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A Network Analysis of the Chinese Intersectoral Interaction

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Abstract. We present a detailed analysis of inter-sectoral linkages over China's 36 sectors. By employing the tools of non-linear equations and complex network, the economic sectors are represented as nodes, transaction among sectors as paths. The presented method not only helps us visualizing the structure of the national economy, but also identifying the mechanisms underlying the interconnected economic dynamical system. Empirical analysis on China's input-output tables indicates that the inter-sectoral transaction facilitates the national-wide economic efficiency in China has been improved; inter-sectoral transactions display a core-periphery structure.

Keywords: Intersectoral Linkages, Complex Network, Core-Periphery Structure

1. Introduction

As a generalization of a nation's economy, inter-sectoral transaction displays the process by which outputs in one sector produce inputs of other sectors and depicts inter-industry relations of an economy. The interaction among different sectors provides the very foundation of commodity market equilibriums and brings about economic spillover and innovation diffusion (Park, 2004 [1]; Malerba, Mancusi and Montobbio, 2007[2]). Moreover, innovations are embodied in the exchanged intermediate goods and services, while one sector's innovative activity can be measured by its innovative efforts, see Montresor [3]. Intersectoral innovation diffusion can be studied in different areas of a country, see Chang and Shih [4], or compared among different countries, see Shih and Chang [5]. The former found different technological focus between Taiwan and Mainland China, the latter found technological knowledge transmission among four blocks of countries.

We propose a complex network analysis that—despite its simplicity—covers entire intermediate transactions and provides novel testable predictions. The economic transactions among sectors are described by interactions processes of various types of nodes and edges in complex economic network. The complex network analysis also has advantages in visualizing the industrial structure and identifying important sectors and their changes in the economy. Similar to ours, Leoncini *et al.* [6] claim that the joint utilization of the input-output approach and the network methodology provides solutions to analyzing inter-sectoral interaction within national economic systems.

2. Network Analyses for Intersectoral Interaction

This article is based on the 1997, 2001 and 2005 National Input-Output Survey of China, which was constructed by the National Economy Balances Department of State Statistical Bureau. In order to be consistent with national statistical yearbook, national economy system is subdivided into 36 sectors (see Table 1) which are interconnected through input purchases or output sales.

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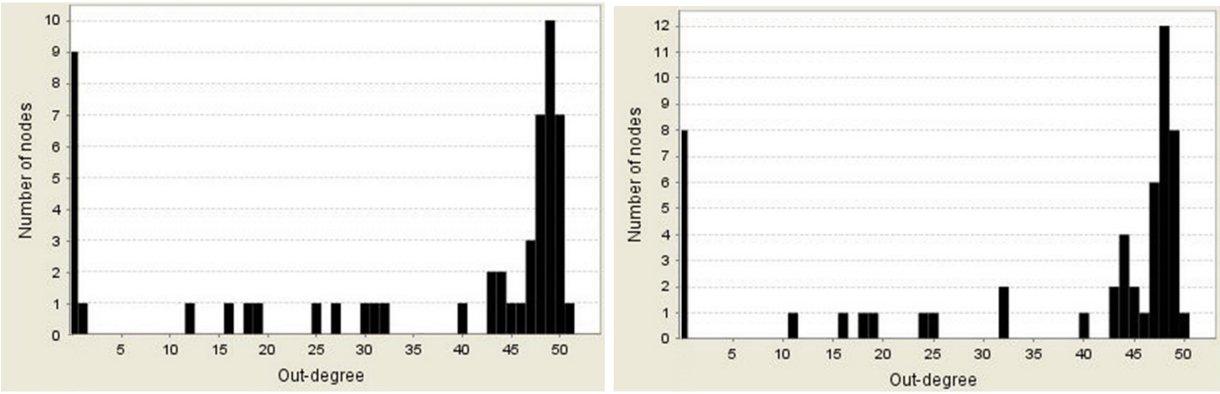
2.1. Out-Degree Analysis on 36 Sectors in China.

In economic complex system, network is composed of nodes which represent sectors, and edges which represent various tangible and intangible ties, e.g. people, material and service. Fig. 1 is topology analysis of 36 industries in China at 1997 and 2005. The indegree/outdegree indicates import/export volume of an industry to other industries. Obviously there is a rapid growth in outdegree, which denoting increase in export volume of national economic sectors as a whole.



