The structure and evolution of Japanese production network

Hiromitsu Goto[1], Yuji Fujita[1], and Wataru Soma[1]

[1]College of Science and Technology, Nihon University, Narashino-dai 7-24-1, Funabashi, Japan,
hiromitsu.goto.phys@gmail.com

One of the most important networks in the economy is a production network, which is the directed network formed by firms and trade relationships. It has recently been shown that the shape of firm-level Japanese production networks is different from the World Wide Web well known as a bow-tie [1]; the giant weakly connected component (GWCC) of Japanese production networks form a tightly-knit structure with a core giant strongly connected component (GSCC) surrounded by IN and OUT components constituting two half-shells, which were named the *walnut* structure after its shape [2]. However, the relation between its structure and the dynamics of the economy remains unclear. Here we investigate the component dependence and its change of Japanese production networks in terms of the industry and firm size distribution using the data collected by Tokyo Shoko Research (TSR) Inc. from 2006 to 2016, which includes one million firms and several million supplier-customer links.

We represent the data as a directed network composed of active firms and supplier-customer links and not contained self-loops, where inactive and failed firms are excluded by using an indicator flag on the basic financial information. Here we focus on the GWCC of the network, which is the largest connected component when it is viewed as an undirected graph and includes the almost all of the active firms. Moreover, in terms of the flow of products, the GWCC can be decomposed into the parts defined as follows: GWCC = IN + GSCC + OUT + TE , where the GSCC is the largest connected one when viewed as a directed graph and the firms which can reach to and from the GSCC via a directed path are named IN and OUT components, respectively. The rest of the GWCC are named as tendrils (TE). In order to investigate the dynamics of Japanese economy, we analyzed the networks using the data collected in 2006, 2011, 2012, 2014 and 2016 in terms of components of walnut structure as listed in Table 1.

We visualized the network structure in Figure 1 (left), whose components are decomposed as IN, GSCC and OUT in right insets. The nodes are sized according to the number of links and colored by the industrial sector. It is apparent that the decomposition reflects the flow of industrial structure. As reported in [2], the shortest path length from GSCC to IN/OUT component in the walnut structure is at most four. This appears in the difference of the degree distribution between the components, which appears also in the size distributions. In order to discuss the dynamics of the network, moreover, we computed the from-to matrix for the firms staying as the GWCC in the whole years; 517,983 firms. Especially, there are 353,619 firms not moving from own component, which account for 68.3% of the firms located on the GWCC in whole period; the fractions for each component are 7.2% (IN), 68.9% (GSCC), 23.6% (OUT), 0.3% (TE). We show the degree dependence of the rewiring ratio of the links for the firms staying in GWCC in Figure 1 (midle). The existence of the stable framework in the walnut structure can be seen in Figure 1 (right) under the rewiring; the elements of matrix F_{ab} represents the number of firms located in components a and b in 2011 and 2016, respectively.

We have investigated the structure of Japanese production network using the firm-level data from 2006 to 2016 in order to understand why it is the shape of walnut. Although about 20% of links of networks of the GWCC are rewired per five years, the Japanese production network has the stable framework of production flow in our observation. Therefore, we believe that the walnut structure results of the developed economy in Japan as the ecosystem having a giant core

Component	2006	2011	2012	2014	2016
GWCC	894,678	991,118	1,014,494	1,066,476	1,066,037
IN	18.0 %	18.1 %	18.7 %	20.3 %	20.6 %
GSCC	45.8 %	49.7 %	49.0 %	49.5 %	49.7 %
OUT	32.7 %	28.5 %	28.5%	26.5 %	26.2 %
TE	3.5 %	3.6 %	3.7 %	3.7 %	3.5 %
# of links	3,573,119	4,459,205	4,558,494	4,897,050	4,974,826

Table 1: Sizes and fraction of components in walnut structure in different year.

of the GSCC. Our study can provide the framework for future studies to model the evolution of networks in the economy having the specific industrial structure.

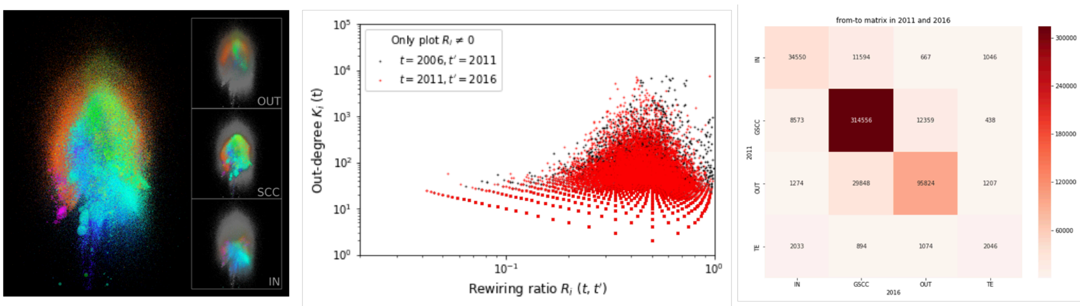

Figure 1: Visualization of network colored by each industrial sector (left), the degree dependence of rewiring ratio in defferent five years (middle) and the from-to matrix between the components in last five years (right).

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