural & engineering services, Goods repair services
Group 3*: Sectors:* 7, *Density:* 0.405, *Connectivity:* 0.450, *EI:* 0.840
Agriculture, Fishing, Food-beverages, Repair of machinery & equipment, Accommodation & food services, Membership organisation services, Other personal services
Group 4*: Sectors:* 6, *Density:* 0.433, *Connectivity:* 0.392, *EI:* 0.856
Chemicals, Pharmaceutical products, Plastics, Furniture & other manufactures, Human health services, Social work services
Group 5*: Sectors:* 6, *Density:* 0.667, *Connectivity:* 0.683, *EI:* 0.817
Other transport equipment, Land transport, Water transport, Air transport, Support transport services, Rental & leasing services
Group 6*: Sectors:* 4, *Density:* 0.583, *Connectivity:* 0.583, *EI:* 0.914
Mining, Petroleum products, Electricity, Water services

In general, the tendency of a sectoral group to create sub-groups of activities is denoted in the case where its connectivity (global clustering coefficient) is higher than its density. The global clustering coefficient is measured as the ratio of the number of sectoral triangles with complete connections among each other, to the total number of sectoral triangles, which are formed with at least two linkages among them. Thus, the tendency of sub-group formation is higher in the two largest groups, namely, in *Group 1* of trade and other services and *Group 2* of construction activities. In opposite, this tendency is smaller in *Group 3* of agriculture, food and tourism, and *Group 5* of transport.

Amongst others, these results suggest the need to increase interconnectivity, through the cooperation and establishment of new synergistic schemes among the activities of agriculture, food industry and tourism services. In addition, they stress the need to enhance interconnectivity and interoperability among (passenger and freight) transport modes, through developing and upgrading facilities and services that facilitate combined transport operations and integrated logistics schemes[4].

Table 2: Matrix of significant interrelationships among the sectoral groups of the Greek economy

	Trade & Other Services	Construction	Agri-Food & Tourism	Chems-Pharmas-Health	Transport	Energy
Trade & Other Services	1	0	1	0	1	0
Construction	0	1	0	0	0	0
Agri-Food & Tourism	0	0	1	0	0	0
Chems-Pharmas-Health	0	0	1	1	0	0
Transport	0	0	0	0	1	0
Energy	1	1	1	1	1	1

[4] Detailed examples and suggestions regarding the formulation of an integrated strategic transport policy in Greece are provided in Tsekeris (2013).

In order to represent the pattern of influence of one sectoral group on the other groups, the method of comparing the density of directional links among each pair of groups, in relation to the total density of links in the whole economy network, is employed (McCulloh et al., 2013). In the case where the measure of the former (group-pair) density is larger than that of the latter (total) density, then, it is considered that there is a significant influence of one group on the other. This network of inter-group relationships is illustrated here in a matrix form in Table 2, wherein a significant impact is represented with an entry equal to 1, or, otherwise, 0.

The largest number of significant inter-group relationships originates from the group of energy (towards all the other groups). Other significant inter-group relationships originate from the group of trade and other services (towards those of agriculture, food industry and tourism, and transport), and from the group of chemical and pharmaceutical industries and health services (towards that of agriculture, food industry and tourism).

These patterns indicate the limited extent of cooperation and synergistic effects among different sectoral groups or activity clusters. In turn, they suggest the need for increasing connectivity between groups/clusters of the national economy, in order to enhance its overall efficiency and robustness. In particular, the results demonstrate that structural changes/improvements in the energy sectors, such as those of electricity production and distribution (e.g., through promoting renewable energy sources and more efficient-smart energy management systems), are expected to have benefits which would be mostly diffused into the other groups of sectors of the Greek economy.

