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Comparing patterns of intersectoral innovation diffusion in Taiwan and China: A network analysis

Pao-Long Chang[a,b,*], Hsin-Yu Shih[a]

[a]Institute of Business and Management, National Chiao Tung University, 4F, 114, Sec. 1, Chung-Hsiao W. Road, Taipei 100, Taiwan
[b]Department of Business Administration, Feng Chia University, 100, Wen-Hwa Road, Taichung 407, Taiwan

Abstract

This paper presents a quantitative method for comparing the structure and performance of intersectoral innovation diffusion in the Taiwanese and Chinese innovation systems. The network of intersectoral innovation diffusion is constructed and proxied by the product-embodied R&D flow matrices calculated by the use of data on input–output tables and sectoral R&D expenditure. The two networks are structurally compared with the help of methodologies derived from the network analysis, which are conducted at the national, cluster and individual levels to thoroughly examine the multi-embededness of the sectors situated in a technological diffusion network.

This study shows that the two systems have similar distributions of key sectors, including the cores, i.e. machinery and equipment, electronic parts and components, and the sources, i.e. chemicals and basic metals, of innovation flows. However, significant differences also exist. For example, the Taiwanese system is characterized by higher degrees of systemic connection and hierarchy, while the Chinese system has looser density and less centralization. Additionally, the Taiwanese system appears capable of more efficient innovation diffusion among vertically related industries than the Chinese system due to the former containing more effective clusters. Finally, China's technological concentration is centered on heavy industry, while Taiwan is focused on high-tech industry.

Keywords: Intersectoral innovation diffusion; Innovation system; Network; Taiwan; China

1. Introduction

Since the appearance of Freeman's work on the technological development of Japan (Freeman, 1987), national innovation systems (NIS) have become a popular concept among policy-makers seeking to develop the innovation and competitiveness of national or regional economies, while also attracting the attention of numerous researchers working on institutional economics and innovation (e.g. Lundvall, 1992; Nelson, 1993; Patel and Pavit, 1994; Metcalfe, 1995; Galli and Teubal, 1997; Capron et al., 2000). NIS is generally recognized as comprising complex functions and interactions among various institutions involved in the generation, diffusion, and utilization of innovations. Although the capacity for original innovation is one of the main sources of economic growth, in particular the capacity to exploit economical potential and opportunities of the inventions for widespread diffusion throughout the economy is the real driving force (Helpman, 1998). The performance of most manufacturing and service industries depends on putting technology to work by adopting and using ideas and products developed elsewhere (Papaconstantinou et al., 1998). For a long time, the economic growth of Taiwan and China has derived mainly from the manufacturing sector. Therefore, in comparing the performance of Taiwan and China in innovation, addressing innovation diffusion among the industries of the two economies is the crucial first step, since this is the primary mechanism driving the NISs in the two economies.

Recently advances in the emergence of NIS-related papers stress that innovation is an integrated process that must be analyzed at the system level. However, most studies on NISs focus mainly on institutional mapping and inter-organizational knowledge flows by using a qualitative approach (OECD, 1997). Although these types of approaches can separately describe the 'real' situations of a system, it is difficult to display the 'essential' conditions

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* Corresponding author. Tel.: +1-886-2-2349-49-30; fax: +1-886-2-2349-4931.

E-mail address: paolong@cc.nctu.edu.tw (P.-L. Chang).

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of a system in an integrated manner. Few studies of NISs adopting quantitative approaches exist that successfully simplify complex phenomena. Moreover, those quantitative studies of NISs that do exist are mostly focused on addressing the surface indicators of innovation activities and performance (e.g. Chiesa et al., 1996; Coombs et al., 1996; Nasierowski and Arcelus, 1999), making it difficult to uncover the essential contexts of NISs based on an integrated consideration.

To achieve a fundamental and aggregate comparison of innovation systems of Taiwan and China, this study attempts to describe and compare their essential and primary mechanism, that is, the intersectoral innovation diffusion, via a quantitative approach. This study uses product-embodied R&D flows as a proxy for inter-industry innovation diffusion. Although the use of the input–output approach for measuring the NIS is traditionally considered restricted, the areas limited by this approach, for example its ignoring of all institutions involved in NISs except industries (Kumaresan and Miyazaki, 1999) and its treatment of NIS as a one-way or static system (Carlsson et al., 2002), are not the main issues of this study. In addition, looking for alternative analytical tools that can measure systemic and structural features better than the traditional indicators and methodologies of the input–output approach can, this study adopts network analysis, previously employed by Leoncini et al. (1996, Leoncini and Montresor, 2000, 2001a, 2001b), to analyze the extent to which differences in the structure of the two innovation systems can be explained by underlying characteristics such as the degree of the systemic connection and hierarchy at the macro level, to picture clusters of industries which share technology at the meso level, and to identify those sectors where innovation originates and those which benefit most or least from technological innovation diffusion at the micro level. Unlike the emphases of Leoncini et al.'s previous studies, which stressed the interaction of four different subsystems that comprise technological systems, namely industrial, innovative, commercial and institutional subsystems, this study focuses on the multi-embededness of the sectors situated in the technological diffusion network within innovation systems, and employs network analysis to examine the network structures at three different levels to achieve a more complete and essential understanding of intersectoral innovation diffusion than previous studies.

2. Methodologies

2.1. Constructing intersectoral innovation diffusion networks: an input–output approach

Technology diffusion refers to the various mechanisms through which firms acquire innovative technology externally rather than generating it internally (Papaconstantinou et al., 1998). For the dual phases of corporate R&D investment (Cohen and Levinthal, 1989), not only developing innovative technology but also improving firms' capability of absorption and learning of technology developed elsewhere, all firms with R&D investments are involved in diffusion processes (Hubner, 1996). Technology transfer or acquisition is the most important type of relationships in innovation systems (Carlsson et al., 2002), some of which take place via markets, some via non-market interaction. In addition, the diffusion of innovation following the way of its realization involves two types. One type is disembodied diffusion, which is related to the transmission of ideas, knowledge, expertise, or technology in a way that does not involve physical intermediaries. In an intersectoral context, this type of diffusion is typically studied by means of analyzing patent flow matrices (e.g. Massini, 1998), patent citation matrices (e.g. Verspagen, 1997), or technological proximity matrices (e.g. Goto and Suzuki, 1989). The other type is product-embodied diffusion, in which inputs purchased by industries from upstream industries embody entirely new commodities or quality improvements. This type of intersectoral innovation diffusion is generally analyzed using input–output tables and sectoral R&D expenditures (e.g. Leoncini et al., 1996; Sakurai et al., 1997; Papaconstantinou et al., 1998; Leoncini and Montresor, 2000, 2001a, 2001b; Peeters et al., 2001).

Empirically, although knowledge and technology are diffused through various channels, Drejer (2000) finds that the identification of product-embodied R&D flows is a major first step in understanding the structure of an NIS. An analysis of product-embodied R&D flows that uncovers major sources for the spread of technology in the economic system can point out sectors that significantly influence the entire system through the diffusion of technology as a result of transactions between industries. Therefore, this study uses product-embodied diffusion of sectoral R&D expenditures to compare the primary innovation mechanisms of Taiwan and China. This methodology is based on two assumptions. First, R&D expenditures are assumed to be able to be considered as a proxy for the expansion of technological knowledge involving improvements in product quality or production processes. Second, intermediate goods and services transacted intersectorally are assumed to work as carriers of innovative technologies between industries. In this respect, there is a following assumption that the R&D embodiment in an imported input is assumed to be proportionately distributed across all of the industries that use it.

The product-embodied diffusion can be demonstrated by measuring the R&D expenditures of upstream industries that are embodied in the inputs for the industries that use it. The main advantage of this methodology is that a comprehensive feature of innovation systems can be captured through quantitative analysis of input–output tables and R&D expenditures, thus avoiding the limitations associated with case studies. In terms of weakness, this methodology limits the channels of technology diffusion to the purchase of intermediate and capital inputs. However, regarding the comparison between the Taiwanese and Chinese innovation systems, both of which represent manufacturing-dominated economies, the use of the analysis of product-embodied R&D diffusion across industries in the two economies is an effective and efficient methodology.

