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Exploring the backward and forward linkages of production network in a developing country

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This paper applies social network analysis (SNA) techniques to the input–output table in order to investigate the production network of Pakistan's economy. Through different network measures, it identifies the sectors that exert significant direct and indirect impacts on other sectors. The findings reveal that, overall, sectors have weak forward linkages relative to backward linkages. The services sectors, particularly transportation and trade services, have the highest out-degree (a measure of forward linkages). In contrast, the manufacturing sectors demonstrate comparatively lower connectivity than the services sectors. The sectors of electricity, petroleum, and chemicals emerge as the most widely utilized inputs across various industries. Despite their relatively moderate immediate absorption in downstream industries, these sectors possess the potential to affect other industries indirectly. Considering the combined measures of network analysis, these sectors also emerge as the most crucial sectors in Pakistan's production network. This suggests that enhancing efficiency in the energy, refining, and petrochemical industries will yield the highest economy-wide impact.

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Introduction

Almost all the major events, such as the Great Depression and the Oil price shock of the 1970s, affected a particular industry or technology that propagated throughout the economy and affected the world economy. Understanding the propagation mechanism of these shocks is important as such events have shaped the macroeconomic theory and affected the way policymakers address the disruptions in economic activity (Acemoglu et al., 2015). In this context, it is pertinent to consider an economy as a network of interlinked production units, each depending on their input suppliers to produce output, which, in turn, is forwarded to other downstream units (Oberfield, 2018). The network theory helps understand the underlying structure of the production network and the interdependence of different nodes within a production network to better inform the policymakers to recover from adverse shocks (Elliott et al., 2022).

From Pakistan's perspective, two events have brought to the forefront the importance of interconnections at the firm and sector level in understanding the variations in aggregate economic performance and the reasons why some sectors are more affected by shocks than others. Consider first the floods in Pakistan that resulted in the significant destruction of human and physical capital. Its effects would have been largely restricted to the affected areas if it were unconnected from other sectors. The floods disrupted the national economy and supply chains that it entailed (Jamshed et al., 2021). Second, the growing phenomenon of power load shedding, particularly after 2007–08, emerged as one of the key supply-side constraints to the growth of Pakistan's economy. It led to significant losses in output, employment, exports, and a decline in private investment. This not only directly affected the sectors that use electricity/power as a major input, but it also indirectly affected other primary sectors such as agriculture, financial services, retail trade, and transportation services (Rauf et al., 2015; Nawaz and Alvi, 2018).

As Carvalho (2014) explains, the common theme in the above two examples is that disruptions through the critical nodes in a network of production expose the aggregate economy to a recession. According to Carvalho (2014), there are two reasons why aggregate fluctuations may arise in the economic structure dominated by a small number of hubs supplying inputs to many firms and sectors. Firstly, disruptions in economic activity in one major hub-like production unit can propagate throughout the production network and affect aggregate economic performance, much in the same way as flight delays and cancellations at a major airport have a disruptive impact on flight schedules throughout the country. There are no close substitutes, at least in the short run; therefore, respective users are affected by disturbances at the source. Secondly, the presence of these hubs provides shortcuts through which these supply chain networks become easily navigable. That is, hubs shorten distances between otherwise disparate parts of the economy that do not directly trade inputs. The above two examples highlight the role of interconnectedness in the propagation of shocks from one sector to the whole economy in the face of major disruptions. Even absent these major disruptions, understanding the interconnectedness of different sectors within an economy is required to better understand the circular flow of the economy and formulate economic policies to stimulate and resolve bottlenecks to economic growth. For instance, if government plans to reallocate public expenditures to sectors that have relatively higher backward and forward linkages, then that reallocation can have a higher economywide impact.

The production networks these days are very complex, with multi-layer international and local sourcing and technology-enabled business models, which are constantly evolving. Any such complex network requires a different set of techniques that inform about the network properties, linkages between different sectors, and transmission mechanism of shocks. One such technique is the social network analysis (SNA) approach. SNA comprises a set of techniques to analyze the patterns of relationships between actors (Knoke and Yang, 2019). The relationship between actors can be of many types, including exchange of information, goods and services, transfer of technology, information, or expenditures. In addition, the actors can be individuals, institutions, community organizations, or industries. The SNA focuses on relationship patterns, such as who exchanges information with whom, which industries provide key inputs to other industries, and which community organizations are more closely connected. Furthermore, it offers different measures and tools to visually represent and quantify a network's characteristics and track how they grow and change over time (Correa and Ma, 2011).

The social network analysis approach considers network ties as channels through which many things flow, such as information about job openings (Granovetter, 1995), disease (Morris, 1993), inter-bank financial contagion (Summer, 2013), and crimes (Reiss, 1988). This approach has wide-ranging applications, but it is used mainly to explore the actors or network positions that are most likely to receive flows, actors with the highest impact on the whole network, and rapidly transfer shocks to other actors. More recently, network characteristics have also been analyzed using econometric techniques such as fixed-random effect models, Dyadic regression, event study models, etc. (Graham, 2020). The selection of econometric models depends on their suitability according to the characteristics of networks, availability of data, and objective of the network-based analysis, i.e., impact analysis, process evaluation, or formative analysis to improve a program.

One of the leading examples is the SNA approach utilized by Hidalgo et al. (2007) to measure the evolution of international trade at the product level and map product space. Their analysis of international trade using network analysis provided the basis for various new measures related to export potential and potential for diversification. More recently, Liu and Kim (2019) used the SNA approach and the Input–output (IO) relationship between sectors to evaluate the production-inducing effects of the various sectors, and Lee (2019) analyzed the transmission of domestic and external shocks through the IO network. These studies highlight the importance of network structures in the transmission of economic shocks and provide powerful visualizations that enhance understanding of the transmission mechanism.

The contribution of this paper lies in its exploration of Pakistan's production network using an input–output (IO) table, focusing on the application of social network analysis (SNA) techniques. The absence of research on Pakistan related to network analysis of IO tables makes this study significant and valuable. Also, IO table analysis using SNA techniques is lacking in the case of developing countries. By utilizing SNA, the study aims to uncover the underlying structure of Pakistan's production network, analyze the characteristics of the production network, and identify influential sectors using measures derived from SNA. By employing these techniques, the study aims to enhance understanding of the transmission mechanism of government policies and provide visualizations that aid in comprehending the network dynamics. First, the input–output table is used to compute linkages between sectors. Second, the measures from social network analysis are used to analyze the characteristics of Pakistan's production network, including the key influential sectors in the production network from different perspectives. The next section provides a theoretical background and basic IO model, followed by details of data and methodology, results and discussion, and the final section concludes.

Theoretical background

Basic IO model. The interindustry analysis is usually conducted to highlight linkages between key industries in domestic and international production networks and to provide bases for making strategies and policies of economic development. The literature on inter-industry analysis mostly utilizes input-output (IO) tables in analyzing the inter-linkages between different sectors of the economy and their implications for propagation shocks (Inoue and Todo, 2019), environmental spillovers (Muller, 2016; Førsund, 1985), value addition and exports (Antràs et al., 2012). This study utilizes the IO table for Pakistan and Network Analysis methods to measure and visualize the network characteristics of industries.

The measures of network analysis and its applications to economic analysis are growing, particularly for input–output networks. For instance, Blöchl et al. (2011) analyzed the propagation and length of shocks throughout the economy using measures of network analysis. Montresor and Marzetti (2009) analyze the innovation process in OECD economies using IO tables. One of the leading examples is the network approach utilized by Hidalgo et al. (2007) in measuring the evolution of international trade at the product level and mapping product space. Their analysis of international trade using network analysis provided the basis for various new measures related to export potential and potential for diversification.

In addition to compelling visuals, network analysis provides a large number of measures to understand various aspects of the connectedness of a particular node (industry) in the network (production/value chains). For instance, the network matrices help in measuring the relative importance of a particular industry in the overall production network based on its linkages with the number of industries. One of the basic measures in this regard is degree centrality, which gives relative importance to a node based on its connectivity with the rest of the nodes in the network. Formally, it is calculated based on the number of connections of a node. The in-degree and out-degree versions of degree centrality measures are based on the direction of links coming in and out of a particular node, respectively.

