TEMPORAL CHANGES IN THE STRUCTURE OF CHICAGO'S ECONOMY: 1980 - 2000

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Abstract:
In an attempt to further explore the impact of structural changes in the Chicago economy, two methods will be employed to attempt to reveal the nature of any fragmentation/hollowing out process operating in the Chicago economy, namely the superposition decomposition method and Q-analysis. Superposition decomposition can decompose a flow into the sum of a set of weighted extreme tendencies acting according to each extreme tendency's importance in the total intermediate flows. Q-analysis provides an alternative "slicing" procedure to uncover a hierarchy in the structure of relationships. Using a set of annual input-output tables, the applications to Chicago's economic structure analysis in the period of 1980 to 2000 revealed the development of a simpler production structure inside the region, the declining interactions of manufacturing with other sectors in the region while there was increasing interactions of service with other sectors. While the total output of manufacturing did not decrease, all these features provide another evidence of hollowing-out effect in Chicago's economy found by others (Hewings *et al.*, 1998). Also, it reveals production fragmentation patterns at the regional level, paralleling findings of similar processes at the international level.

1. Introduction

During the last two decades of the last century, the Chicago metropolitan region lost almost 0.5 million jobs in the manufacturing sector, yet gained even more non-manufacturing jobs. The turnover of 1 million jobs represented about 25% of total employment during that period. During this time, total output increased. Hewings *et al.* (1998) interpreted the changes as those resulting from a hollowing-out phenomena; an alternative, yet complementary explanation may be provided by the process of the fragmentation of production. Fragmentation was first used by Jones and Kierzkowski (1990) to describe the segmented production process linked by services, domestically or internationally. Jones and Kierzkowski (2001) suggested that fast growing service activities are the cause of fragmentation. Recently, fragmentation is receiving great attention internationally because it is the dominant feature of fast-growing globalization. Does this process also operate at the regional level? How would it be reflected in the structure of the region's economy? Using the set of annual input-output tables derived from an econometric-input-output model of the Chicago economy, this paper will explore the impacts of these changes on the structure of the economy, focusing on the changes in the nature and strength of the interdependencies between sectors.

Two methods will be employed to attempt to reveal the nature of any fragmentation/hollowing out process operating in the Chicago economy, namely the superposition decomposition method and Q-analysis. Superposition decomposition can decompose a flow into the sum of a set of weighted extreme tendencies acting according to each extreme tendency's importance in the total intermediate flows. Q-analysis provides an alternative "slicing" procedure to uncover a hierarchy in the structure of relationships.

This paper is organized as follows: a brief review of structural decomposition approaches will be provided in the next section. Sections three and four describe the two methods of Q-analysis and superposition flow decomposition. Following this exposition, the application to Chicago's production structure from 1980 to 2000 will be made. Some summary remarks complete the paper.

2. Structural decomposition

Structural analysis has come to be one of the more important applications of input-output analysis. Among the methodologies that have been developed so far, structural decomposition analysis (SDA) has been received much emphasis. Rose and Casler (1996) provided a detailed review of SDA. While new applications on SDA can be found in Albala-Bertrand (1999), Alcala *et al.* (1999), Mukhopadyay and Chakraborty (1999), Wier and Hasler (1999), Dietzebacher *et al.* (2000), Hitomi *et al.*. (2000), Jacobsen (2000), Casler (2001), Dietzenbacher (2001), and Milana (2001), these new applications still follow the traditional SDA, that decomposes observed changes into determinant parts, like technology, final demand or synergistic interactions between these two components. While the intermediate transactions part details the production pattern revealing the sectoral interdependence in an economy, seldom is the analysis conducted to decompose other than the intermediate transactions in an input-output table.