Following a previously established methodology of the study on innovation diffusion (Marengo and Sterlacchini, 1990), intersectoral innovation diffusion can be proxied by a matrix $R(n \times n)$ of the product-embodied R&D expenditures. The matrix R equals the sectoral direct R&D intensity (R&D expenditure per gross output, i.e.$\hat{r}(\hat{x})^{-1}$) multiplying by the direct and indirect intermediate flows of products and services (expressed by the Leontief inverse), and by final demand, which is obtained as follows:

$$R = \hat{r}(\hat{x})^{-1}(I - A)^{-1}\left(\hat{d}\right) \tag{1}$$

where $\hat{r}(n \times n)$, $\hat{x}(n \times n)$ and $\hat{d}(n \times n)$ denote the sectoral diagonal matrices of R&D expenditure, gross output and final demand, respectively, A represents the matrix of input–output coefficients and thus $(I - A)^{-1}$ is the Leontief inverse. Each cell, R_{ij}, of the matrix measures the direct and indirect R&D expenditure of industry i that is embodied in the final demand for the commodity produced by industry j.

Since this study is interested in comparing innovation systems with respect to their structural and relational elements based on comparable indicators, we have to get rid of scale effects resulting from differences in the size of industries and countries. Previous studies (e.g. Leoncini et al., 1996; Leoncini and Montresor, 2000, 2001a, 2001b) employed methods based on dividing the elements of each row/column by the relative total to overcome this problem. These operations are good for resulting in a comparative base among constituent sectors within a certain row/column but, however, they are unable to produce a comparable base for displaying the differences between industries or countries because the sum of normalized elements of every row/column is always equal to one after these kinds of data transformation. For this reason, we propose a unit value matrix R^{unit} defined as:

$$R^{unit} = \hat{r}(\hat{x})^{-1}(I - A)^{-1} \tag{2}$$

to produce the comparative criterion on a per dollar basis for the final demand of each sector. Each cell, R_{ij}^{unit}, of the matrix denotes the direct and indirect R&D expenditure by industry i, embodied in per dollar of final demand for the commodity produced by industry j.

In terms of data, the input–output data and sectoral R&D expenditure for Taiwan are sourced from the Taiwan Input–Output Tables for 1999 (Directorate-General of Budget, 2002), the most recent year available, and Economic Statistics Annual of Taiwan for 2000 (Ministry of Economic Affairs, 2001), respectively. Meanwhile, the input–output data and sectoral R&D expenditure for China are derived from the Input–Output Table of China, 1997 (Department of National Economy Accounting, State Statistical Bureau, 1999), which is the most recent year available, and the China Statistical Yearbook on Science and Technology 1998 (National Bureau of Statistics, 1998), respectively. All values are calculated in US dollars. A difference of 2 years exists in the comparison of the two economies, the data for Taiwan are from 1999, while those for China are from 1997, an unavoidable time lag owing to restrictions on data availability. Since national economic data remain fairly consistent over time, a difference of 2 years is not particularly important. In addition, regarding the database matching, this study examines 21 manufacturing sectors rearranged in vertically integrated industries as follows, (1) food, beverages and tobacco; (2) textiles; (3) apparel and clothing accessories; (4) leather and fur; (5) furniture, wood and bamboo products; (6) paper and paper products; (7) printing and publishing; (8) chemical materials; (9) chemical products; (10) petroleum and coal products; (11) rubber products; (12) plastic products; (13) non-metallic mineral products; (14) basic metals; (15) metal products; (16) non-electrical machinery and equipment; (17) electrical machinery and equipment; (18) electronic and telecommunication products; (19) electronic parts and components; (20) transport equipment; (21) precision instruments.

2.2. Comparing patterns of intersectoral innovation diffusion networks: network analysis

Network analysis is a recently developed set of methods for the systematic study of social structures. Although mainly developed for the study of sociology, the indicators and techniques of network analysis are extremely suitable for application to examine the structural features of the interactive relationships of an innovation system (Leoncini et al., 1996; Leoncini and Montresor, 2000). Derived from graph theory, network analysis attempts to describe the structure of interactions (displayed by edges) between given entities (displayed by nodes), and applies quantitative techniques to produce relevant indicators and results for studying the characteristics of a whole network and the position of individuals or groups in the network structure. This study employs network analysis, instead of the traditional indicators of input–output literatures, to examine and compare the structural characteristics of innovation systems of Taiwan and China, where the 21 manufacturing sectors are treated as nodes and the innovation diffusion among them is treated as a series of edges.

Network analysis employs two kinds of mathematical tools to represent information on relationship patterns among actors, namely graphs and matrices. Graphs are extremely useful ways of presenting visual and immediate structure on a network. However, when numerous actors and/or varieties of relations exist, graphs may become visually complex to the point that pattern discernment becomes difficult. Meanwhile, the matrices method is good at treating large networks through the application of mathematical and computer tools to locate and summarize patterns. For complementary purposes, this study adopts both representations.

In this study, the R^{unit} matrix represents a valued network, meaning that the edges of the network measure linkages with different magnitude and need to be dichotomized. Therefore, the cell of the R^{unit} matrix must be a binary transformation, comprising 1s and 0s if it is to exceed the cut-off value k:

$$R_{ij}^{dic} = 1\text{if}R_{ij}^{unit} > k, R_{ij}^{dic} = 0\text{if}R_{ij}^{unit} \le k. \tag{3}$$

The fact that threshold value chosen for k is exogenous is a major limitation of this methodology (Leoncini and Montresor, 2000). However, this study applies the above technique to compare the structure of two networks on a relative basis so that the limitation can be ignored, while the choice of k can result in uncovering the different patterns of the two networks.

The network perspective stresses multiple levels of analysis (Scott, 1991; Wasserman and Faust, 1994; Degenne and Forse, 1999). Differences among actors are traced to the constraints and opportunities arising from how they are embedded in networks; on the other hand, the structure and characteristics of networks grounded in and enacted by local interactions among actors. This study examines the structures of the two economies using network analysis at the national, cluster and individual levels, thus allowing the thorough examination of the multi-embeddedness of the sectors situated in networks. The rest of this section describes the indicators and techniques of network analysis suitable for examining the structural characteristics of diffusion networks at different levels.

Focusing first on the network as a whole, Leoncini et al. have employed network density as an index of the systemic connection of an innovation system. Network density as composed by n nodes is generally defined as the proportion of the number of existing links (e) to the maximum possible number of links:

$$D = \frac{e}{n(n-1)}. \tag{4}$$

The density of the network corresponding to an innovation system is assumed to be able to measure its internal cohesion. That is, the higher the density of the network, the more connected the innovation system, and vice versa (Leoncini and Montresor, 2000).

At individual level, indicator–centrality is used to obtain the positional features of an individual sector within networks. The indegree (C_{in}) and outdegree (C_{out}) of centrality of a given sector are formally defined as:

$$C_{in}^{i} = \sum r_{in}; C_{out}^{i} = \sum r_{out} \tag{5}$$

where r_{in} and r_{out} denote one of the input and output flows of sector i, respectively. The use of the indicators corresponding to innovation systems as the inputs and the outputs of a sector represent intersectoral innovation acquisitions and exportations, respectively. Comparing the two measures of inward and outward centralities of a given sector is capable of revealing whether this sector is a source, core or terminal of innovation diffusion.

Although the centrality index is referred to a single sector, it can be combined to study the scale of structural hierarchy of innovation systems at the system-wide level by calculating the inward (H_{in}) and outward (H_{out}) degrees of centralization, generally defined as:

$$H_{in} = \frac{\sum_{i}\left(C_{in}^{i*} - C_{in}^{i}\right)}{(n-1)(n-2)}; H_{out} = \frac{\sum_{i}\left(C_{out}^{i*} - C_{out}^{i}\right)}{(n-1)(n-2)} \tag{6}$$

where C_{in}^{i*} and C_{out}^{i*}, respectively, denote the inward and outward centralities of the most central sector, $i*$. The centralization measures the difference in centrality between the most central sector and other sectors. A high centralization index indicates a very hierarchic system that, corresponding to innovation systems, is less conductive to interactive innovation diffusion than a low centralization system with an evenly distributed structure (Leoncini et al., 1996).