From the IO table, using input use (x) of sector j from sector i, and output (X) of sector j, input coefficients are computed using the following equation:

$$a_{ij} = \frac{x_{ij}}{X_i} \tag{1}$$

The input coefficients show the importance of industry i as an input supplier to industry j and are interpreted as the value of inputs from sector i per unit of output of sector j. Given the vector of input coefficients, the vector of total output can be expressed in terms of intermediate input (AX) and final demand (Y) as follows:

$$AX + Y = X \tag{2}$$

$$X = (I - A)^{-1} Y = l_{ij} y \tag{3}$$

Finally, $(I - A)^{-1} = L = [l_{ij}]$ is known as the Leontief inverse or total requirement matrix. The elements (l_{ij}) of the Leontief inverse matrix (L) show that if the final demand of sector j increases by one unit, the total output of sector i increases by l_{ij} units directly or indirectly. In other words, l_{ij} measures the importance of sector i as a direct and indirect input supplier to industry j.

Data and methodology. In addition to compelling visuals, network analysis provides a large number of measures to better understand various aspects of the connectedness of a particular node (industry) in the network (production/value chains). For instance, the network matrices help in measuring the relative importance of industry in the overall production network based on its linkages with the number of industries.

One of the basic measures is degree centrality, which gives relative importance to a node based on its connectivity with the rest of the nodes in the network. A degree of centrality is the extent of local connectivity, i.e., nodes with lots of neighbors are central. Formally, it is calculated based on the number of connections of a node as follows:

$$C_{\mathrm{D}}(n_i) = \sum_j x_{ij}$$

where C_{D} is the degree centrality of a node (sector), n_i is the sum of all its connections with other nodes (sectors) (j), and x is a matrix of relationships. This measure is an indicator that allows knowing the importance score based on the number of direct relations of each node (sector) within a network (Laghridat and Essalih, 2023). The in-degree and out-degree versions of degree centrality are based on the direction of links coming in and out of a particular node, respectively. In our case, we are more interested in relative importance linkages between sectors. Therefore, we use elements of the inverse Leontief matrix as weights.

Different measures explain the connectedness of nodes in a network; each gives a different dimension as follows:

i. The closeness centrality or *geographic centrality* measures how close a node is to all other nodes in the network. A node at the geographic center would have higher closeness centrality. Also, a node may have relatively few direct connections but is well-positioned due to the presence of highly connected nodes, as the direct connection will have high closeness centrality as this measure quantifies the proximity of a node to others in terms of geodesic distance.

ii. The betweenness centrality is *transit centrality* will be higher for nodes where a lot of transit *can* happen. For example, in Fig. 1B, the shortest path to go from one node A to another C is A–B–C. If a node has strong betweenness centrality it means it is situated on many shortest paths in the network. Nodes with higher betweenness centrality can be considered critical because they offer a direct path between otherwise disconnected clusters. Betweenness centrality is formally measured as follows:

$$C_{\mathrm{B}}(n_i) = \sum_{j>k} \frac{g_{jk}(N_i)}{g_{jk}}$$

where g_{jk} is the number of shortest paths between any two nodes (sectors other than n_i) and $g_{jk}(N_j)$ is the number of those paths that contain sector, n_i. In Fig. 1A, the betweenness centrality of node F is $3/13 = 0.23$, because it is located on the three shortest paths in the graph out of the thirteen possible shortest paths between any two nodes.

iii. The eigenvector centrality or authority is the nodes connected to central nodes that are central themselves (recursive approach). In other words, sometimes, being connected to many other nodes is not critical, but being connected to the most influential nodes is more important. This is, in a way, an improved version of the closeness centrality measure as it shows whether a node has a higher proportion of its connection with influential nodes. It is measured as follows:

$$C_{\mathrm{e}}(n_i) = \lambda \sum_j x_{ij} e_j$$

where X_{ij} is the relationship matrix weighted by the degree centrality of node j, and λ is the graph's eigenvalue for the eigenvector of node i.

The above measures are used to construct the network structure of nodes (industries) through visualizations based on

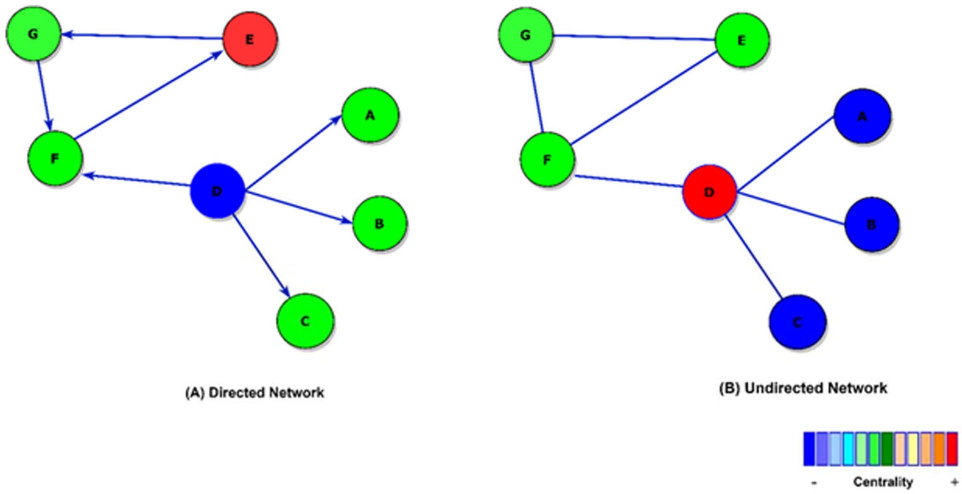

Fig. 1 Topology of directed and undirected networks.

graph theory. The relationships between nodes (industries) are based on difference measures explained above that determine how nodes are placed in an overall structure characterized by dense, transitive, strong, and reciprocal ties. When translated into visualization, these relationships are represented by edges, ties, or links that connect these industries. These visualizations are used to qualitatively assess the strength and importance of various nodes (industries) in the whole network. The advantages of social network analysis techniques are twofold. First, it can handle and make sense of large relational datasets and effectively explain the overall structure of the overall network. Second, it provides flexibility to identify the influential nodes (industries) in the overall network, such as in terms of in-degree (use of inputs from other sectors) and out-degree centrality (provision of inputs to other sectors in the network).

In addition to the characteristics of the overall network, we are also interested in describing the local structure of key industries. This goal is achieved by ego-networks whereby a focal node is selected, and all the nodes in the neighborhood of that focal node are analyzed. The nodes in the neighborhood of the focal node can be directly linked or indirectly.

The data on the IO table for Pakistan is taken from the Global Trade Analysis Portal (GTAP-9) database by Aguiar et al. (2016). This study uses the 2011 IO table that contains 57 sectors. The direction of relationships between sectors is based on the IO table, and the weighting matrix is simply the Inverse Leontief matrix. Moreover, the ego-network can be constructed in terms of in-degree, out-degree, or both types of neighborhoods. In our analysis of ego-networks, we will construct both types of neighborhoods at 2 steps from the focal node. The analysis of the ego-network provides insights in terms of strong and weak ties of the focal node (industry) as well as the range of direct impact of the focal node on the number of nodes and indirect impact if 2-step ego-network is constructed.

The IO tables are available in different forms based on the level of disaggregation and sector classification systems. The IO used in this paper is processed to convert it into a matrix format containing N output sectors given each in columns and J input sectors given each in rows. The final format is illustrated in Table 1. In addition to the output and input sectors represented by columns and rows, respectively, the table includes three additional rows at the end of the matrix that give the sum of total intermediate use, value-added, and each sector's total output. The classification system by GTAP distinguishes between 57 sectors that are used in the construction of the IO table. Although it is relatively aggregated at a sector level, the GTAP IO tables are available for a wide range of countries; therefore, the results and visualizations are comparable with other countries at the same disaggregation level. The list of sectors included in the IO table is given in Appendix Table 1A.