4. Key sectors and critical sectors and links of the Greek economy network

4.1 Results of centrality measures

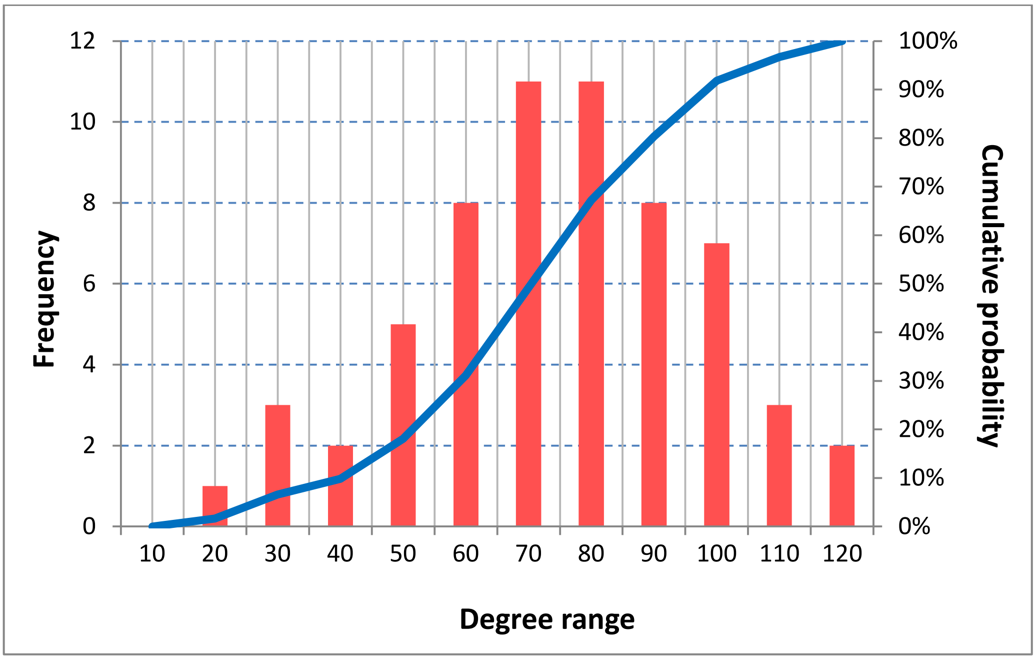
The identification of the (potential) influence of each sector on the whole economy network and, hence, of the key sectors, is based on the calculation of some important centrality measures. The consideration of diverse centrality measures allows classifying and interpreting various economic sectors in accordance with different development policy objectives (e.g., efficiency, stability, resilience). Specifically, four basic centrality measures are calculated here, i.e., degree centrality, betweenness centrality, closeness centrality and eigenvector centrality, as described in the following paragraphs. The detailed results of all network centrality measures and relevant ranking for each sector are presented in Table 3.

(a) *Degree centrality*: it refers to the total degree (number of connections) that a sector possesses in the network. Figure 2 shows the total degree distribution, which indicates that about 2/3 of the sectors have up to 80 connections in the network. Hence, this type of network (national economy) can be considered as being different than most of the other (social, information, technological) network types usually met in the literature (Newman et al., 2006; Caldarelli, 2007; Katerelos et al., 2013), which are characterized by exponential and power-law (or scale-free) degree distributions with very long right tails.

The increase of the total degree of the Greek economic sectors is generally found to have a statistically significant positive impact on the amount of input-output flow among them (Figure 3). Specifically, such high-degree sectors as the wholesale and retail trade, financial services, construction, accommodation & food services, petroleum products and food & beverages, perform the largest amount of purchases/sales in the system.