Finally, the cluster analysis presented in this study is conducted at the meso level so that it can reveal the inter-context between the national and individual levels. Following the supply–demand respect, a cluster is a concentration of industries that prosper because of their interaction by serving as suppliers or users in the value chain (Padmore and Gibson, 1998). Innovation clustering is not serendipitous, but rather is systematically inter-related technical development, the cause of which is frequently driven by the desire to reduce costs that can be achieved by complementary technologies from vertically related industries. To compare the Taiwanese and Chinese innovation systems at this level, the various clusters within their networks can be examined, revealing significant differences in size, shape and number of linkages among the constituent sectors.

Some overlap among these clusters is apparent, and results from the existence of linkages between sectors from different clusters (Peeters et al., 2001). In this sense, the sectors positioning at this kind of place in a network can be referred to using the concept of structural holes, proposed by Burt (1992), which stands for a competitive advantage for an actor with relationships spanning different clusters. Structural holes represent an opportunity to broker the flow of technological information among sectors, and to control the projects that bring together sectors from opposite sides of clusters. Generally, the identified clusters are built on one or two core industries, surrounded by a group of suppliers and users. Additionally, there also existing important industries in a given cluster must be identified owing to their linkages with sectors belonging to other clusters.

Burt (1992) proposes two concepts for measuring structural holes: redundancy and constraint. The general meaning of redundancy is that the ego network of a sector is redundant to the extent that its links are also connected to each other. Redundancy can be measured using the indicator effective size of the egocentric network of each sector, which is formally defined as:

$$\text{Effective size of } i'\text{s network} = \sum_j \left(1 - \sum_q p_{iq} m_{jq}\right), q \neq i,j. \tag{7}$$

Here, p_{iq} is the proportional connection of sector i in relation to q (interaction with q divided by the sum of the relations of i),

$$p_{iq} = \frac{\left(z_{iq} + z_{qi}\right)}{\sum_j \left(z_{ij} + z_{ji}\right)}, i \neq j,$$

and m_{jq} denotes the marginal strength of the relation to q (interaction with q divided by the strongest relation of j),

$$m_{jq} = \frac{\left(z_{jq} + z_{qj}\right)}{\max\left(z_{jk} + z_{kj}\right)}, j \neq k,$$

while z_{ij}, a general element of matrix Z transformed from matrix R^{dic}, indicates the strength of the relation between sectors i and j, respectively,

$$z_{ij} = \begin{cases} 0 & \text{ifnorelationexistsbetween}i\text{and}j \\ 1 & \text{if}i = j \\ 1 - \dfrac{f_{ij}}{n_i} & \text{otherwise} \end{cases}$$

where n_i denotes the number of sectors i can contact, and f_{ij} represents the number of sectors located at the same distance as j to i or closer. The effective size of i in Eq. (7) varies from one, indicating that all members enjoy links to each other, up to the observed number of i's links in the network, n_i, indicating that network members share no links to one another. The ratio of the effective size divided by n_i measures efficiency, and varies from near zero to a maximum of one.

The other concept used to measure structural holes is constraint, that is the extent to which ego is directly and indirectly dependent on others, via crisscrossing connections and the absence of structural holes. The value of constraint, C_i, is given by:

$$C_i = \sum_j \left(p_{ij} + \sum_q p_{iq} p_{qj}\right)^2, q \neq i,j \tag{8}$$

If $C_i = 0$ the ego has numerous disconnected, readily replaceable relations, while if $C_i = 1$ the ego has only one effective connection.

3. Empirical analyses

This study compares the intersectoral innovation diffusion with respect to 21 manufacturing sectors for Taiwan in 1999 and for China in 1997. Concerning the structure of the empirical application, after building the unit value matrices, R^{unit}, one proper cut-off value, k, must be selected to dichotomize the cells of the matrices to apply the binary data to the indicators and graphs of network analysis. Although the choice of threshold value for k is arbitrary, two steps can be implemented for preliminary sensitivity testing to identify the most suitable value for k. First, the difference in the structural patterns of the two systems is reasonably stable since the cut-off value changes from very low to very high, so that we can choose just one cut-off value for carrying out the purposes of this study. Second, the appropriate cut-off value must be selected based on the heuristic criteria that the distinguishing characteristic in the structure of the two networks can be detected, rather than the very high or very low values that characterize almost completely connected or nearly totally unconnected networks. Following these two investigations, $k = 0.0001$ has been chosen, which indicates that R_{ij}^{dic} equals 1, if the direct and indirect amount of R&D expenditure performed by sector i embodied in per dollar final demand of sector j is larger than \$0.0001, otherwise R_{ij}^{dic} equals 0. Consequently, the binary edged matrices, R^{dic}, have been built to allow the implementation of the network analysis for the two systems. In the remainder of this section, we describe and compare the structural features of intersectoral innovation diffusion in Taiwan and China through network analysis at the national, cluster and individual levels, respectively.

3.1. National level

A preliminary visual evaluation of the overall systems can be captured based on the graph approach. Fig. 1 shows that Taiwan appears to be more connected than China. Moreover, Taiwan's graph appears to be made up of numerous loops while China's graph exhibits certain cores

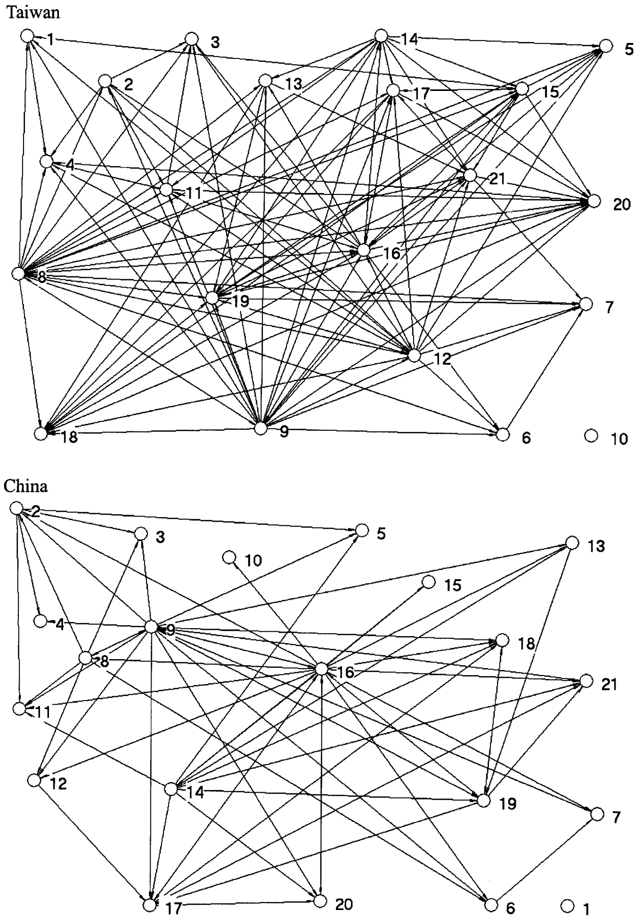

Fig. 1. Graphs of intersectoral innovation diffusion networks in Taiwan and China.

extending to the whole network. Density index and mean of centrality degree ($D_{\mathrm{tw}} = 0.295$, $M_{\mathrm{tw}} = 5.9$; $D_{\mathrm{cn}} = 0.155$, $M_{\mathrm{cn}} = 3.1$, see Table 1) confirm the higher systemic connection of Taiwan compared to China, and particularly, the value of Taiwan's density/mean is almost twice that of China's. Taiwan demonstrates significantly higher variance of outward centrality degrees than of inward ones ($Var_{\mathrm{out,tw}} = 40.0$, $Var_{\mathrm{in,tw}} = 8.8$). Taiwan's outward centrality degrees range between 0 and 19, which causes the average variability from one sector to the next is 6.3 ($S.D._{\mathrm{out,tw}}$), larger than the mean (5.9). So, considerable variation exists in the degree of outward centrality in Taiwan. On the contrary, the variance in the degree of inward centrality in Taiwan appears much more stable, and has a standard deviation of 3.0 ($S.D._{\mathrm{in,tw}}$), less than the mean. The patterns of inward and outward centrality degrees in China are quite similar to those in Taiwan ($Var_{\mathrm{out,cn}} = 25.0$, $Var_{\mathrm{in,cn}} = 2.3$; $S.D._{\mathrm{out,cn}} = 5.0$, $S.D._{\mathrm{in,cn}} = 1.5$). However, significant differences persist owing to the smaller values of these indicators in China compared to Taiwan. Generally, China has lower variability in centrality degrees than does Taiwan.