Table 1 Input–output table format.

Input sector	**Output sector**			
	Output sector 1	**Output sector 2**	**...**	**Output sector *N***
Input sector 1	IC_{11}	IC_{21}	...	IC_{N1}
Input sector 2	IC_{12}	IC_{22}	...	IC_{N2}
...	...	...	**...**	...
Input sector J	IC_{1J}	IC_{2J}	...	IC_{NJ}
Total intermediate consumption (IC)	$IC_1 = \sum_{j=1}^{J} IC_{1j}$	$IC_2 = \sum_{j=1}^{J} IC_{2j}$	...	$IC_N = \sum_{j=1}^{J} IC_{Nj}$
Total value added	VA_1	VA_2	**...**	
Total industry input	$Output_1$	$Output_2$	...	$Output_N$

In the IO table, the magnitudes of interindustry flows are recorded with sectors of origin (producers/input sectors) listed on the left and the same sectors, now destinations (output sectors/purchasers), listed across the top. The input from sector 1 to sector 2 is indicated by IC_{11}; from the column point of view, these show each sector's inputs; from the row point of view, the figures are each sector's outputs. Total value added (VA) is measured for each sector by subtracting total input consumption from output at the bottom of the table.

Results and discussions

First, we discuss the characteristics of the production network where each node represents an industry, and each directed edge represents the input–output linkage between two industries. The weight of the edge corresponds to the strength of the linkage or the size of the Leontief Inverse coefficient. The size of each node is based on the share of the output of a sector in the total output of the economy. Figure 2 gives a visual representation of Pakistan's production network. To focus only on significant linkages, the Leontief inverse coefficients < 0.1 are removed.

The basic features of Pakistan's production network are presented in Table 2. The production network has a total of 58 nodes (industries), and the value for network diameter shows that only 5 steps are required to cross the network. It means that it will take only six steps for a shock to spread from any industry to any other in the production network. This indicates that the production network has low clustering relative to 58 industries in the

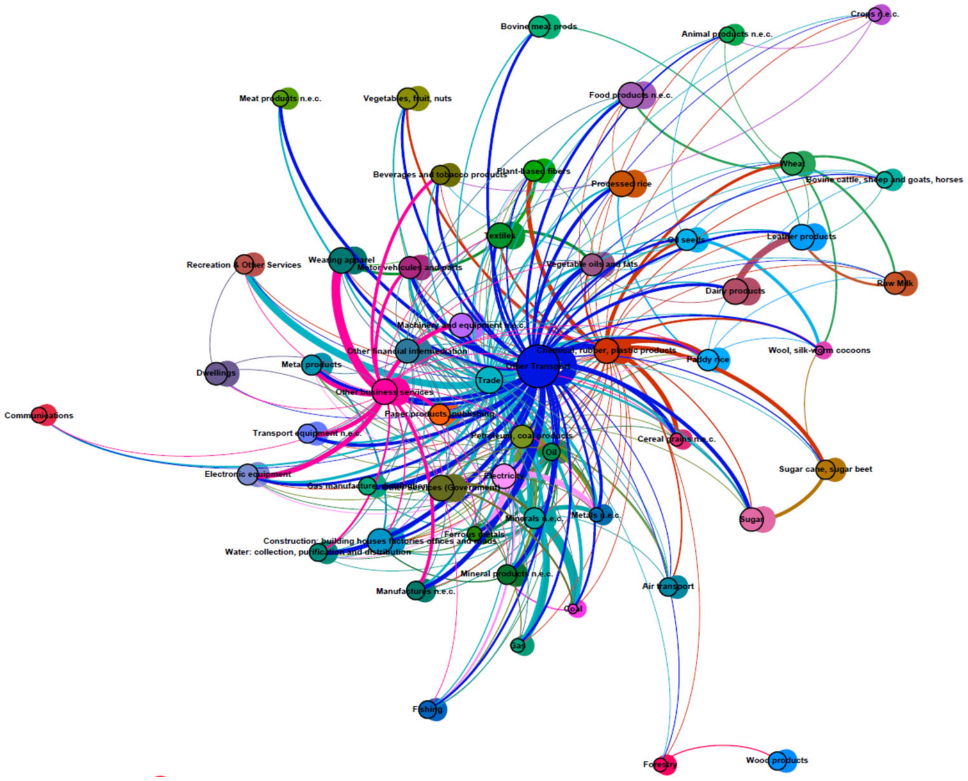

Fig. 2 Pakistan's production network.

Table 2 Summary statistics of production network.

Average degree	4.224
Avg. weighted degree	1.761
Network diameter	5
Graph density	0.074
Modularity	0.29
Connected components	7

Source: Author's calculations.
Edge weight > 0.1. Average degree: The average number of edges connected to a node. Avg. weighted degree: The average sum of the weights of edges connected to a node. Network diameter: The longest and shortest path between nodes within the graph. Graph density: Measures how close the graph is to complete. Modularity: Community detection algorithm. Connected components: Determines the number of connected components in the network.

network. The measure of graph density shows that only 7.4 percent of the nodes are connected (very weak connections are ignored by removing edges with weight <0.1).

The characteristics of Pakistan's production network. First, the distributions of weighted outdegree and indegree measures are skewed, reflecting the unequal status of different sectors in their role as input suppliers and users. As input suppliers, 49 sectors have the same weighted outdegree ranging around 1–2, and the transport and trade sectors have considerably large outdegree >10. Figure 2 gives a graphical presentation of the production network. The size of each arch is based on the size of the inverse Leontief coefficient, and the size of each node is the output share of each industry. The industries with the lowest level of interaction with other industries are positioned in the perimeter. The Transportation sector not only has the highest share in total output in the economy it also is the most connected sector within the overall production network.

To better understand the production network connected to a single key industry, I focus only on one direct connection, while a depth of two steps shows second-level connections—the so-called two-step friends of friends network or ego network in social network analysis. Figure 3 shows the ego network for the electricity sector. The key users of electricity are ferrous metals (iron and steel) and other metals (aluminum, copper, etc.), indicating that the metal industries are highly energy-incentive industries. In addition, the key inputs of the electricity sector are petroleum, oil, and coal, indicating that electricity is mainly produced from petroleum oil, specifically furnace oil and coal. The second level connections show that the electricity sector is also affected by transport, and trade, directly and via the petroleum and oil sector.

The ego network for petroleum and coal products can affect even more industries, such as chemical, rubber, and plastic products, the mineral sector, and the air transport sector (see Fig. 4). Notice that the ego network for petroleum and coal products has all the sectors that are affected by the electricity sector because petroleum and coal are key inputs of the electricity sector. Therefore, almost all the second-level connected sectors of electricity sectors are also affected by the petroleum sector. In fact, oil and electricity are the closest sectors to the petroleum sector. The existence of chemical rubber and plastic products in the periphery of the ego network of the petroleum sector indicates that the petrochemical industry is less developed in Pakistan. Generally, the countries that have improved petroleum refining technology, in addition to refined oil, produce a variety of petrochemical products that are further used in transportation and as industrial inputs.