(a) Outdegree at 1997 (b) Outdegree at 2005

Fig.1: Topological Measurements of Industries Interaction

2.2. Betweenness, Power and Reach Centrality Analysis on 36 Sectors in China

Next, we arrange and numerate 36 industries in China in a sequence according to statistical yearbook, and use network topology index to analyze the data of 36 industries from 1996 to 2005. Table 1 lists some network topology analysis. The first index, *betweenness centrality*, is computed by the contribution of a vertex to all possible maximum flows. This index allows us to understand both resources flow and transaction mode of an economy. Sectors such as 'Medicines', 'Non-metallic Mineral Products' and 'Measuring and Cultural Instruments' display higher value of betweenness centrality, implying that these sectors have heavier transaction loads and occupy a center place in industrial structure. The second index is *Bonacich's power centrality*. The more important a given sector is as supplier and user, the larger the value of Bonacich's power centrality is. From the magnitude of the impact of an industry, we can judge when it arises or decline. Sectors such as 'Artwork and Supply of Electric and Heat Power', 'Medicines' and 'Mining and Washing of Coal' display large value of Bonacich power, implying that these sectors have large impact on sectors which have small magnitude of transaction as suppliers and users. As pillar industries in China's economy, the products of these three sectors are production factor of other sectors. Their development influences economy quality and efficiency, decides the transformation of economy development mode, and impacts the living standards of millions of people. The third item, *reach centrality*, is calculated by the number of nodes each node can reach the furthest node. In multinational complex network where the node represents countries, highly connected countries commonly tend to connect with other well connected ones, see Gligor and Ausloos [7]. Same to industry, sectors connects together and even clusters into industry associations where technology tends to converge. Sectors have higher values of reach centrality, implying better connectivity, such as 'Artwork and Electric and Heat Power', 'Medicines', 'Mining and Washing of Coal',

Table 1. Topology analysis of 36 industries in China

Node	Industry	Topology Analysis			Node	Industry	Topology Analysis		
		btwn	power	reach			btwn	power	reach
A	Mining and Washing of Coal	3.6	4.44	12	S	Raw Chemical Materials	1.21	0.06	0.16
B	Petroleum and Natural Gas	2.81	4.16	11.3	T	Medicines	14.24	4.44	12.01
C	Ferrous Metal	0	0.54	1.45	U	Chemical Fibers	11.06	0.03	0.08

	Ores								
D	Non-Ferrous Metal Ores	1.21	0.65	1.76	V	Rubber	3.09	0.65	1.75
E	Nonmetal Ores	0.04	0.59	1.6	W	Plastics	6.89	0.74	1.99
F	Food from Agriculture	2.35	0.75	2.04	X	Non-metallic Mineral Products	11.46	3.04	8.21
G	Food	2.35	0.4	1.08	Y	Ferrous Metals	4.81	3.94	10.66
H	Beverages	1.87	0.07	0.2	Z	Non-ferrous Metals	4.81	1.49	4.03
I	Tobacco	0	0	0	AA	Metal Products	5.48	2.37	6.42
J	Textile	4.23	1.58	4.27	AB	General Purpose Machinery	5.48	2.68	7.24
K	Textile Wearing Apparel	4.07	0.48	1.3	AC	Special Purpose Machinery	5.48	1.47	3.97
L	Leather, Fur, Feather	4.07	0.18	0.5	AD	Transport Equipment	5.48	0.98	2.66
M	Timber, Wood, Bamboo	8.92	0.61	1.64	AE	Electrical Machinery	5.48	1.88	5.08
N	Furniture	8.92	0.46	1.24	AF	Communication, Computers	5.48	0.88	2.38
O	Paper and Paper Products	9.08	1.55	4.19	AG	Measuring Instruments	11.46	2.22	6.01
P	Printing, Recording Media	0.91	0.43	1.17	AH	Artwork and Electric Power	4.81	6.77	18.32
Q	Culture, Education and Sport	1.53	0.05	0.14	AI	Production of Gas	0.16	0.09	0.25
R	Petroleum, Nuclear Fuel	0.24	3.7	10	AJ	Production of Water	0.94	0.27	0.73

2.3. Core-Periphery Structure.

To identify key sectors that are central for economic development, we divide 36 industries into two subgroups: a core whose members are densely tied to each other and a periphery whose members have more ties to core members than to each other. The highly connected nodes in core area have better chances of reaching new edges than their less. The steps of analyzing sectoral transaction are as following. Firstly, find vectors such as the intersectoral transaction matrix and its transpose which are as close as possible to each other. Secondly, assess the degree to which the network falls into a core-periphery structure for different sizes of core are calculated. Each measure places the industry with the highest coreness score in the core and all other industries in the periphery. Thirdly, compare coreness scores with the ideal scores for every industry by using correlation measure and Euclidean distance. Fig. 2 gives graphical representation of China's industrial structure. The degree of vertex i denotes the number of vertex which is connected with different edges of vertex i. Through these edges, a sector obtains resources or technology from the network and improves production efficiency. The higher level of connectedness, the larger the number of proliferative sectors.