Centralization index analysis ($H_{\mathrm{in,tw}} = 33.7\%$, $H_{\mathrm{out,tw}} = 72.4\%$; $H_{\mathrm{in,cn}} = 10.5\%$, $H_{\mathrm{out,cn}} = 71.3\%$) confirms the above-mentioned characteristic patterns of inward and outward centrality degrees in Taiwan and China. In addition, the degree of centralization index also implies that the sectoral partitions of a diffusion system can be regarded as a hierarchic network (i.e. high centralization degree) or an evenly distributed one (i.e. low centralization degree). Both Taiwan and China have a hierarchic structure that is higher in outward linkages than in inward linkages. To the extent that a network is not connected, a structural basis for stratification may exist. That is, on the outward linkage aspect, both whole networks are characterized by considerable concentration or centralization. Specifically, the power of individual sectors varies rather substantially in outward linkages, meaning that the advantages are rather unequally distributed in the outward linkage parts of both networks. The degree of outward centralization in Taiwan is similar to that in China, but the degree of inward centralization is significantly lower in China than in Taiwan. On the inward linkage aspect, although both systems are quite evenly distributed, the Chinese network is less concentrated than the Taiwanese one. That is, the individual sectors within the Chinese system share power and advantages in the inward linkage more equally than those within the Taiwanese system.

3.2. Cluster level

Cluster analysis is conducted herein for two purposes. First, clusters can be generally viewed as reduced-scale innovation systems, so that the resulting subgroups can be analyzed with ease. Second, from the perspective of network analysis, the linkages among sectors within a certain cluster are so dense and 'strong' that these constituent sectors can transfer innovative technology to/from one another more easily, and thus each sector in the cluster may reach a similar technological level.

The two-stage clustering procedure can be applied to identify five clusters in the Taiwanese innovation system: a chemicals and electronic (CE) cluster (sectors: 8, 9, 12, 13, 16, 18, 19); a metal and equipment (ME) cluster (sectors: 5, 14, 15, 17, 20, 21); a consumer goods (CG) cluster (sectors: 1, 2, 3, 4, 11); a paper and printing (PP) cluster (sectors: 6, 7); and a petroleum and coal products cluster (sector: 10). The 'small' cluster of petroleum and coal products is treated as part of cluster CE since a very large part of its sales are made to this cluster and because of the nature of the products involved. Thus the Taiwanese innovation system contains four clusters in total (Fig. 2). On the other hand, the Chinese innovation system contains five clusters (reduced from six originally, for the same reasons as the petroleum and coal products as noted above) (Fig. 3): a chemical and textiles (CT) cluster (sectors: 2, 3, 4, 8, 9, 10, 11, 12); a metal and machinery (MM) cluster (sectors: 5, 14, 15, 16, 17, 20);

Table 1
Indexes of intersectoral innovation diffusion networks in Taiwan and China

Sector	Taiwan					China				
	Inward centrality	Outward centrality	Effective size	Efficiency	Constraint	Inward centrality	Outward centrality	Effective size	Efficiency	Constraint
1 Food, beverages and tobacco	4	1	2.8	0.560	0.325	0	0	0	0	0
2 Textiles	3	4	2.8	0.398	0.344	3	4	4.8	0.684	0.355
3 Apparel and clothing accessories	6	0	2.1	0.347	0.349	3	0	1.3	0.444	0.545
4 Leather and fur	6	3	3.3	0.476	0.314	2	0	1.3	0.625	0.605
5 Furniture, wood and bamboo products	7	0	2.9	0.408	0.297	3	0	2.5	0.833	0.380
6 Paper and paper products	4	1	1.9	0.380	0.354	3	1	2.0	0.500	0.490
7 Printing and publishing	6	0	3.1	0.514	0.311	3	0	1.3	0.444	0.542
8 Chemical materials	2	19	11.6	0.610	0.218	2	6	3.8	0.545	0.372
9 Chemical products	3	19	11.4	0.602	0.220	2	16	12.5	0.780	0.220
10 Petroleum and coal products	0	0	0	0	0	1	0	1.0	1.0	1.0
11 Rubber products	7	4	4.0	0.449	0.290	5	0	2.7	0.540	0.362
12 Plastic products	6	14	9.7	0.605	0.220	3	1	2.0	0.500	0.432
13 Non-metallic mineral products	4	3	3.0	0.429	0.308	3	1	2.0	0.500	0.422
14 Basic metals	3	10	5.5	0.455	0.272	1	10	7.3	0.727	0.293
15 Mental products	6	8	5.1	0.464	0.277	2	0	1.0	0.500	0.649
16 Non-electrical machinery and equipment	10	16	9.3	0.581	0.222	5	16	12.5	0.780	0.221
17 Electrical machinery and equipment	8	6	3.9	0.386	0.299	5	4	4.4	0.549	0.383
18 Electronic and telecommunication products	9	3	3.8	0.375	0.293	5	1	2.4	0.483	0.433
19 Electronic parts and components	9	9	6.4	0.489	0.263	5	4	3.7	0.524	0.395
20 Transport equipment	12	0	6.1	0.507	0.258	4	1	1.8	0.450	0.460
21 Precision instruments	9	4	4.9	0.444	0.274	5	0	2.4	0.480	0.406
Descriptive statistics										
Sum (S)	124	124	103.6	9.479	5.708	65	65	72.7	11.888	8.965
Mean (M)	5.9	5.9	4.9	0.451	0.272	3.1	3.1	3.5	0.566	0.427
Variance (Var)	8.8	40.0	10.0	0.017	0.006	2.3	25.0	11.6	0.040	0.037
Standard deviation (S.D.)	3.0	6.3	3.2	0.131	0.075	1.5	5.0	3.4	0.199	0.193
Min.	0	0	0	0	0	0	0	0	0	0
Max.	12	19	11.6	0.610	0.354	5	16	12.5	1	1
Network indicators										
Density (D)	0.295					0.155				
Centralization (H)	33.7%	72.4%				10.5%	71.3%			

an electronics and instruments (EI) cluster (sectors: 13, 18, 19, 21); a paper and printing (PP) cluster (sectors: 6, 7); and an agro-food (AF) cluster (sector: 1).

3.2.1. Taiwanese clusters

3.2.1.1. Chemicals and electronics (CE) cluster. The CE cluster is the largest cluster in the Taiwanese economy, consisting of eight sectors. The distribution of the sectors within the CE cluster is bipolar, leading to two subgroups: a subgroup built around the electronics-related sector and a subgroup built on sectors related to the chemicals industries. This phenomenon illustrates the strong connection between the two subgroups based on the producer-user process in Taiwan. The constituent sectors of this cluster possess strong mutual linkages (density of cluster CE, $D_{\mathrm{CE}} = 0.518$), and have identical centralization in both inward and outward linkages (inward and outward centralization of cluster CE, $H_{\mathrm{in,CE}} = 45.2\%$, $H_{\mathrm{out,CE}} = 45.2\%$). Furthermore, cluster CE is very closely linked with the other clusters, especially possessing strong outward linkages with clusters ME, CG and PP, yet has only weak inward linkages with clusters ME and CG. The CE cluster is located at the core position surrounded by the other three clusters. However, it is a technological exporting cluster rather than a receiving cluster relatively.