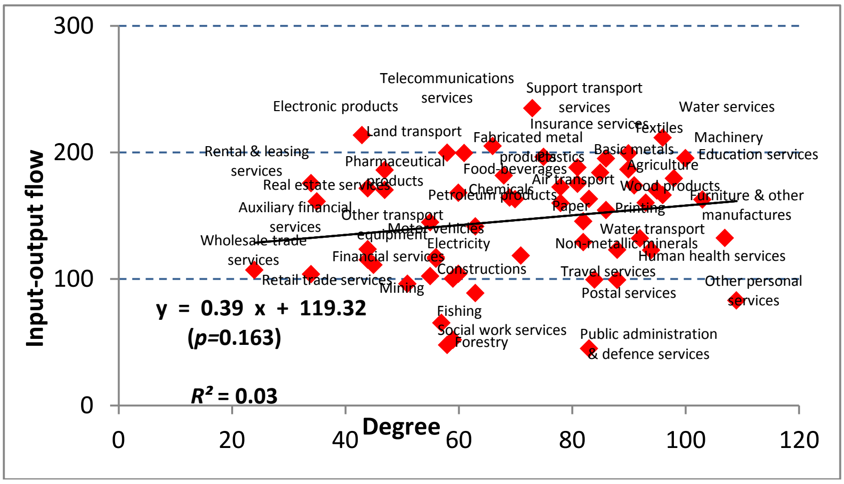
The connectivity, in terms of the total degree, is found to be very low correlated with and have a statistically insignificant impact on small-size transaction flows (<10 million euro). However, this relationship is found to have a high correlation (R^2=0.85 and R^2=0.76, respectively) and becomes statistically significant for both moderate (between 10 and 100 million euro) and high (>100 million euro) transaction flows. Thus, strengthening the interconnectivity and value agglomeration among sectors is expected to yield significant economies of size and to boost the rate of economic development in the country.

Figure 2: Frequency histogram and cumulative probability of the degree (total number of linkages) of the Greek economy sectors

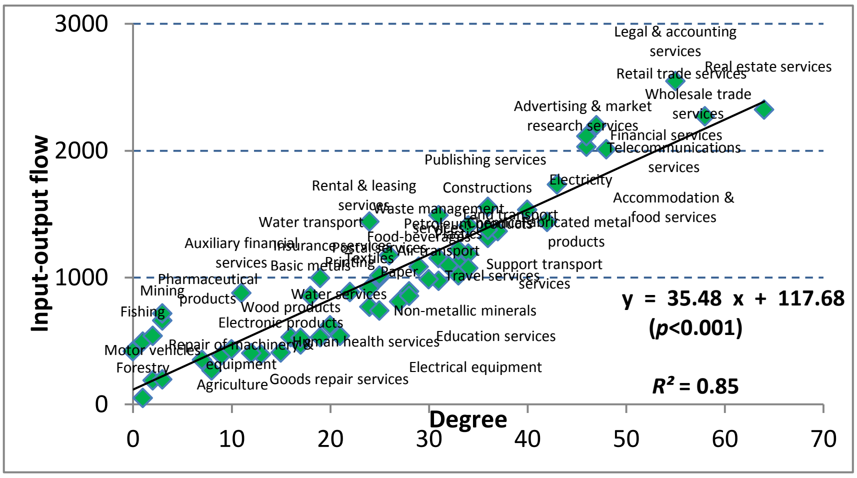


Let us denote as a_{ij} the entry in the adjacency matrix A, which takes the value 1 if there is an edge (directional connection) between the sector i and sector j (then, these two sectors are referred to as adjacent or connected), otherwise it is 0. The row degree (or out-degree) of sector i is defined as $d_i = \sum_j a_{ij}$ and its column degree (or in-degree) is defined as $d_j = \sum_i a_{ij}$. Then, the degree centrality is calculated here as the normalized sum of the row degree and column degree of each sector, that is, the sum of the outgoing links and incoming links, respectively. An increased degree centrality generally relates to higher capability for a sector to exercise influence on, have access to and exchange information/resources with other sectors. Thus, based on the present results (Table 3), the sectors of the wholesale trade services, petroleum products, construction, food industry and financial services can be regarded as the most influential and potential leaders in their own groups as well as in the whole network.

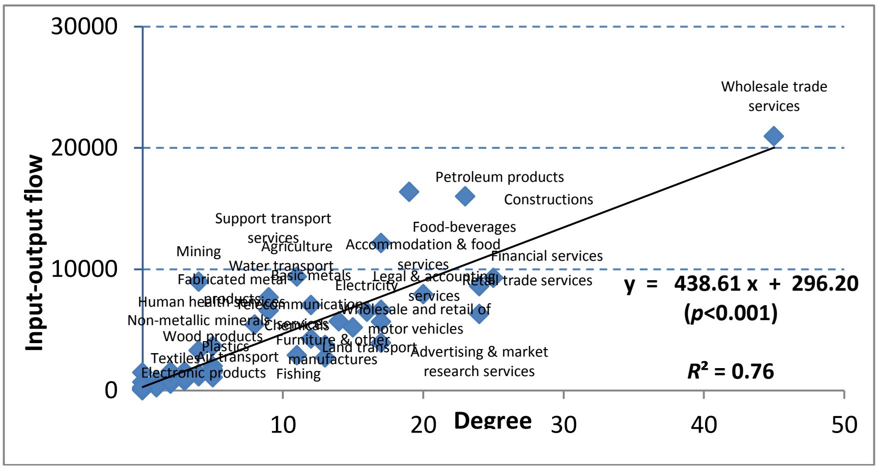
Figure 3: Relationship between the input-output flow (in million euro, basic current prices of 2010) and the degree of each sector of the Greek economy, for (a) flows<10 million euro, (b) 10<flows<100 million euro, and (c) flows>100 million euro.