The ego networks of the textile sector in Fig. 5 highlight the neighboring/close sectors. The textile sector is one of the largest sectors of Pakistan in terms of value-added and contribution towards gross domestic product. It provides raw materials to the wearing apparel sector and plan-based fibers, and its major inputs come from chemicals, transportation, and trade services. It is also the sector that has the largest share in overall exports of the

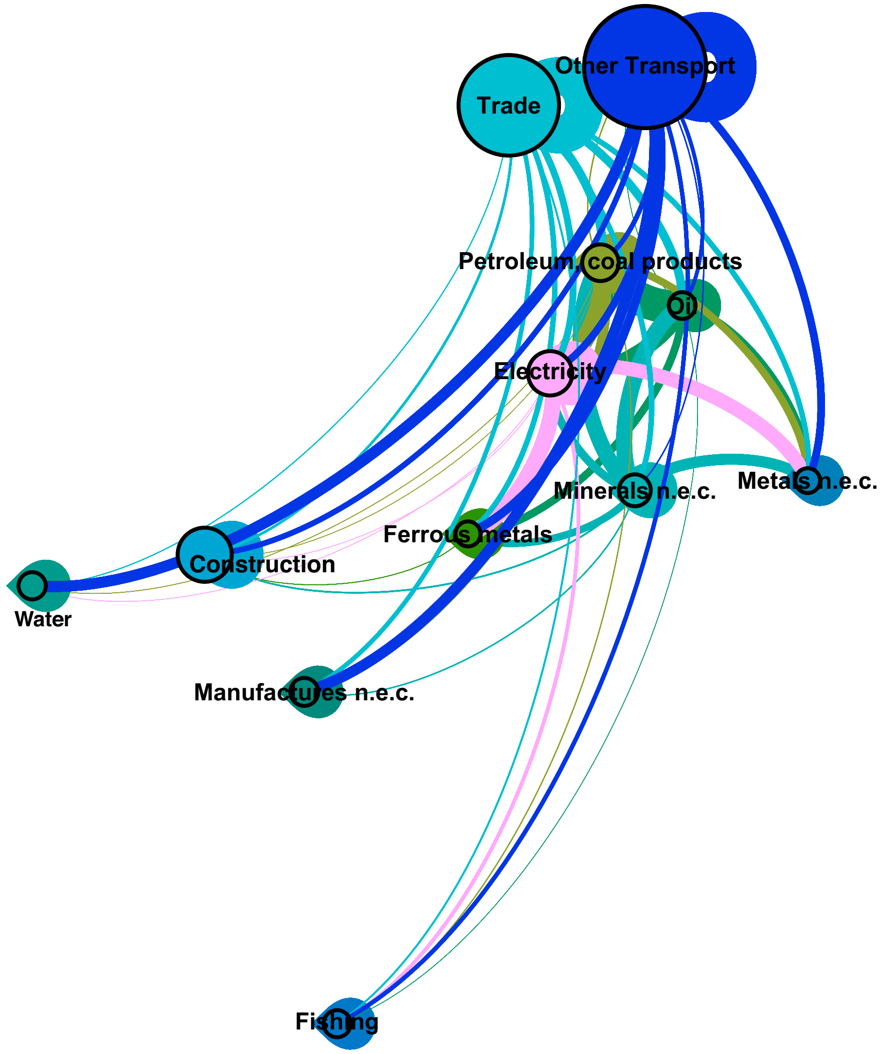

Fig. 3 Ego-network of electricity.

countries. However, the relatively smaller ego network of the textile sector indicates that it is less integrated into the domestic production network and indicates that it can have a limited economy-wide impact if there is growth in the textile sector.

The key direct forward linkages of the textile sector are plant-based fibers and wearing apparel, which are more downstream industries of the textile sector. Compared to the textile sector, wearing apparel takes considerably more inputs from services sectors including business services, financial intermediation, and transport services as inputs. This indicates that a lot of services are dependent heavily on the textile sector via the wearing apparel sector.

The ego network of the transport sector, given in Fig. 6, shows that it is highly connected with the rest of the economy in terms of both backward and forward linkages. The sector not only has an important role in linking different sectors of the economy, but it also helps spatial transformation in the economy and facilitates domestic commerce and international trade. Figure 5 shows that the transport sector can have a wide-ranging impact on the whole economy, and some of the closely linked sectors include the machinery, equipment, petroleum, and oil sectors. Inefficiencies in the transport sector can decrease domestic economic activity and decrease the competitiveness of exports. According to the World Bank's report on Pakistan's transport sector, the inefficient transport sector is costing Pakistan's economy roughly 4–6% of GDP per year. Therefore, transport reforms are central to achieving sustained economic growth.

Business services such as financial management, marketing, and integration of information technology products are also important for various sectors of the economy. Figure 7 shows that the key sector that is linked with the business services sector is wearing apparel sector followed by financial intermediaries such as banks and financial institutions. A considerably large ego network indicates that business services also play a critical role in the economic growth of Pakistan. Generally, the business services sector is more linked with relatively developed and large sectors which are textile and apparel, transport, trade, and machinery and equipment sector.

The wholesale and retail trade sector is one of the largest sectors within the services sector. The key sector that uses wholesale and retail trade services is petroleum, oil, and minerals, followed by construction (see Fig. 8). One of the limitations of the analysis of the IO table is that we have not included international trade in our analysis; otherwise, there could be stronger linkages of the trade sector with other sectors. Nevertheless, domestic trade is mainly linked with the transportation and energy sectors, including petroleum, oil, and electricity, followed by other business services.

Figure 9 displays the distribution of indegree and outdegree in the network, with most industries having very few weighted

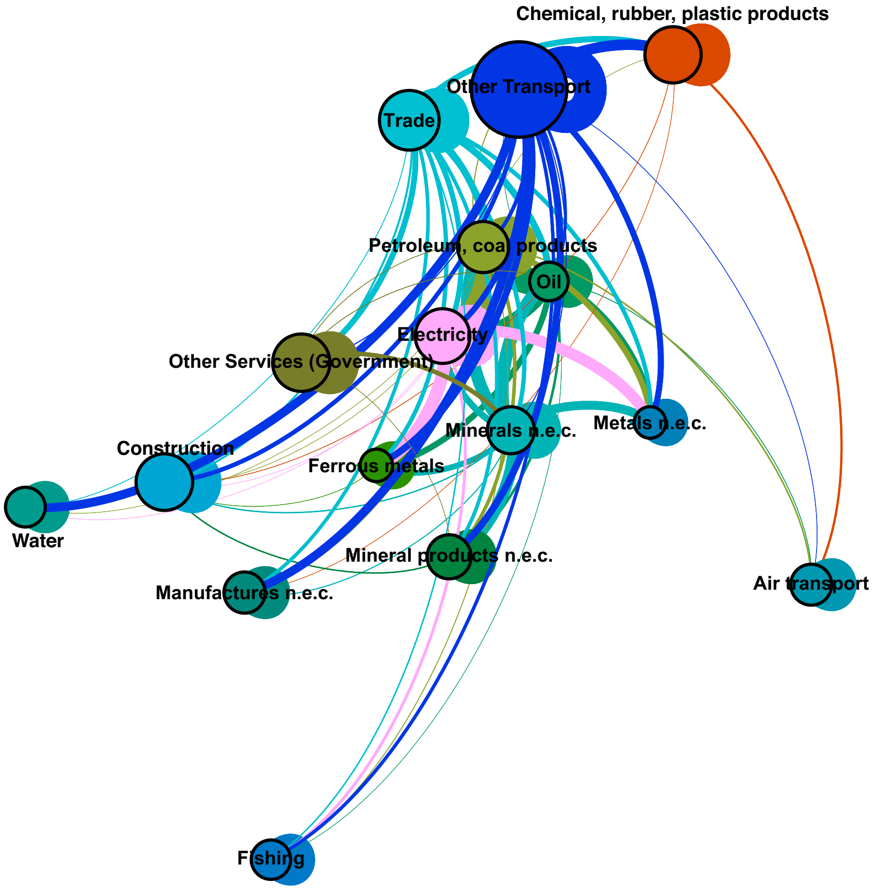

Fig. 4 Ego network of petroleum and coal sector.