3.2.1.2. Metal and equipment (ME) cluster. The ME cluster, containing six sectors, is the second largest cluster in Taiwan. Compared with other clusters, cluster ME has a medium level of systemic connection ($D_{\mathrm{ME}} = 0.467$). ME has higher hierarchic structure in outward linkages than inward linkages ($H_{\mathrm{in,ME}} = 50\%$, $H_{\mathrm{out,ME}} = 80\%$). Regarding the outside linkages, the ME cluster has mutual linkages with cluster CE, in which its inward connection with CE is

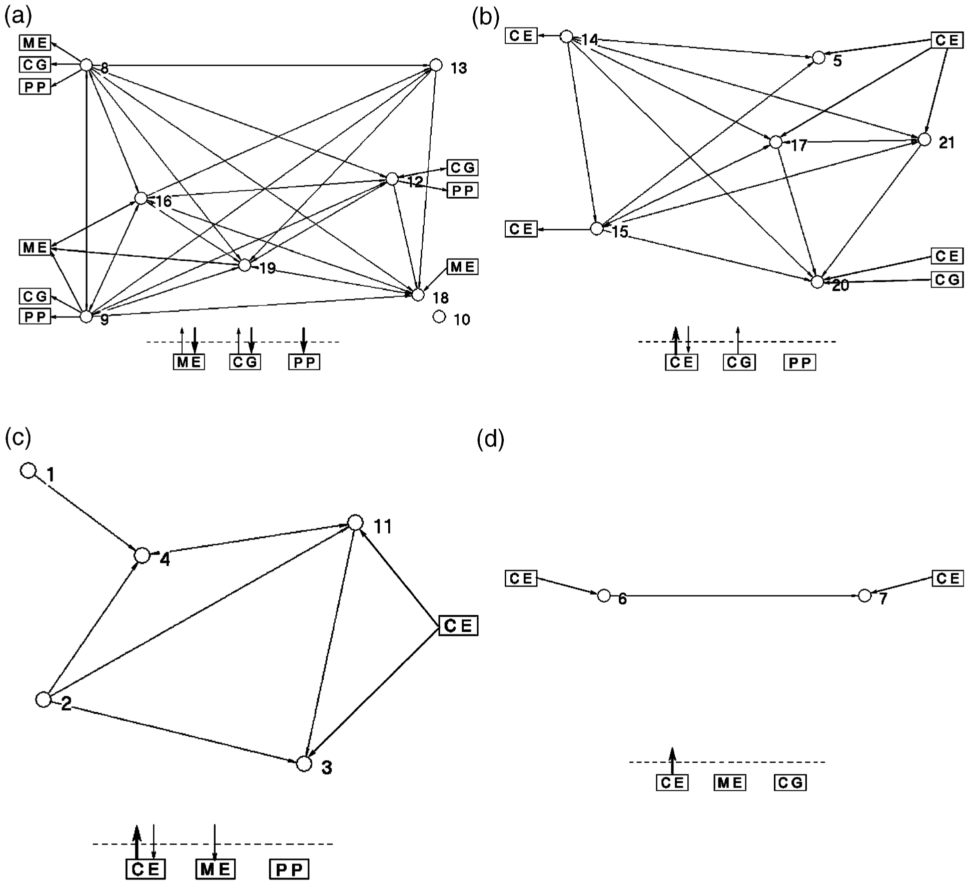

Fig. 2. The four technological clusters in Taiwan.

stronger than its outward connection. Moreover, the ME cluster is still inwardly linked with cluster CG. The ME cluster accepts innovation from the other clusters more than transferring innovation to them.

3.2.1.3. Consumer goods (CG) cluster. The CG cluster has a medium size, and comprises five sectors. The various sectors belonging to cluster CG have only weak systemic connection ($D_{\mathrm{CG}} = 0.467$), yet share equal and high centralization in both inward and outward linkages ($H_{\mathrm{in,CG}} = 66.7\%, H_{\mathrm{out,CG}} = 66.7\%$). The CG cluster exports technology to clusters CE and ME, but with a weak connection, while receiving technology from cluster CE with strong tie.

3.2.1.4. Paper and printing (PP) cluster. The PP cluster is small and compact, comprising just two sectors. This cluster contains a one-way linkage between the two sectors ($D_{\mathrm{PP}} = 0.5$). Owing to the number of constituent sectors, the cluster is unable to calculate the degrees of inward and outward centralization. In addition, the PP cluster is purely a receiver of technology, having inward connections with cluster CE, and not outstanding outward linkages with any other clusters.

3.2.2. Chinese clusters

3.2.2.1. Chemical and textiles (CT) cluster. The CT cluster, consisting of eight sectors, is the largest cluster in the Chinese system. However, the systemic connection of the CT cluster is weaker than that of the other clusters in China ($D_{\mathrm{CT}} = 0.25$). Within this cluster, the distribution of the constituent sectors is extremely hierarchical in the outward linkages ($H_{\mathrm{out,CT}} = 81.0\%$), but quite even in the inward linkages ($H_{\mathrm{in,CT}} = 23.8\%$). Cluster CT is an open cluster, maintaining significant linkages with other clusters, and a particularly strong mutual connection with cluster MM. Furthermore, cluster CT still has outward connections with clusters EI and PP, but the linkages are weaker than its linkages with cluster MM. Relatively speaking, the CT cluster transfers more technology to other clusters than it receives from them.

3.2.2.2. Metal and machinery (MM) cluster. The MM cluster, containing six sectors, is a large and homogeneous cluster, almost entirely made up of sectors involved in the metal machinery production system. Within this cluster, its constituent sectors have close connections with one another ($D_{\mathrm{MM}} = 0.40$) but, like cluster CT, the hierarchical structure

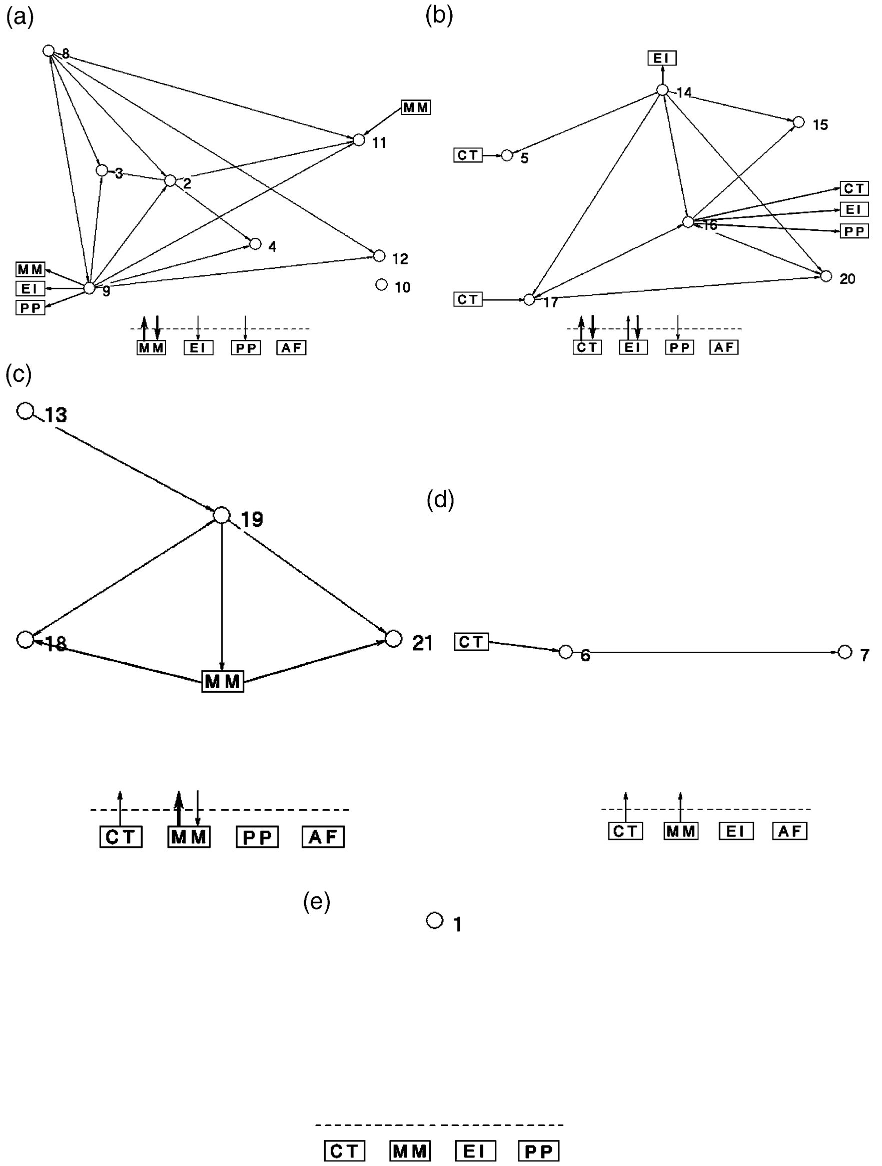

Fig. 3. The five technological clusters in China.

is higher in outward linkages than inward linkages ($H_{\mathrm{in,MM}} = 30\%$, $H_{\mathrm{out,MM}} = 90\%$). The MM cluster requires special attention due to its central position and numerous connections with almost every other cluster. The MM cluster has strong mutual linkages with cluster CT, strong outwards and weak inwards links with cluster EI, and is engaged in pure technology transfer to cluster PP.