(a)



(b)



(c)

(b) *Betweenness centrality*: it is defined as the ratio of the sum of shortest paths (namely, most efficient –with the minimum number of links– value chains) that pass through a sector to the total number of shortest paths between any two other connected sectors. Namely, by denoting as v_{jki} the number of shortest value chains that pass through sector *i* and v_{jk} the total number of shortest value chains connecting sectors *j*-*k*, the betweenness centrality of sector i is defined as $bc_i = \sum_{j,k \neq i} v_{jki} / v_{jk}$. By denoting as N the number of sectors, this measure is normalized by dividing bc_i with $[(N-1)(N-2)]$. Sectors with increased betweenness centrality may be regarded as potential influential, in terms of their ability to most influence the diffusion of resources among other sectors, by facilitating, mediating, hindering or modifying the connections between them. They bear the influence of their own group onto the other groups and they can also be considered as critical for the stability and resilience of the whole economy network. As shown in Table 3, such sectors mainly refer to wholesale trade services, accommodation and food services (tourism), constructions, petroleum products and financial services.

(c) *Closeness centrality*: it concerns the inverse of the average distance D_{ij}^{-1} (that is, the number of connections or walks, which comprise the value chain linkages) from one sector i to all other sectors $j \neq i$ in the economy network. Specifically, the (normalized) measure of closeness centrality cc_i for sector i can be expressed as $cc_i = \sum_j D_{ij}^{-1} / (N-1)$. Sectors with increased closeness centrality may be considered as having an influence on a larger number of other sectors, compared to those sectors with smaller closeness centrality. This is because closeness can be associated with a relatively low cost of access to resources or transaction with other sectors. Sectors with high closeness centrality (Table 3) are mainly those of telecommunication services, insurance services, electronic products, paper industry, and computer & information services.

Table 3: Results of network centrality measures and relevant ranking for the Greek economy sectors (top 10 sectors for each metric are grey shaded)