In contrast to standard SDA, some efforts have been made to analyze the production pattern by decomposing intermediate transactions in an input-output system. The conventional qualitative input-output analysis (QIOA) developed by Schnabl and Holub (1979) and Holub and Schnabl (1985) split the intermediate transaction flow (say, **T**) into several layers based on the Euler power series of technical coefficient matrix **A**. With a filter critical value, the sliced transaction matrices can be transferred to Boolean matrices with 0 or 1 entries, showing the pattern of economic links among sectors in each layer up to a certain layer. Some information may have lost upon the set-up filter critical value when the decomposition is conducted.

An alternative approach that also seeks to decompose the structure hierarchically is the method of superposition flow decomposition that examines the degree to which the structure of flows might be decomposed into a set of weighted subflows (Sonis, 1980; Sonis and Hewings, 1988, 2001; Jackson *et al.*, 1989), in which the sublflows can be expressed in the form of extreme tendencies. The weights may be considered as analogous to weights in a multi-objective programming context; the decomposition proceeds hierarchically, with the most important flow extracted first with the weight describing the share of the total flow. The economic links among sectors can be shown in two ways: forward linkage and backward linkage. Q-analysis, proposed by Atkin (1974) to analyze the structure of human interactions, is an option to explore the intersectoral relationships. Sonis and Hewings (2000) have applied Q-analysis to sectoral structural analysis in the context of an exploration of changes in the Israel economic structure. Legrand (2002) provides some new applications of Q-analysis in social systems.

In this paper, superposition flow decomposition and Q-analysis will be employed for the analysis. Superposition decomposition is conducted by decomposing the flow systematically according to the importance of each decomposed extreme tendency. On the other hand, since the decomposition is one based on hierarchical weighted extreme tendencies, with the weights representing the share of total flow, much attention can be paid to the more important decomposed flows. Furthermore, each decomposed extreme tendency shows the pattern of the flow represented by ones and zeros, which is fitted in Q-analysis to explore the sectors' interaction relationship.

The QIOA can reveal some flow patterns by applying the filter procedure, but it will lose some information. Further, there is the problem of the appropriate definition of the filter. Standard SDA can decompose the total output changes between different time periods into three parts, but cannot provide the sectoral interaction relationship behind the changes. Hence, superposition flow decomposition and Q-analysis will be used in this paper. The two methods will now be described in the following sections.

3. The Description of the Methodology of Q-analysis

3.1 A brief description

Q-analysis is a method to describe the structure of relationships, and was introduced by Atkin (1974). Suppose there are two finite sets Y and X, each of which has elements $y_i\,(i=1,2,\cdots,m)$ and $x_i\,(i=1,2,\cdots,n)$. Suppose that the sets Y and X are related according to a specific condition; the binary zero-one matrix $\Lambda=\lambda_{ij}$, which is defined as an incidence matrix, describes the relationship $(\lambda\subset Y\times X)$. Define the relationship so formed as a *simpilical complex K*, which can be denoted by $K_Y(X;\lambda)$; the pattern is shown in figure 1. Note that the inverse relation $\lambda^{-1}\subset X\times Y$ defines a *simplicial complex* $K_X(Y;\lambda^{-1})$, whose pattern is shown in figure 2.

λ	X
Y	(λ_{ij})

Figure 1 Pattern of $K_Y(X;\lambda)$

λ^{-1}	Y
X	(λ_{ij}^{-1})

Figure 2 Pattern of $K_X(Y;\lambda^{-1})$

In figure 1, a *p*-simplex, σ_p, is constructed with distinctive $(p+1)$ vertices ($p+1$ elements from X vertex set), that is λ related to *Y*. For example, suppose Y_1 in *K* has four vertices, X_1, X_3, X_4, X_7, then $<X_1, X_3, X_4, X_7>$ forms a 3-simplex, σ_3.