3.2.2.3. Electronics and instruments (EI) cluster. The EI cluster is medium in size, comprising four sectors, and has a cluster of medium systemic connections ($D_{\mathrm{EI}} = 0.333$). This cluster is dominated by various high-tech industries. The inward and outward distributions of centralization are identical and high within this cluster ($H_{\mathrm{in,EI}} = 66.7\%$, $H_{\mathrm{out,EI}} = 66.7\%$). Regarding the outside linkages, the EI cluster is an innovation receiver rather than an exporter because of its strong inwards linkage with cluster MM and weak inwards linkage with cluster CT, along with a weak outwards connection with cluster MM.

3.2.2.4. Paper and printing (PP) cluster. The patterns of the PP cluster in the Chinese system closely resemble those in the Taiwanese system. Specifically, the Chinese PP cluster comprising two sectors, identical to those in Taiwan, joined by a close one-way linkage ($D_{\mathrm{PP}} = 0.5$), and characterized as a pure innovation receiver with inward linkages from clusters CT and MM.

3.2.2.5. Agro-food (AF) cluster. The AF cluster has a single sector, and is not closely related to the other clusters.

Relatively, this compact cluster occupies a peripheral position in the Chinese economy.

The two systems exhibit some similarities and differences at the cluster level. Both the Taiwanese and Chinese systems contain a core cluster, namely cluster CE in Taiwan and cluster MM in China, which occupies a central position and is in charge of innovation diffusion among the other clusters, especially in acting as a technology provider. The MM cluster in China is made up of sectors mainly related to the metal machinery industries, while the CE cluster in Taiwan comprises two subgroups, one around electronic-related industries and the other related to the chemicals sectors. Additionally, the inside systemic connection and outside linkages of Taiwanese clusters are stronger than those of Chinese clusters due to the Taiwanese system having a higher density at the national level. Finally, within clusters, the Chinese sectors have more asymmetric sectoral structure than the Taiwanese sectors on the outward linkages, but the opposite applies for the inward linkages.

3.3. Individual level

The analyses at the national and cluster levels enable the thorough examination of the structural characteristics of a certain sector situated in the national system and cluster that this sector belongs to. Centrality index analysis at the individual level shows a given sector is either dependent (the indegree measuring sectoral dependence) or pervasive (the outdegree measuring sectoral pervasiveness) in the national system. Moreover, comparing each sector's indegree with outdegree reveals it is a source, core or terminal of innovation diffusion. In addition, the three indexes measuring structural holes, i.e. effective size, efficiency and constraint, can indicate which sectors possess the advantages of being structural holes in the network. On the other hand, applying the results of cluster analysis to an individual sector allows illustrating the sector's network characteristics in the cluster that it belongs to. Furthermore, examining the overlapping sectors between clusters with inward or outward linkages can reveal that the sector, within the cluster that it is associated with, serves as a receiver or exporter of innovative technology from or to the other clusters. Table 2 summarizes the comparison of individual sectors between Taiwan and China at the national and cluster levels.

At the national level, both networks possess three outstanding core sectors: sectors 12 (plastic products), 16 (non-electrical machinery and equipment) and 19 (electronic parts and components) in Taiwan, and sectors 16, 17 (electrical machinery and equipment) and 19 in China. Particularly, sector 16 is the most central in both systems, not only being situated at the core of the national network and cluster that it belongs to, but also being located in critical positions with numerous advantages in the form of structural holes controlling interactions with other clusters. In Taiwan, sector 16, which belongs to cluster CE, controls the mutual linkages with cluster ME, while in China sector 16 belongs to cluster MM, and controls the outwards connections with clusters CT, EI and PP. Owing to the nature of the manufacturing tools, sector 16 is highly pervasive, with an outdegree that exceeds its indegree. Sectors 16 and 17 confirm the importance of technological tool sectors based on process innovation. However, unlike sector 16, sector 17 is dependent in both systems, and acts as a technology receiver of cluster ME from cluster CE in Taiwan and of cluster MM from cluster CT in China. Sector 19, which is an intermediate, has very even distribution between the inward and outward linkages in both networks. Sector 19, located within cluster EI in China, is a core and exports technology to cluster MM. While in Taiwan, sector 19 is located within cluster CE, and has the appearance of a dependent intermediate and transfers innovation to cluster ME. Another core sector in Taiwan, sector 12, is highly pervasive and handles the mutual linkages with cluster CG and outward connections with cluster PP, meaning that it possesses the advantages of structural holes. In contrast, in China sector 12 is relatively dependent, with no active interactions with sectors in either its located cluster or other clusters, and consequently is a terminal within cluster CT.

The Taiwanese system contains three pervasive sources, namely sectors 8 (chemical materials), 9 (chemical products) and 14 (basic metals), while the Chinese system contains just two such sources, namely sectors 9 and 14. Acting as the materials of the technological concentration in both systems, sector 8 in Taiwan occupies a more critical position than in China because in Taiwan it is not only located in the central both in the national network and in cluster CE, but also has the power to control outward interactions with clusters ME, CG and PP, yet in China it is merely a penetrative source within cluster CT. In both Taiwan and China, sector 9 is definitely an important pervasive source of technology at both the national and cluster levels, and thus is responsible for transferring technology to numerous other sectors and clusters. This phenomenon confirms that the chemicals sector is one of the key industries in both systems. Sector 14, due to the nature of working as intermediate, is another pervasive source with numerous outwards overlapping linkages. However, at the national level, sector 14 has more advantages in the form of structural holes in China than in Taiwan. The critical positions of sectors 8, 9 and 14 confirm the important role of technological intermediate and capital-intensive industries in the Taiwanese and Chinese innovation systems, especially for Taiwan.

The most notable difference between Taiwanese and Chinese systems appears in the most dependent sectors. In Taiwan, the technological terminals are limited to three

Table 2
Comparing patterns of individual sector at national and cluster levels between Taiwan and China

Sector	Taiwan		China	
	National level	Cluster level	National level	Cluster level
1 Food, beverages and tobacco	Dependent	A pervasive sector within cluster CG	An outlier	Composing entire cluster AF
2 Textiles	An intermediate	A source within cluster CG	An intermediate	A core within cluster CT
3 Apparel and clothing accessories	A dependent terminal	A terminal within cluster CG The receiver from cluster CE	A dependent terminal	A terminal within cluster CT
4 Leather and fur	Dependent	A dependent sector within cluster CG	A dependent terminal	A terminal within cluster CT
5 Furniture, wood and bamboo products	A dependent terminal	A terminal within cluster ME The receiver from cluster CE	A dependent terminal	A dependent sector within cluster MM The receiver from cluster CT
6 Paper and paper products	Dependent	A source within cluster PP The receiver from cluster CE	Dependent	A source within cluster PP The receiver from cluster CT
7 Printing and publishing	A dependent terminal	A terminal within cluster PP The receiver from cluster CE	A dependent terminal	A terminal within cluster PP
8 Chemical materials	A pervasive, penetrative source Advantages of structural holes	A penetrative source within cluster CE The exporters to clusters ME, CG and PP	Pervasive	A penetrative source within cluster CT
9 Chemical products	A pervasive, penetrative source Advantages of structural holes	A penetrative source within cluster CE The exporters to clusters ME, CG and PP	A pervasive, penetrative source Advantages of structural holes	A penetrative source within cluster CT The exporters to clusters MM, EI and PP
10 Petroleum and coal products	An outlier	An outlier within cluster CE	Dependent	An outlier within cluster CT
11 Rubber products	Dependent	A core within cluster CG The receiver from cluster CE	A dependent terminal	A terminal within cluster CT The receiver from cluster MM
12 Plastic products	A pervasive core Advantages of structural holes	A core within cluster CE The receiver from cluster CG and the exporters to clusters CG and PP	Dependent	A terminal within cluster CT
13 Non-metallic mineral products	An intermediate	An intermediate within cluster CE	Dependent	A source within cluster EI
14 Basic metals	A pervasive, penetrative source	A source within cluster ME The exporter to cluster CE	A pervasive, penetrative source Advantages of structural holes	A penetrative source within cluster MM The exporter to cluster EI
15 Mental products	A pervasive intermediate	A pervasive intermediate within cluster ME The exporter to cluster CE	A dependent terminal	A terminal within cluster MM
16 Non-electrical machinery and equipment	A pervasive core Advantages of structural holes	A core within cluster CE The receiver from cluster ME and the exporter to cluster ME	A pervasive core Advantages of structural holes	A core within cluster MM The exporters to clusters CT, EI and PP