Sector	Degree centrality		Betweenness centrality		Closeness centrality		Eigenvector centrality	
	Value	*Rank*	Value	*Rank*	Value	*Rank*	Value	*Rank*
Agriculture	0.009	*11*	0.072	*10*	0.230	*53*	0.228	*6*
Forestry	0.000	*61*	0.000	*34*	0.189	*58*	0.000	*61*
Fishing	0.001	*54*	0.000	*35*	0.078	*60*	0.015	*46*
Mining	0.010	*7*	0.000	*36*	0.215	*54*	0.771	*2*
Food-beverages	0.013	*4*	0.136	*6*	0.325	*16*	0.251	*4*
Textiles	0.002	*41*	0.000	*37*	0.311	*22*	0.020	*40*
Wood products	0.002	*34*	0.017	*22*	0.322	*17*	0.025	*36*
Paper	0.002	*44*	0.000	*38*	0.353	*4*	0.016	*43*
Printing	0.002	*45*	0.003	*26*	0.285	*38*	0.015	*45*
Petroleum products	0.017	*2*	0.172	*4*	0.312	*21*	0.879	*1*
Chemicals	0.004	*25*	0.001	*29*	0.326	*15*	0.061	*23*
Pharmaceutical products	0.002	*33*	0.000	*39*	0.285	*37*	0.019	*41*
Plastics	0.003	*27*	0.006	*23*	0.300	*30*	0.045	*28*
Non-metallic minerals	0.004	*26*	0.000	*40*	0.293	*32*	0.100	*19*
Basic metals	0.007	*18*	0.102	*8*	0.315	*18*	0.089	*21*
Fabricated metal products	0.007	*17*	0.017	*19*	0.295	*31*	0.117	*16*
Electronic products	0.001	*53*	0.000	*41*	0.366	*3*	0.007	*55*
Electrical equipment	0.001	*47*	0.000	*42*	0.345	*7*	0.021	*37*
Machinery	0.001	*52*	0.000	*43*	0.262	*48*	0.010	*50*
Motor vehicles	0.000	*59*	0.000	*44*	0.249	*51*	0.004	*59*
Other transport equipment	0.000	*60*	0.000	*45*	0.210	*56*	0.003	*60*
Furniture & other manufactures	0.002	*36*	0.000	*31*	0.288	*35*	0.020	*38*
Repair of machinery & equipment	0.001	*49*	0.000	*46*	0.306	*28*	0.011	*48*
Electricity	0.007	*16*	0.022	*16*	0.307	*27*	0.192	*7*
Water services	0.001	*51*	0.000	*47*	0.276	*42*	0.011	*49*
Waste management services	0.003	*28*	0.005	*24*	0.338	*8*	0.046	*27*
Constructions	0.017	*3*	0.185	*3*	0.279	*39*	0.248	*5*
Wholesale and retail of motor vehicles	0.004	*24*	0.017	*21*	0.337	*9*	0.067	*22*
Wholesale trade services	0.023	*1*	0.587	*1*	0.310	*24*	0.364	*3*
Retail trade services	0.011	*6*	0.002	*28*	0.329	*12*	0.168	*10*
Land transport	0.005	*22*	0.057	*12*	0.306	*29*	0.119	*15*
Water transport	0.008	*14*	0.017	*20*	0.272	*43*	0.191	*8*
Air transport	0.002	*35*	0.000	*33*	0.308	*26*	0.035	*31*
Support transport services	0.009	*10*	0.003	*27*	0.331	*10*	0.152	*12*
Postal services	0.002	*37*	0.000	*48*	0.268	*45*	0.016	*44*
Accommodation & food services	0.010	*8*	0.225	*2*	0.326	*14*	0.152	*11*
Publishing services	0.003	*29*	0.017	*18*	0.310	*23*	0.026	*35*
Broadcasting services	0.002	*32*	0.004	*25*	0.346	*6*	0.014	*47*
Telecommunications services	0.006	*20*	0.018	*17*	0.372	*1*	0.060	*24*
Computer & information services	0.002	*42*	0.000	*49*	0.351	*5*	0.017	*42*
Financial services	0.012	*5*	0.171	*5*	0.314	*19*	0.172	*9*
Insurance services	0.002	*38*	0.000	*50*	0.372	*2*	0.028	*34*
Auxiliary financial services	0.002	*39*	0.000	*51*	0.293	*33*	0.031	*32*
Real estate services	0.009	*9*	0.088	*9*	0.329	*13*	0.141	*13*
Legal & accounting services	0.008	*13*	0.033	*14*	0.255	*50*	0.106	*18*
Architectural & engineering services	0.007	*15*	0.041	*13*	0.262	*49*	0.110	*17*
Scientific research & development servic	0.001	*48*	0.000	*32*	0.149	*59*	0.004	*58*
Advertising & market research services	0.006	*21*	0.118	*7*	0.234	*52*	0.049	*25*
Other scientific & technical services	0.003	*30*	0.000	*52*	0.312	*20*	0.037	*29*
Rental & leasing services	0.002	*43*	0.000	*53*	0.278	*40*	0.020	*39*
Travel services	0.002	*40*	0.000	*54*	0.277	*41*	0.030	*33*
Security & investigation services	0.009	*12*	0.060	*11*	0.330	*11*	0.124	*14*
Public administration & defence services	0.007	*19*	0.000	*55*	0.000	*61*	0.096	*20*
Education services	0.001	*50*	0.000	*56*	0.310	*25*	0.007	*54*
Human health services	0.004	*23*	0.000	*30*	0.262	*47*	0.047	*26*
Social work services	0.000	*58*	0.032	*15*	0.214	*55*	0.007	*56*
Creative, arts & entertainment services	0.001	*46*	0.000	*57*	0.286	*36*	0.009	*51*
Sporting & recreation services	0.001	*55*	0.000	*58*	0.269	*44*	0.005	*57*
Membership organisation services	0.003	*31*	0.000	*59*	0.264	*46*	0.037	*30*
Goods repair services	0.000	*57*	0.000	*60*	0.291	*34*	0.008	*53*
Other personal services	0.001	*56*	0.000	*61*	0.194	*57*	0.008	*52*
Average	**0.005**		**0.037**		**0.284**		**0.093**	