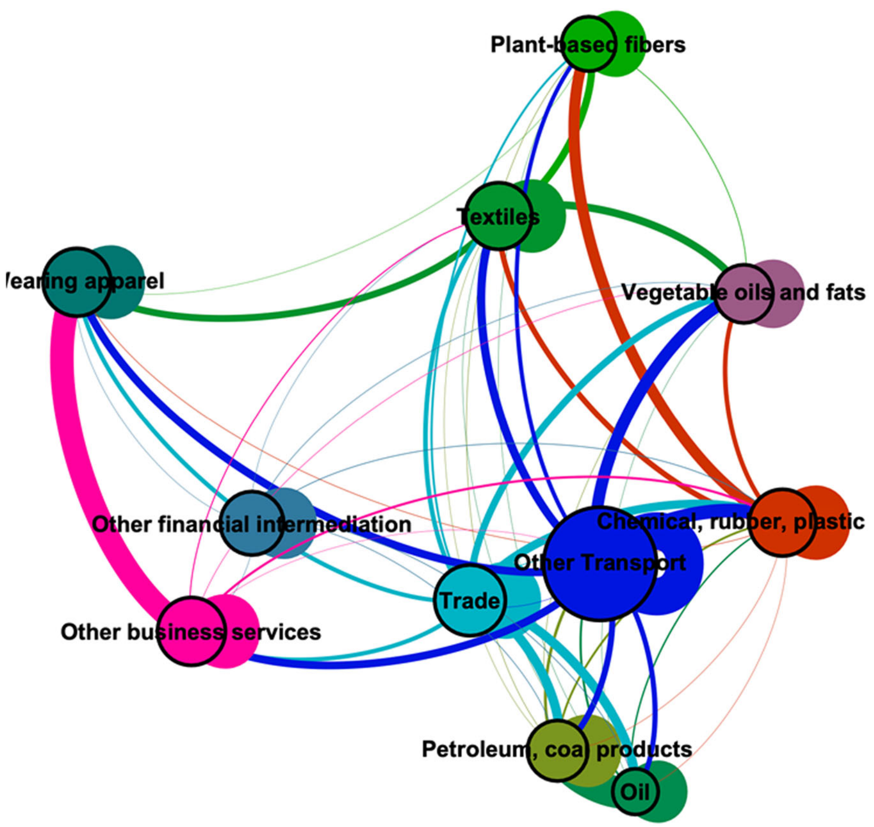

Fig. 5 Ego network of textile sector.

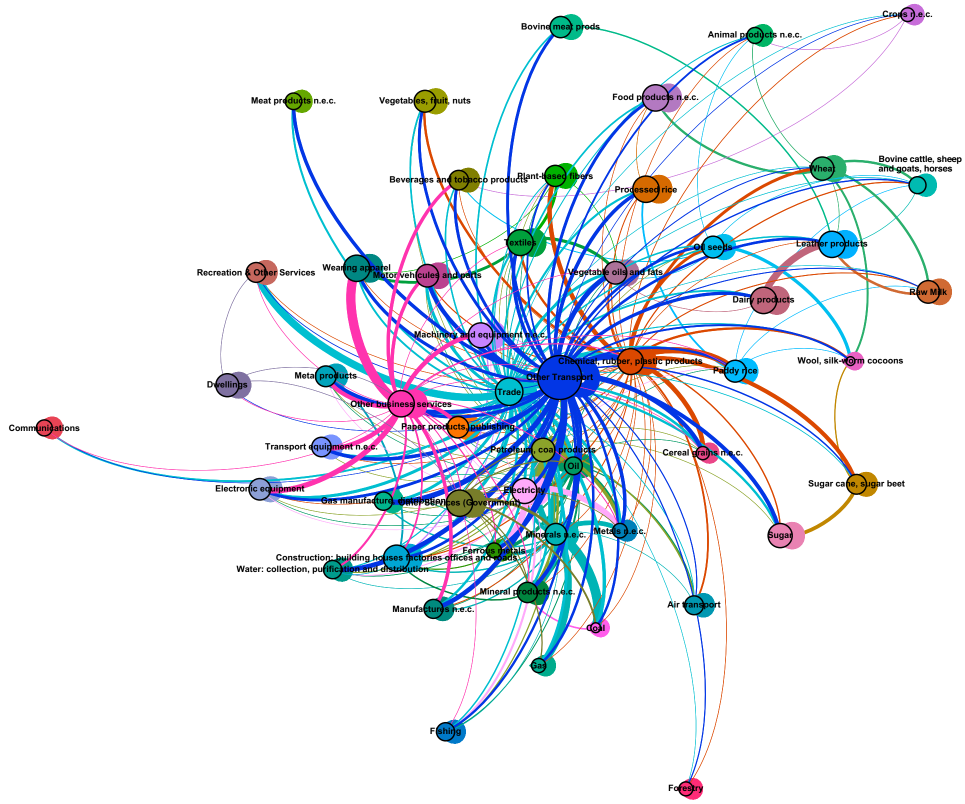

Fig. 6 Ego-network of other transport sectors.

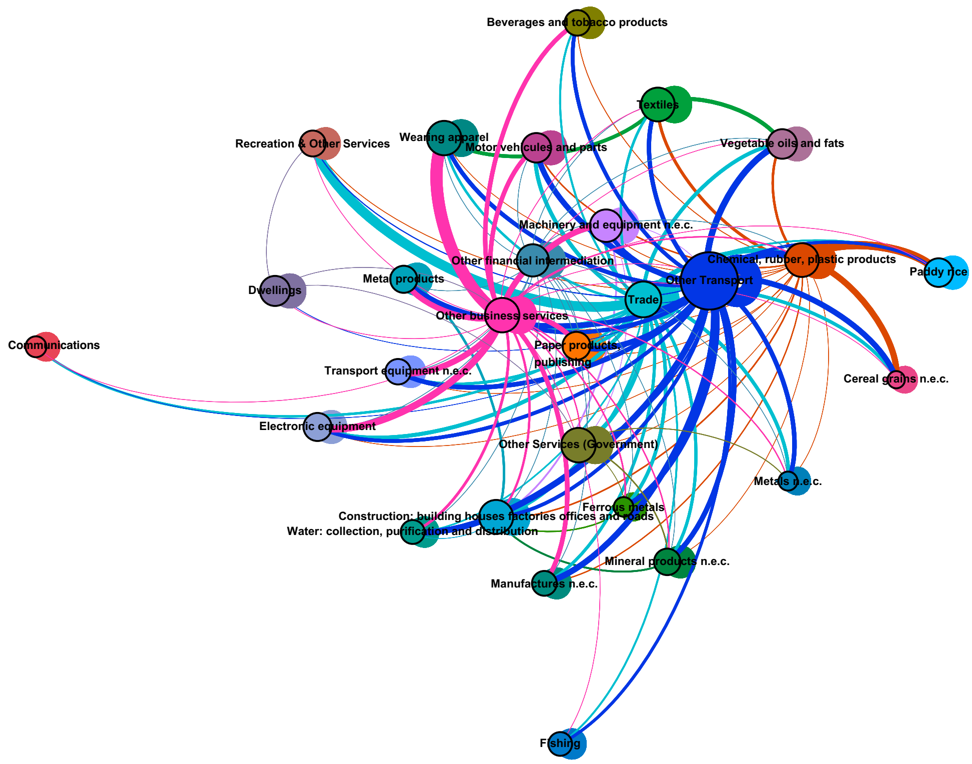

Fig. 7 Ego network of business services.

indegree and outdegree ties with other industries and even fewer with a very large number of ties. The distribution of weighted outdegree is positively skewed indicating that some industries have considerable large ties with other industries—indicating that there are a small number of general-purpose industries that supply to a large number of industries in the economy.