(*continued on next page*)

Table 2 (*continued*)

Sector	Taiwan		China	
	National level	Cluster level	National level	Cluster level
17 Electrical machinery and equipment	Dependent	A core within cluster ME The receiver from cluster CE	A dependent core	A core within cluster MM The receiver from cluster CT
18 Electronic and telecommunication products	Dependent	A penetrative terminal within cluster CE The receiver from cluster ME	Dependent	Mutual linkages with sector 19 within cluster EI The receiver from cluster MM
19 Electronic parts and components	A core/intermediate	A dependent intermediate within cluster CE The exporter to cluster ME	A core/intermediate	A core within cluster EI The exporter to cluster MM
20 Transport equipment	A dependent terminal	A terminal within cluster ME The receivers from CE and clusters CG	A dependent, penetrative terminal	A penetrative terminal within cluster MM
21 Precision instruments	Dependent	A dependent sector within cluster ME The receiver from cluster CE	A dependent terminal	A terminal within cluster EI The receiver from cluster MM

sectors related to consumer merchandise, that is, sectors 3 (apparel and clothing accessories), 5 (furniture, wood and bamboo products) and 20 (transport equipment), while in China the terminals not only include consumer merchandise, namely sectors 3, 4 (leather and fur), 5, 20 and 21 (precision instruments), but also include some material products, that is, sectors 11 (rubber products) and 15 (metal products). Being involved in the production of traditional consumer goods, sectors 3, 4 and 5 receive technology from various sectors within and outside the clusters to which they belong; for example, sectors 3 and 5 in Taiwan have inward connections with cluster CE, and sector 5 in China have inward linkages with cluster CT. The centrality analysis of sector 20 in Taiwan shows that it is the industry with the highest level of technological integration with other industries, absorbing 12 different technological sources from sectors within its located cluster ME, as well as sectors of clusters CE and CG especially, yet it lacks any outward linkage. In contrast, sector 20 in China is a general dependent sector and acts as a penetrative terminal within cluster MM. Notably, sector 21 is one of the largest terminals in China, receiving technology from five sectors, with three inward linkages from cluster MM and just one from its located cluster, EI. In contrast, the two-way interaction of sector 21 is higher in Taiwan than in China. However, sector 21 is still a dependent sector in Taiwan, and works as a technological receiver from cluster CE. Another important integrated industry in China is sector 11, which is a dependent terminal in the national network and within cluster CT, as well as a receiver from cluster MM. Nevertheless, although sector 11 in Taiwan is dependent and acts as a receiver of cluster CG, mainly receiving technology from cluster CE, it still has some outward connections with sectors within its located cluster and with other clusters. The two systems hold some distinctive features in sector 15, which is a pure dependent terminal in the Chinese national system and within cluster MM, but is a pervasive intermediate in the Taiwanese national network and within its located cluster, while also being able to serve as an exporter of cluster ME to cluster CE.

Sector 18 (electronic and telecommunication products) is a high-tech and capital-intensive industry. Although dependent in both networks, this sector presents two distinguishing innovative processes. In Taiwan, the innovation inputs of sector 18 mainly from its located cluster CE, which made up of chemicals and electronic-related sectors; in China its technology flows mainly come from cluster MM (not its located cluster EI, but within cluster EI it has strong mutual interactions with sector 19) which comprises metal and machinery industries.

Sector 2 (textiles) works as a technological intermediate in the Taiwanese system. However, within its located cluster CG, which comprises consumer goods, it acts as a source for the use of the other sectors, while it has to receive materials such as those from sectors 8 and 9 and thus serves as a receiver for the other clusters, particularly cluster CE. Sector 2 in China, as an intermediate at the national level, belongs to cluster CT that consists of consumer goods and materials, and thus it is a core sector within this cluster. Another intermediate sector in Taiwan is sector 13 (non-metallic mineral products), which is dependent in both systems. However, the position of this sector is not critical due to its low centralities.

Sectors 6 (paper and paper products) and 7 (printing and publishing) are made of cluster PP in both systems, and show an innovative dynamic of producer-user process, that is, sector 6 is the technological source and sector 7 is the receiver within cluster PP. Nevertheless, in Taiwan, both sectors simultaneously act as the receivers of cluster PP from cluster CE, while only sector 6 acts as the receiver from cluster CT in China.

Sector 10 (petroleum and coal products) is completely isolated in Taiwan. From the perspective of materials, this demonstrates how poor Taiwan is in these kinds of natural resources. Meanwhile, sector 10 in China is nearly insulated, just with an inward connection from sector 16. On the input side, rich petroleum and coal supplies exist in China because of the large amount of non-electrical machinery and equipment available for mining them. On the output side, the fact that there is no outward linkage on sector 10 suggests that the downstream industries based on petroleum and coal products are not active in China. Sector 1 (food, beverages and tobacco) is entirely isolated in China, and it has no interaction with the other sectors, meaning that it comprises an insulated cluster AF by itself. This phenomenon demonstrates how this traditional sector is barely influenced by and scarcely influences the remaining sectors in the Chinese system. In Taiwan, sector 1, belonging to cluster CG, is a dependent industry and receives technological flows mainly from chemical-related sectors, showing a process of innovation involving materials and their users.

4. Conclusions

This paper examined the intersectoral patterns of product-embodied R&D diffusion in the Taiwanese and Chinese innovation systems using methodologies that employ the input–output approach to construct the intersectoral innovation diffusion matrices and allow the structural comparison of the two systems at three different levels based on the graph and indicator analyses derived from the network analysis. These applications have been successfully applied to demonstrate the usefulness of the proposed methodologies and illustrate the international comparative element and thus reveal the structural nature of the two innovation systems.

However, the quantitative product-embodied linkages analyzed here represent only one important part of a NIS. The major limitation of this study is the lack of concern regarding the linkages to the knowledge system (that is, universities and research institutes), the informal knowledge and the other institutions in a NIS. In addition, due to constraints of data availability, this study has made some assumptions and approximations. Despite these limitations, this study represents a good starting point for quantitative analysis in an international comparative context and provides some good initial results for follow-up research on these relevant topics.

Regarding the general analytical results of this study, first, at national level the systemic connection in Taiwan is found to be higher than in China, as demonstrated by the density analysis. This means that the Taiwanese technological innovation system has higher internal cohesion than the Chinese system, thus creating relatively efficient diffusion. However, compared to Taiwan, the centralization analysis reveals that China has a less hierarchic structure than Taiwan, indicating that the sectors in the Chinese system share more symmetric advantages of structural position than they do in the Taiwanese system, an observation that is also confirmed by analysis of structural holes.

Second, the two systems are found to have different technological concentrations. Besides both systems specializing in chemical sectors, Taiwan also focuses on the high-tech sectors (electronic industries), while China concentrates on the traditional sector (heavy industry). This different concentration reflects the different industrial development trajectories of the two countries, with Taiwan developing high value-added industries and China develops industries based on the utilization of natural resources.

Third, the appearance of technological clusters is more significant in Taiwan than in China, confirming the high division of industry in Taiwan and strong integration of supply chains. Furthermore, the technological clusters in China are so loose that it is difficult for Chinese industries to share technology owned by the other sectors within the clusters that they belong to.