(d) *Eigenvector centrality*: it calculates the centrality of each sector in terms of the principal eigenvector of the economy network. The defining relationship of an eigenvector is $\lambda v = Av$, or $(A - \lambda I)v = 0$, where A is the adjacency matrix, I is the identity matrix, λ is a constant (the eigenvalue) and v is the eigenvector. An eigenvector is proportional to the row sums of a matrix formed by summing all powers of A matrix, weighted by the corresponding powers of the reciprocal of the eigenvalue. Hence, this measure considers the number of connections or walks from one sector to groups of other sectors. An increased eigenvector centrality of one sector denotes that it is connected with other groups or sectors with high connectivity (clustering coefficient). Therefore, sectors with increased eigenvector centrality have a potentially leading or large influence in the economy network, compared to other sectors which are isolated or have limited connections. Such sectors (Table 3) mainly refer to the petroleum products and mining, with the sectors of wholesale trade services, food & beverages, constructions, water transport and agriculture to follow by far.

Each of the network centrality measures examined before represents a different process by which the key sectors may influence the flow of transactions within the national economy. Although they are conceptually distinct, a considerable conceptual overlap may also exist between them. Table 4 shows that half of the correlations between the network centrality measures are statistically significant, i.e., among the degree and betweenness centrality (0.69), the degree and eigenvector centrality (0.72), and the betweenness and eigenvector centrality (0.45). By and large, the relatively moderate degree of correlation indicates that, on the one side, there is no redundancy in measuring those metrics, and, on the other side, they measure separate mechanisms of how the influence or power of one sector is diffused into and pull the other ones.

Table 4: Correlation analysis of the network centrality measures and the output demand multiplier (*DM*) of each sector of the Greek economy

	Degree	*Betweenness*	*Closeness*	*Eigenvector*	*DM*
Degree	1.000				
Betweenness	**0.685 [0.000]**	1.000			
Closeness	0.022 [0.865]	0.120 [0.358]	1.000		
Eigenvector	**0.715 [0.000]**	**0.449 [0.000]**	0.016 [0.902]	1.000	
DM	0.201 [0.121]	0.205 [0.113]	-0.018 [0.890]	0.004 [0.976]	1.000

Notes: Brackets indicate *p*-values. Bold figures show correlation values with p<0.01.

In addition, the typical analysis of input-output tables is employed to identify key economic sectors[5]. Specifically, the output demand multiplier (*DM*) of each sector is calculated by use of the inverse Leontief matrix. These multipliers can provide a plausible metric of the demand-driven response of the system to external shocks or policy interventions in some sector. By denoting as w_{ij} the amount of inter-industry transaction flows (sales) from sector i to sector j, Y_i the total final demand for sector i's product, X_i the total output of sector i, and $b_{ij} = w_{ij} / X_i$ the corresponding technical coefficients, the input-output model of the economy can be expressed as $X_i = b_{i1} X_1 + \ldots + b_{ij} X_j + \ldots + b_{iN} X_N + Y_i$ for each sector $i = 1, \ldots, N$, or, in a matrix form, $X = B\,X + Y$, which yields $X = (I - B)^{-1}\,Y$. The term $(I - B)^{-1}$ is known as the Leontief inverse matrix. This matrix, denoted as L, takes into account both the direct and indirect effects, which induce more production (and employment) not only from sector i itself but also from all other related sectors, since more inputs are required. The output multiplier (also referred to as backward linkage measure) for sector i is calculated as the column sum of matrix L, which depicts the total output of all sectors given a one-unit's (one extra euro's) worth increase of the final demand for that sector's output. Table 4 demonstrates that the *DM* positively correlates with the network centrality measures, except for the closeness centrality, which mostly concerns neighboring effects among sectors. However, all these correlations are found