The analysis based on measures of centrality, i.e., weighted in-degree centrality and out-degree centrality, simply shows the

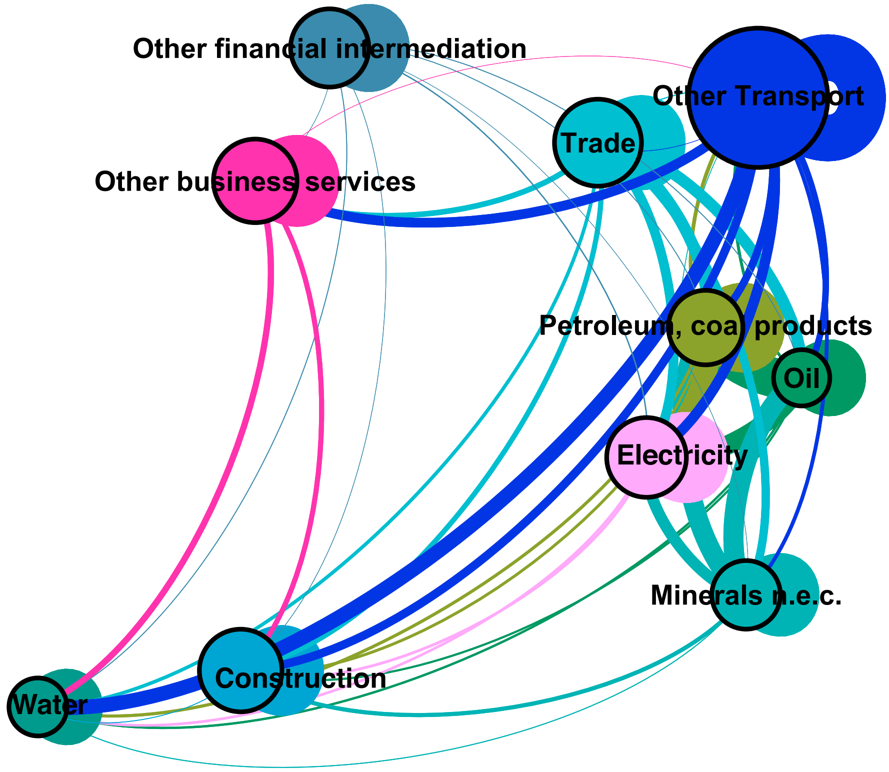

Fig. 8 Ego network of wholesale and retail trade.

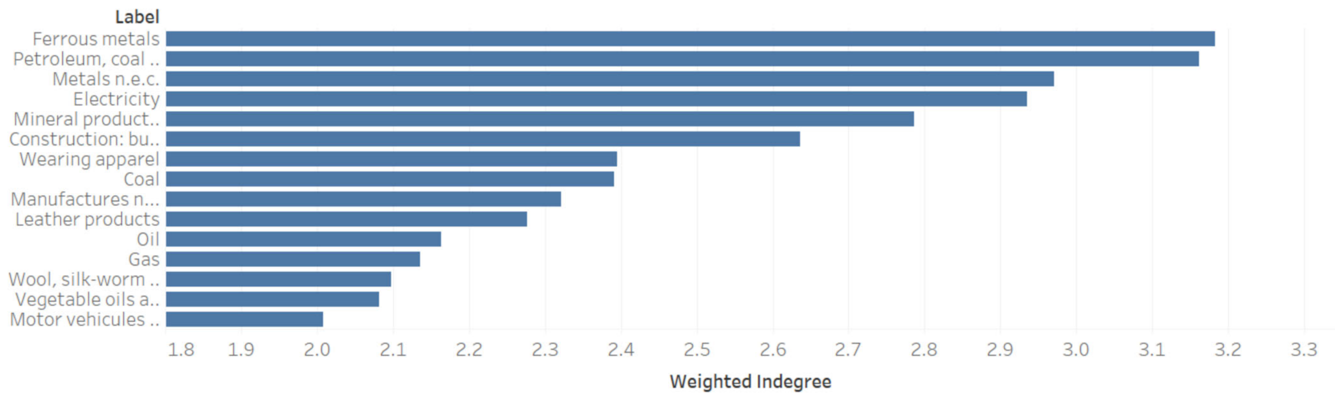

Fig. 9 Top 15 sectors by indegree and outdegree.

backward and forward linkages, respectively. Figure 8 shows that a large proportion of goods and services from other sectors are invested in metals (mainly iron), electricity, mineral products, and construction sectors—so these sectors can be considered primary sectors. Also, notice that compared to outdegree, the numbers for indegree are considerably smaller, indicating relatively weak backward linkages. From the perspective of outdegree, two service sectors, transportation and trade (wholesale and retail trade), have the highest connectivity among all sectors, followed by other business services, minerals, and chemical sectors. The value of weighted outdegree is considerably higher for transportation and wholesale and retail trade services, which indicates the strong forward linkages of these sectors with other sectors of the economy. This also indicates that transportation and trade services supply to many other sectors and the connectivity of manufacturing sectors is considerably less than services sectors.

The scatter plot in Fig. 10 shows the weighted in-degree and out-degree for all the industries. From the plot, we can see a generally positive correlation between the weighted in-degree and out-degree of the sectors. Some sectors are relatively less integrated in the overall production network both in terms of backward and forward linkages, e.g., water transport, wool, communications, and animal products sector. The sectors that have relatively stronger backward- linkages include food products, leather products, sugar and recreation, and other services. Similarly, the sectors that have relatively strong forward linkages include insurance and financial intermediation. The sectors that have both strong backward and forward linkages are services sectors, i.e., Transport and Trade, followed by goods sectors, chemical, rubber and plastic products, and petroleum products.

Second, in terms of betweenness centrality, i.e., a measure of how well situated a node is in terms of the paths that it lies (see Fig. 11). A node may be relatively disconnected compared to other nodes in a network, but if it can bridge otherwise disconnected clusters, then it will have high betweenness centrality. It is not surprising that the transport sector has the

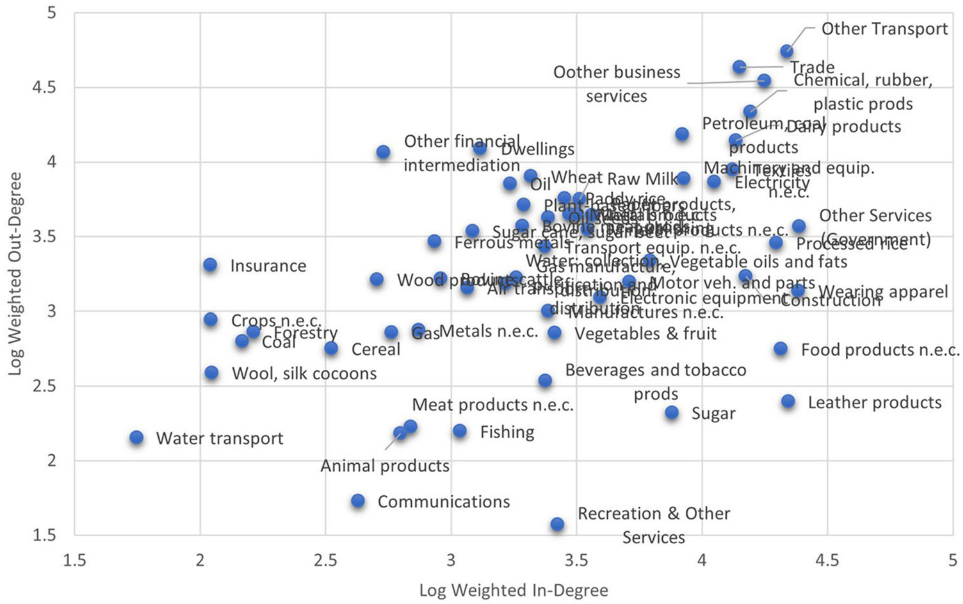

Fig. 10 Correlation between weighted in-degree and out-degree.