Fourth, this study highlights the chemical industries, as well as the non-electrical machinery and equipment industries as the key sectors with great structural advantages in both systems, confirmed by the results of the centrality and structural holes analyses. Furthermore, this study notes the food-related industries, as well as the petroleum and coal industries as being (nearly) isolated sectors in both networks.

Finally, this study reveals the similar distribution of the cores and sources of innovation flow in both systems. Both systems make significant use of materials and manufacturing equipment as diffusion channels. However, China has considerably more terminal sectors than Taiwan, which block innovation flows and thus reduce the degree of systemic connection in the Chinese innovation system.

Given the linguistic, cultural, racial and historical similarities between Taiwan and China, plus their geographical proximity and the increased opening up of public and private sector exchanges between the two sides (Chang and Shih, in press), the comparative analysis of the two innovation systems leads to numerous policy implications. Generally, the Taiwanese economy is more developed than the Chinese economy, meaning that the Chinese government can benefit from referring to the Taiwanese technological development experience, and that Taiwanese enterprises can expand their business territories into mainland China to achieve economies of scale. This study can offer to innovation policy-makers on both sides valuable insights based on the underlying similarities and differences between the two innovation systems.

References

Burt, R.S., 1992. Structural Holes: The Social Structure of Competition, Harvard University Press, Cambridge.

Capron, H., Cincera, M., Dumont, M., 2000. The national innovation system of Belgium: the institutional profile. In: Capron, H., Meeusen, W. (Eds.), The National Innovation System of Belgium, Physica Verlag, Heidelberg.

Carlsson, B., Jacobsson, S., Holmen, M., Rickne, A., 2002. Innovation systems: analytical and methodological issues. Research Policy 31, 233–245.

Chang, P.L., Shih, H.Y. The innovation systems of Taiwan and China: a comparative analysis. Technovation (in press).

Chiesa, V., Coughlan, P., Voss, C.A., 1996. Development of a technical innovation audit. Journal of Product Innovation Management 13, 105–136.

Cohen, W., Levinthal, D., 1989. Innovation and learning: the two faces of R&D. Economic Journal 99, 569–596.

Coombs, R., Narandren, P., Richards, A., 1996. A literature-based innovation output indicator. Research Policy 25, 403–413.

Degenne, A., Forse, M., 1999. Introducing Social Networks, Sage Publications, London.

Department of National Economy Accounting, State Statistical Bureau, 1999. Input–Output Table of China, 1997. Beijing: China Statistics Press.

Directorate-General of Budget, 2002. 1999 Input–Output Tables, Taiwan Area, the Republic of China. Taipei: Directorate-General of Budget, Accounting and Statistics.

Drejer, I., 2000. Comparing patterns of industrial interdependence in national systems of innovation—a study of Germany, the United Kingdom, Japan and the United States. Economic Systems Research 12, 377–399.

Freeman, C., 1987. Technology and Economic Performance: Lessons from Japan, Pinter Publishers, London.

Galli, R., Teubal, M., 1997. Paradigmatic shifts in national innovation systems. In: Edquist, C., (Ed.), Systems of Innovation: Technologies, Institutions and Organizations, London, Pinter Publishers.

Goto, A., Suzuki, K., 1989. R&D capital, rate of return on R&D investment and spillover of R&D in Japanese manufacturing industries. Review of Economics and Statistics 71, 555–564.

Helpman, E., 1998. General Purpose Technologies and Economic Growth, MIT Press, Cambridge.

Hubner, H., 1996. Decisions on innovation and diffusion and the limits of deregulation. Technovation 16(7), 327–339.

Kumaresan, N., Miyazaki, K., 1999. An integrated network approach to system of innovation—the case of robotics in Japan. Research Policy 28, 563–585.

Leoncini, R., Maggioni, M.A., Montresor, S., 1996. Intersectoral innovation flows and national technological systems: network analysis for comparing Italy and Germany. Research Policy 25, 415–430.

Leoncini, R., Montresor, S., 2000. Network analysis of eight technological systems. International Review of Applied Economics 14, 213–234.

Leoncini, R., Montresor, S., 2001a. The automobile technological systems. An empirical analysis of four European countries. Research Policy 30, 1321–1340.

Leoncini, R., Montresor, S., 2001b. DRUID 2001 Nelson and Winter Conference. A comparative analysis of core and extra-core relationships in technological systems, Available from http://www.druid.dk/conferences/

Lundvall, B.A. (Ed.), 1992. National Systems of Innovation: Towards a Theory of Innovation and Interactive Learning, Pinter Publishers, London.

Marengo, L., Sterlacchini, A., 1990. Intersectoral technology flows. Methodological aspects and empirical applications. Metroeconomica 41, 19–39.

Massini, S., 1998. Conference on The Economics of Science and Technology: Micro Foundations and Policy, held in Urbino. Intersectoral flows of technology: an international comparison of technological specialization profiles, Available from http://www.ifs.org.uk/

Metcalfe, S., 1995. The economic foundations of technology policy: equilibrium and evolutionary perspectives. In: Stoneman, P., (Ed.), Handbook of the Economics of Innovation and Technological Change, Blackwell Publishers, Oxford, UK.

Ministry of Economic Affairs. Economic Statistics Annual, Taiwan Area, the Republic of China 2000. Taipei: Department of Statistics, Ministry of Economic Affairs, 2001.

Nasierowski, W., Arcelus, F.J., 1999. Interrelationships among the elements of national innovation systems: a statistical evaluation. European Journal of Operational Research 119, 235–253.

National Bureau of Statistics. China Statistical Yearbook on Science and Technology 1998. Beijing: China Statistics Press, 1998.

Nelson, R.R. (Ed.), 1993. National Innovation System: A Comparative Analysis, Oxford University Press, Oxford.

OECD. Diffusion Technology to Industry: Government Policies and Programmes. Paris: OECD, 1997.

Padmore, T., Gibson, H., 1998. Modelling systems of innovation: II. A framework for industrial cluster analysis in regions. Research Policy 26, 625–641.

Papaconstantinou, G., Sakurai, N., Wyckoff, A., 1998. Domestic and international product-embodied R&D diffusion. Research Policy 27, 301–314.

Patel, P., Pavit, K., 1994. National innovation system: Why they are important and how they might be measured and compared. Economics of Innovation and New Technology 3, 77–95.

Peeters, L., Tiri, M., Berwert, A., 2001. Identification of techno-economic clusters using input–output data: application to Flanders and Switzerland. OECD, Innovative Clusters: Drivers of National Innovation Systems, OECD, Paris.

Sakurai, N., Papaconstantinou, G., Ioannidis, E., 1997. Impact of R&D and technology diffusion on productivity growth: empirical evidence for 10 OECD countries. Economic System Research 9, 81–109.

Scott, J., 1991. Social Network Analysis: A Handbook, Sage Publications, London.

Verspagen, B., 1997. Measuring intersectoral technology spillovers: estimates from the European and US patent office databases. Economic System Research 9, 47–65.

Wasserman, S., Faust, K., 1994. Social Network Analysis: Methods and Application, Cambridge University Press, Cambridge.

Pao-Long Chang is a professor at the Institute of Business and Management, National Chiao Tung University, Taipei, Taiwan. Currently, he is visiting at Feng Chia University, Taichung, Taiwan, as a chair professor of Business Administration. He received a BS in mathematics from Fu-Jen Catholic University in Taiwan, and a MA in mathematics from State University of New York at Albany and a PhD in mathematics from the University of Washington in USA. His previous articles have appeared in the Journal of the Operational Research Society, Journal of Environmental Management, Computers and Operations Research, Industry and Innovation, International Journal of Production Economics, Technovation, International Journal of Technology Management, IEEE Transactions on Engineering Management and IEEE Transactions on Semiconductor Manufacturing among others. His current research interests are in the areas of Technology Management and Operations Research.

Hsin-Yu Shih is a PhD candidate at the Institute of Business and Management, National Chiao Tung University, Taipei, Taiwan. He received a BEng in chemical engineering from National Taiwan University in Taiwan, and an MBA from National Sun Yat-Sen University in Taiwan. His research interests center on management of technology and innovation. His industrial background includes 8 years' experience in the information industry, working in product development and strategy planning in both a Taiwanese and Chinese based information firm.