[5] Detailed analysis of the input-output tables and resulting multipliers in Greece is provided in Athanassiou et al. (2014).

to be relatively small and none of them statistically significant at the conventional levels of confidence. In particular, the largest correlations are observed between the *DM* and the measures of degree centrality (0.20) and betweenness centrality (0.21), at the confidence levels of 88% and 89%, respectively. Therefore, the network centrality metrics can be generally used to complement, if not to substitute, the Leontief-inverse-based method in order to identify the key sectors in the national economy.

4.2 The influence of sectors on the stability of the economy

The influence of individual sectors on the stability and resilience of the national economy network can be calculated within two measures. The first measure concerns the impact of a complete drop (by -100%) of the sales/purchases of one sector, e.g., due to a severe exogenous shock or a country-wide systemic failure, on the network fragmentation. It depicts the set of critical sectors whose failure would most adversely affect (fragment) the whole network connectivity. The calculation of fragmentation is based on the average number of connections that one sector i requires to transact with other sectors $j \neq i$ in the network. The second measure refers to the reach of each sector. It is calculated within the average-distance-weighted reach of each sector i on all other sectors $j \neq i$ in the economy network.

Table 5 presents the most critical set of sectors, in terms of their impact on network fragmentation and the reach to all other sectors. In the former case, it is observed that the set of most critical sectors is relatively more heterogeneous than the latter one, as it comprises diverse economic activities from the primary (agriculture, fishing), the secondary (various manufacturing activities, electricity, construction) and the tertiary (transport, financial and real estate services, education and other services) production sectors, which can mostly preserve the connectedness of the whole economy. The results concerning the reach to other sectors highlight the importance of various manufacturing industries (wood, paper and electronic products, and electrical equipment) and, particularly, the role of diverse types of services in safeguarding and facilitating the propagation of transaction flows within the network. Hence, these most critical sectors might strengthen value chains and enhance them, through helping to integrate production processes that involve different tradable goods and services.

Table 5: The most critical set of sectors in terms of their impact on network fragmentation and their reach to all other sectors

Impact on network fragmentation	Reach of impact on whole network
Agriculture	Food & beverages
Fishing	Wood products
Food & beverages	Paper industry
Wood products	Chemicals
Printing	Basic metals
Petroleum products	Electronic products
Chemicals	Electrical equipment
Plastics	Waste management services
Fabricated metal products	Wholesale and retail of motor vehicles
Machinery	Retail trade services
Electricity	Support transport services
Construction	Accommodation & food services
Water transport	Broadcasting services
Air transport	Telecommunications services
Financial services	Computer & information services
Insurance services	Financial services
Auxiliary financial services	Insurance services
Legal & accounting services	Real estate services
Education services	Other scientific & technical services
Other personal services	Other personal services

Last, a third measure concerning the robustness of the national economy network refers to the most influential links among sectors. These links are identified through calculating the edge betweenness centrality (bc), that is, the ratio of the number of shortest paths (with the minimum number of connections) between a pair of connected sectors that pass through the specific link to the total number of shortest paths among that pair. Table 6 indicates in order the most influential links of the Greek economy network, in terms of the normalized value their betweenness centrality. The results largely depict the importance of the financial sector services as well as of those sectors related to information and communication technologies (telecommunication services, computer & information services and electronic products) on retaining the robustness of the whole economy. This outcome may also signify the reliance of the total economic activity on networking, the liquidity conditions and the appropriate level of financing, whose deficiency was crucial for the outbreak and persistence of the current recession in the country.