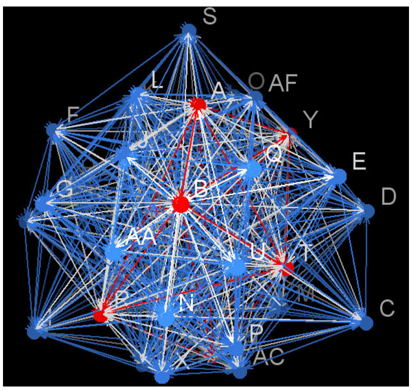


Fig. 2: Structure of 36 Industries in China

It is found that six industries display larger coreness score with well-defined interfaces to other industries and constitute core industries. Their names are: AH (Artwork and Supply of Electric Power and Heat Power): 0.558253; A (Mining and Washing of Coal): 0.39; Y (Smelting and Pressing of Ferrous Metals): 0.36; B (Extraction of Petroleum and Natural Gas): 0.29; T (Manufacture of Medicines): 0.25; R (Petroleum, Coking, Processing of Nuclear Fuel): 0.25. It is found that new sectors such as energy industry and bio-pharmacy industry are in the core of economic structure.

The economy is expected to be self-adaptive and grow at the same steady state rate. When a shock destabilizes economy system, the economy diverges from the baseline steady-state path, and the intersectoral transaction loses balance. By comparing indicators and graphs, researchers can use complex network analyze economic structure and compare the economic changes before and after exogenous shock. On one hand, if the shock is technology improvement on sector s, sector s would increase production efficiency and decrease the demand of raw material. Thus the innovation of sector s would impact unfavorably on supplying sectors. This is called innovation diffusion and can be calculated by the output change of supplying sectors. On the other hand, if the shock is infrastructure improvement on sector s in region i, other sectors at region i cannot be excluded from public goods and might improve efficiency and decrease demand simultaneously. The negative impact of decreased demand on supplying sectors might be offset by the benefit of infrastructure. Due to increasing return of public goods, demand and supply will reach new balance and the overall efficiency would be improved.

In an open economy, decreased demand would impact unfavorably on sectors in other regions who are suppliers for this region. But if there is convergence across regions, productivity in different regions gains through agglomeration economies. Full consideration of this issue is beyond the scope of the present article, and the reader is referred to any standard text on the subject.

3. Nonlinear Transmissions

The transaction among regions and industries are described by interactions processes of various types of nodes and edges in complex economic network, which are asymmetric and non-linear. Let *P (t)* be material transmission, and *Q (t)* be non-material transmission, ϱ be the radial component of the gravitational force between material transmission and non-material transmission, ι_1 and ι_2 be arbitrary parameters. A nonlinear network model of intersectoral dependence system is written as:

$$\begin{cases} P(t) = sinh(\varrho)\times P(t) - Q(t) \\ Q(t) = sinh(\varrho)\times Q(t) - P(t) \\ \varrho = \iota_1 \times P(t) - \iota_2 \times Q(t) \end{cases} \tag{1}$$

Now we change equ (1) into Fig 3.

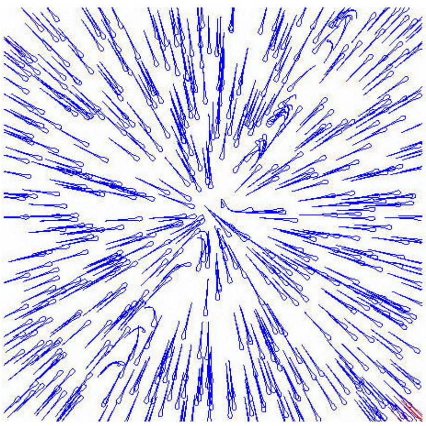


Fig.3: Stable Limit Circle of Regional and Industrial Dependence

The arrows in Fig. 3 indicate the direction of increasing time t. and industry cluster. A sector's performance is dependent on transaction with neighboring sectors. Ready access to innovation of other sectors improves competitive advantages. UN survey shows that the greater dynamism of industrial sector is derived from its capacity to forge greater vertical sectoral integration by processing raw materials and semi-industrial inputs. Stable limit circle in Fig. 3 appears when upstream and downstream sectors bring about cross-functionally cost-minimization, shared infrastructure, coordinated capabilities and Marshallian pecuniary advantages. Strategies can be devised for enhancing accessibility and linkages such that more industries can receive beneficiaries of infrastructure spillover.

4. Summary

Various attempts have been made to investigate the impact of intersectoral transaction on economic efficiency and on productivity. Different from conventional model-based methods, this study conducts topology analysis on intersectoral linkage and its impact on national economy it based on real input-output data. Moreover, this paper visualizes the intersectoral linkages in the economic network.

The integral approach in this paper provides a novel solution to multi-sectors material flow analysis and national-wide resource management. First, the topological parameters of economic complex network, such as nodes connectivity, betweenness centrality and modal weight, help assess strength, robustness and vulnerability of industrial sectors. Second, the ranking of nodes is useful in comparing sector performance and discriminating industrial structure. Third, the input-output matrix, especially after being refined by Breiger and Arabie algorithms [8], outlines the commodity consumption across different sectors.

China's input-output data suggests that China is in the process of production efficiency improvement and technology diffusion; the industrial sectors react to intersectoral transaction and form a core-periphery structure; the trade flows between different sectors leads to nonlinear convergence.

5. Acknowledgment

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