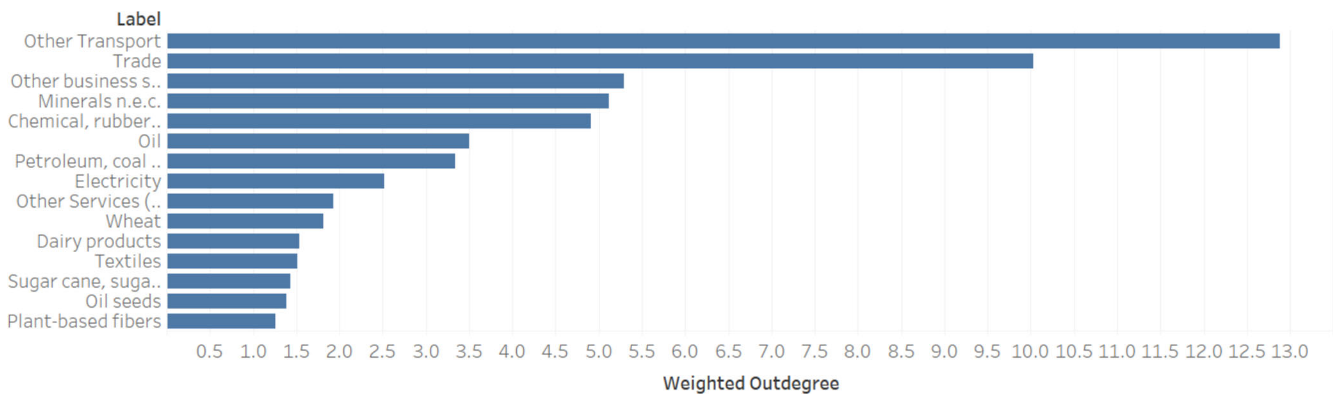

Fig. 11 Top 15 sectors by betweenness and eigenvector centrality.

highest betweenness centrality followed by petroleum products and chemical products. This also highlights that all the sectors in the product network perceive the spillover effects from petroleum products and transport services as quickly as possible—which makes the whole production network vulnerable to oil prices and exchange rates.

Similarly, a node will have high eigenvector centrality if it has high connectivity with high-influencing nodes. Again, electricity and petroleum products are two sectors with the highest eigenvector centrality—which again shows the vulnerability of our production network as both of these sectors are susceptible to exchange rate fluctuations and oil prices. Although electricity, petroleum, and chemical sectors have average weighted out-degree, they are widely used inputs in other sectors. For instance, electricity may have fewer immediate customers downstream, but indirectly, many sectors can be affected by shocks in this industry.

In this analysis of the IO table, we have only considered the domestic input-output relationship between industries—exports and imports are not included. This is one of the reasons why the textiles sector is not even in the top 15 sectors with respect to eigenvector centrality. The ego network of this key sector clearly shows that its key inputs come from plant-based fibers and the chemical sector, and it is one of the key inputs of the wearing apparel sector. The sector also indirectly affects business services, financial intermediation, and trade.

Figure 12 shows the scatter plot of sectoral value added and degree centrality, linear fitted regression, and distribution of degree centrality. The relationship between value-added and degree centrality is positive but insignificant. However, there is a negative and statistically significant relationship between weighted in-degree and sectoral value added (see Fig. 13). Contrary to weighted in-degree, the value added is positively related to weighted out-degree (see Fig. 14).

As given in the literature (Rungi et al., 2023), on average, the in-degree of industries is higher than the out-degree. Also, out-degree is positively associated with sectoral value-added, and in-degree is associated with low value-added. These results indicate that in sectors that are more reliant or dependent on purchases of multiple other sectors, their value added is relatively low. While those sectors that have more forward linkages have relatively higher value-added. Services sectors such as transport (otp), retail trade (trd), and other business services have high outdegree as well as value-added. Contrary to these services sectors petroleum & chemical (p_c) and oil sectors also have considerably higher weighted out-degree, but their value added is not as high as the services sector.

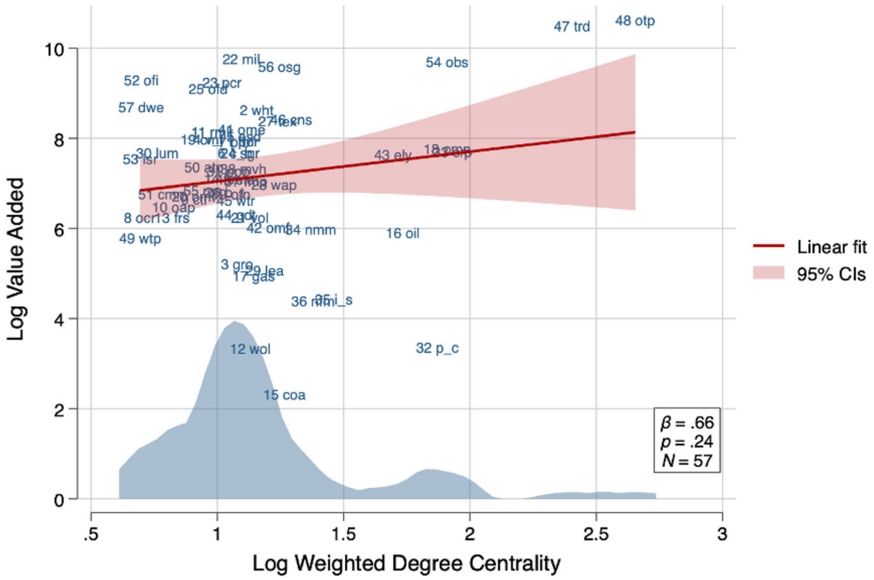

Fig. 12 Value added and weighted degree centrality.

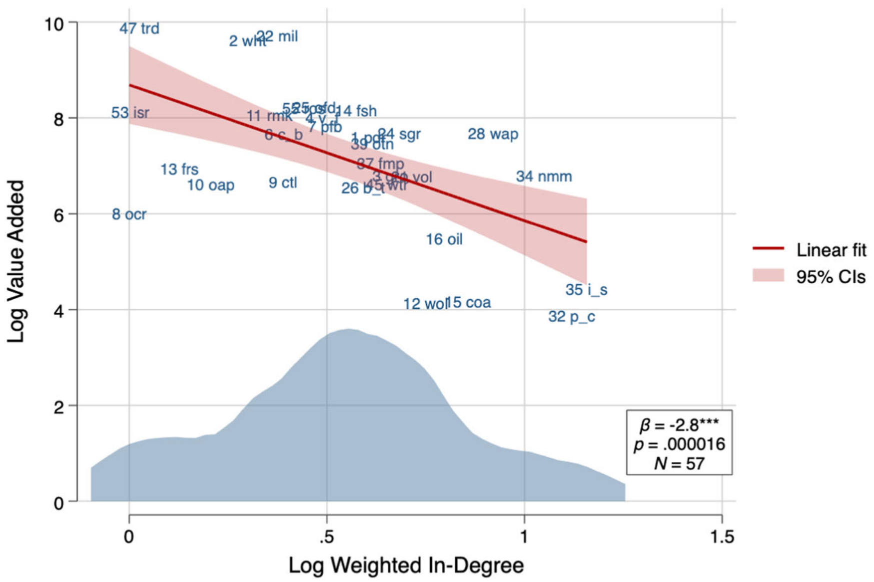

Fig. 13 Value added and weighted in-degree.

These findings have implications for those economies that have higher forward linkages and are relatively stable in terms of economic growth as they are better at reducing the impact of prices, and demand disruptions in a few sectors as they are compensated by demand in other sectors (Olabisi, 2020; Lebdioui and Bilek, 2021). For similar reasons, we find a positive relationship between value-added and weighted out-degree that is mainly driven by the services sectors such as transport, retail trade, and other business services that have demand in multiple other sectors and thus higher forward linkages. These findings are significant in the context of global trends where services are becoming increasingly important in both developed and developing economies. The sectors of electricity, petroleum, and chemicals emerge as vital in the production network due to their widespread use as inputs across various industries. Improving efficiency in these sectors could yield significant economy-wide impacts. In the context of global trade, these sectors' performance can greatly influence a country's trade competitiveness and ability to respond to global market fluctuations, especially in energy prices. The research suggests that for Pakistan, and similarly situated developing countries, strengthening forward linkages and integrating more effectively into global value chains could be key strategies for enhancing their role in international trade. This involves not only improving domestic industries but also aligning them with global demand and supply trends.

Conclusions and policy recommendations

Using the measures of network analysis and the IO table, this study explores Pakistan's production network. The estimates of centrality and betweenness allow inferring how different sectors are interlinked and identify the sectors that hold key positions within the production network with respect to their forward and backward linkages.