Table 6: The most potentially influential links of the Greek economy network

Potentially influential links	Normalized edge *bc* value
Financial services – Electronic products	0.031
Publishing services - Financial services	0.029
Food & beverages – Textiles	0.029
Other scientific & technical services – Agriculture	0.027
Education services – Telecommunications	0.026
Computer & information services – Telecommunications	0.025
Wholesale trade – Computer & information services	0.025
Publishing services – Trade of motor vehicles	0.023
Advertising & market research – Auxiliary financial services	0.022
Auxiliary financial services – Broadcasting services	0.022
Education services – Wholesale trade	0.022
Food & beverages – Support transport services	0.021
Other scientific & technical services – Publishing services	0.020
Human health services – Wholesale trade	0.019
Human health services – Financial services	0.019
Real estate services – Other scientific & technical services	0.018
Motor vehicles – Waste management services	0.018
Forestry – Wood products	0.018
Pharmaceutical products – Food & beverages	0.018
Other personal services – Accommodation & food services	0.017

5. Conclusions

A national long-range strategy of sustainable economic development requires a coherent set of interrelated policies and actions in crucial sectors and activity clusters to pull forward the growth process. Targeted structural reforms and allocation of resources into those sectors are necessary to ensure the efficiency and robustness of the resulting production system. This paper suggests a methodological framework underpinned by the graph theory and network science, to support development policy making in the above issues. More specifically, the structural network analysis of the Greek economy, based on the most recently published input-output table, helps to identify key sectors, critical sectors and distinct groups of tightly-knit economic activities. The various network centrality metrics can be generally considered as complements with each other, as well as with the Leontief-inverse-based (or backward-linkage) measure to determine key sectors. The metrics of degree centrality and betweenness centrality can be regarded as the most correlated ones with the latter measure.

By and large, a development strategy involving the increase of the density of the economy network and clustering of the sectors and activity groups can potentially enhance the diffusion of growth and the production of larger value and higher quality tradable goods and services. Especially, the synergies resulting from the creation of integrated value chains, from the primary production and processing to the distribution, consumption and export, will enable to combine comparative advantages of different sectors and develop knowledge spillovers and innovative practices. Moreover, the increased interactions among specific sectors and activity groups are expected to strengthen the stability of the growth process and diminish the vulnerability of the whole network.

In particular, it is found that such activities as agriculture, fishing, food & beverage production and tourism services exhibit increased value accumulation. Hence, their policy coordination would arguably result in economies of scale and relevant horizontal investments would induce higher multiplier effects on the total economy, compared to individual actions in each of those sectors separately. Similar effects might be triggered by coordinating investment in different transport modes and their support services. Further benefits could be obtained from establishing more and stronger linkages among sectors belonging to different groups, such as those of construction, transport, energy, and trade and other services (mostly related to information and communication technologies).

Based on the current network analysis, key sectors which may potentially contribute to the restructuring of the Greek economy network, by favoring the production of tradable goods and services, are as follows:

(i) products and services related to information and communication technologies,

(ii) construction materials (e.g., metals and wood products) and construction services, mostly those associated with other key sectors,

(iii) innovative agricultural products, food and tourism services,

(iv) support transport (logistics) services and water transport (seaport) services,

(v) electricity production and distribution, and mining.

Some of the above key sectors, such as those relevant with information and communication technologies, electricity, agriculture and (construction-related) manufacturing, can be also regarded as critical sectors. Other critical sectors which could mostly preserve the stability and resilience of the whole economic system are those of wholesale trade, petroleum products and financial sector services. Structural reforms in those critical sectors may potentially have a considerable influence on the clustering of production activities and the connectedness of sectoral clusters, while their benefits may be significantly diffused and have a general impact on the total network.

Last, the density of the economy network and the efficiency and robustness of the total economic activity could be further increased in several ways. Specifically, the promotion of the circular economy model, which involves the waste management and circulation of material flows, can considerably enhance connectivity among production activities and consumption services. Other examples concerning the increase of inter-sectoral linkages relate to activities which aim to improve the efficiency of key economic sectors, such as technological products and services that upgrade the performance of agriculture, energy and transport systems. In this context, a new national industrial policy is required to emphasize on increasing the added value shares of high-technology manufacturing sectors. The significant role of high-technology products also underlines the importance of upgrading education services and research & development to promote knowledge spillovers and innovation practices and, hence, increase the added value and quality of intermediate and final goods and services.

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