In general, the structure of an industry-level production network is sparsely connected in the sense that only transportation and trade services supply to a large number of industries—hence a highly skewed distribution of weighted out-degree. The results show that in

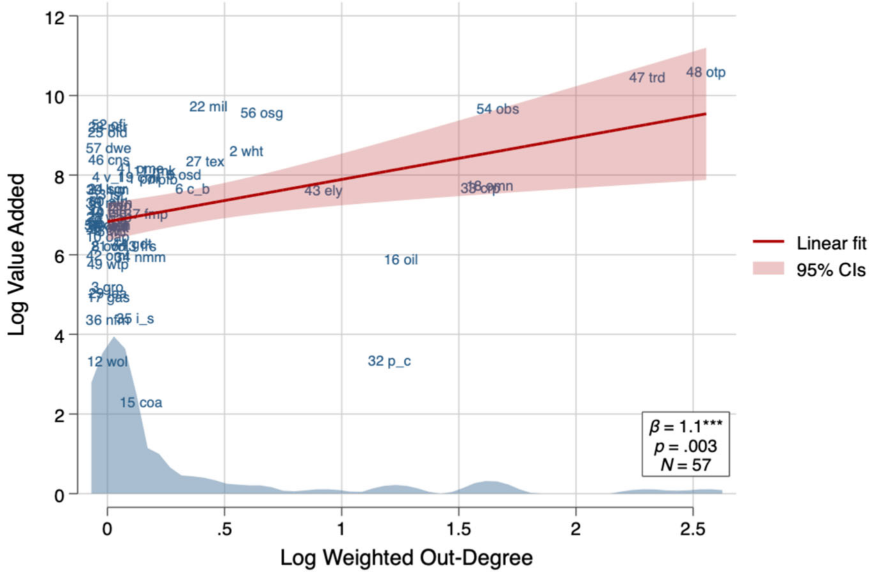

Fig. 14 Value added and weighted out-degree.

terms of forward linkages, the services sectors, mainly transportation and trade services, supply to many other sectors, and the connectivity of manufacturing sectors is considerably less than the services sectors. Electricity, petroleum, and chemical sectors are widely used inputs in other sectors. These sectors are most influential as they have less immediate absorption downstream, but indirectly, shocks in these industries may affect many other sectors.

On the relationship between the value added of the sectors and their centrality measures, our results indicate that there is no statistically significant relationship between value-added and degree centrality. However, when the direction of the measure of centrality is considered, weighted in-degree centrality is negatively associated with value-added, and weighted out-degree is positively associated with value-added. Moreover, the services sectors, i.e. transport (OTP), retail trade (tr), and other business services, have high outdegree as well as value-added compared to industry, food, and other sectors.

Overall, the measures of network analysis, combined electricity, petroleum, and chemical sectors are the most important sectors in Pakistan's production network—this also highlights the vulnerability of our production network as both sectors are sensitive to exchange rate fluctuation and global oil prices. The strategic and economic implications of increasing efficiency in the refining and petrochemical industry are well understood globally; however, it has always been of less concern in Pakistan. The findings of this study have important policy implications in terms of bringing stability and improving the efficiency of these key sectors. In this regard, the new refinery policy is required to provide lucrative incentives to enhance refinery capacity and to establish deep refineries that could feedstock for the petro-chemical industry. An increase in refinery capacity and upgradation of refinery technology is important to increase the efficiency and variety of refined petroleum products. An increase in productivity in these sectors can have a wide-ranging impact on the whole production network. Moreover, the government should provide incentives to attract investment in the petrochemical industry as Pakistan currently imports around $5 billion of petrochemicals (chapter 39 of HS) and other related products annually.

Data availability

The data is obtained from secondary sources which can be assessed: https://www.gtap.agecon.purdue.edu/databases/default.asp.

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References

Acemoglu D, Ozdaglar A, Tahbaz-Salehi A (2015) Networks, shocks, and systemic risk (No. w20931). National Bureau of Economic Research

Aguiar A, Narayanan B, McDougall R (2016) An overview of the GTAP 9 database. J Global Econ Anal 1:181–208

Antràs P, Davin C, Thibault F, Russell H (2012) Measuring the upstreamness of production and trade flows. Am Econ Rev 102:412–416

Blöchl F, Theis FJ, Vega-Redondo F, Fisher EON (2011) Vertex centralities in input-output networks reveal the structure of modern economies. Phys Rev E 83:046–127

Carvalho VM (2014) From micro to macro via production networks. J Econ Perspect 28:23–48

Correa CD, Ma KL (2011) Visualizing social networks. In: Correa CD & Ma KL (eds) Social network data analytics. pp 307–326

Elliott M, Golub B, Leduc MV (2022) Supply network formation and fragility. Am Econ Rev 112(8):2701–2747

Førsund FR (1985) Input–output models, national economic models, and the environment. In: Kneese AV & Sweeney J (eds) Handbook of natural resource and energy economics, vol. 1. Elsevier, pp 325–341

Graham BS (2020) Network data. In: Handbook of econometrics, vol. 7. Elsevier, pp. 111–218

Granovetter M (1995) Getting a job: a study of contacts and careers. University of Chicago Press, Chicago

Hidalgo CA, Klinger B, Barabási AL, Hausmann R (2007) The product space conditions the development of nations. Science 317:482–487

Inoue H, Todo Y (2019) Firm-level propagation of shocks through supply-chain networks. Nat Sustain 2:841–847

Jamshed A, Birkmann J, McMillan JM, Rana IA, Feldmeyer D, Sauter H (2021) How do rural-urban linkages change after an extreme flood event? Empirical evidence from rural communities in Pakistan. Sci Total Environ 750:141462

Knoke D, Yang S (2019) Social network analysis. SAGE publications

Laghridat C, Essalih M (2023) A set of measures of centrality by level for social network analysis. Procedia Comput Sci 219:751–758

Lebdioui A, Bilek P (2021) Do forward linkages reduce or worsen dependency in the extractive sector? NRGI working paper. Natural Resource Governance Institute, London

Lee D (2019) Transmission of domestic and external shocks through input–output network: evidence from Korean industries. International Monetary Fund

Liu Y, Kim D (2019) Understanding of servicification trends in China through analysis of interindustry network structure. In: INFORMS international conference on service science. Springer, Cham, pp. 55–64

Montresor S, Marzetti GV (2009) Applying social network analysis to input–output based innovation matrices: an illustrative application to six OECD technological systems for the middle 1990s. Econ Syst Res 21:129–149

Morris M (1993) Epidemiology and social networks: modeling structured diffusion. Sociol Methods Res 22(1):99–126
Muller NZ (2016) An input–output model of the US economy with pollution externality (No. w22092). National Bureau of Economic Research
Nawaz SMN, Alvi S (2018) Energy security for socio-economic and environmental sustainability in Pakistan. Heliyon 4(10):e00854
Oberfield E (2018) A theory of input–output architecture. Econometrica 86(2):559–589
Olabisi M (2020) Input–output linkages and sectoral volatility. Economica 87:713–746
Reiss Jr AJ (1988) Co-offending and criminal careers. Crime and justice 10:117–170
Rauf O, Wang S, Yuan P, Tan J (2015) An overview of energy status and development in Pakistan. Renew Sustain Energy Rev 48:892–931
Rungi A, Fattorini L, Huremović K (2023) Measuring the input rank in global supply networks. World Econ 46:3081–3115
Summer M (2013) Financial contagion and network analysis. Annu Rev Financ Econ 5:277–297

Author contributions

I. Ahmad conceived the idea, I. Ahmad and S. Alvi collected the data, I. Ahmad and S. Alvi ran the experiment, I. Ahmad and S. Alvi wrote the paper, and I. Ahmad and S. Alvi proofread the paper.

Competing interests

The authors declare no competing interests.

Ethical approval

Ethical approval was not required as the study did not involve human participants.

Informed consent

This article does not contain any studies with human participants performed by any of the authors.

Additional information

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