The structure of the simplicial complex *K* is now examined in greater detail. If two simplexes in *K* share at least $(q+1)$ vertices, they are referred to as *q-near* simplexes, connecting with each other by the sharing of *q* vertices. A finite sequence of *q-near* simplexes defines a sequence of *q-connectivity*. The length of the finite sequence is the key indicator in Q-analysis. The relationship of *q-connectivity* generates the partition of the simplicial complex *K* into *q-connected* components. The enumeration of all *q-connected* components for each dimension $q > 0$ is the essence of the Q-analysis of the simplicial complex *K*. Note that if σ_p and σ_r are *q-connected*, they are also *(q-1)-, (q-2)-, 1,0-connected* in *K*.

3.2 Algorithm of Q-analysis

Q-analysis is applied to identify those pieces of *K*, which are *q-connected*. Following Atkin (1974), the operational basis for Q-analysis is to construct the shared face matrix that is defined as:

$$\mathbf{SF} = \Lambda\Lambda^T - [1]_{m \times m}$$

where Λ is incidence matrix in $K_Y(X;\lambda)$, and $[1]_{m\times m}$ is a matrix with unit entries. The components of the matrix **SF** provide the number of shared faces between simplexes.

The dimension (*N*) of *K* is the largest number on the diagonal of **SF**. Q-analysis seeks to find all the number of distinguished *q-connected* components Q_q, for $0 \le q \le N$. Two *q-dimensional* simplices, σ_p and σ_r, belong to the same *q*-chain if the corresponding rows of the shared face matrix **SF** include at least one column with entries larger than or equal to *q*. The vector $Q = \{Q_N, Q_{N-1}, \cdots, Q_0\}$ is called the *structure vector* of the simplicial complex *K*.

3.3.Construction of a binary matrix describing sectoral relations in the context of input-output tables

In order to perform Q-analysis, it is necessary to construct a binary matrix to describe the relationship of two defined sets. However, in reality, most of the relationships are described as finite numbers. For example, input-output tables describe the inter-sectoral relationship in an economy with definite numerical data, rather than in binary form. These non-binary matrices can be considered as weighted relations; thus, the main objective of applying Q-analysis is to translate the weighted relations into a binary matrix, defined as a slicing procedure in Q-analysis.

In the context of input-output tables, there are many slicing methods have been tried before to transfer the weighted sectoral relations into the form of binary matrixes to show a certain production pattern or sectoral structure. For example, Sonis and Hewings (2000) removed 50% of the smallest components of the Leontief inverse matrix when Q-analyzing the Israel's economic structure. In the variable filter approach used in minimal flow analysis in QIOA noted earlier (Holub *et al.*, 1985, Schnable, 1994), several alternatives were considered. The "one-shot" slicing procedure facilitates the construction of a binary matrix addressing the relationship of sectors in an economy; however, it comes with the cost of losing some important information in a complicated economic system.

4. Superposition Flow Decomposition Method Description

A superposition flow decomposition method examines the degree to which the structure of flows might be decomposed into a set of subflows (Sonis, 1980; Jackson *et al.*, 1989), each of which acts according to extreme tendencies. That is, a given flow matrix Y can be rewritten as a weighted sum of some extreme tendencies matrixes:

$$Y = \sum_{i=1}^{m} p_i X_i ,$$

in which $0 \le p_1 < p_2 < \cdots < p_m \le 1,$ and $\sum_{i=1}^{m} p_i = 1$.

In this fashion, each extreme tendency can be written as a binary matrix describing the inter-sectoral relationship in each hierarchically decomposed level, in which a deeper sector relationship structure can be explored by Q-analysis.

Geometrically, the solution of a linear programming optimization problem takes into account only one vertex of the convex polyhedron of all admissible solutions. In reality, from the point of view of optimization, the representation of the actual state of a regional system requires the application of multi-objective programming. However, simultaneous optimization of two or more objective functions is difficult (Boltiansky, 1973). Hence, as an alternative, it is assumed that each actual state of the linear system (for example, an actual flow system) is the superposition of a set of extreme states of the flow system, that are the optimal solutions of the sequence of optimization problems, presenting the simultaneous action of different extreme tendencies within the linear system. The weights of the extreme states define the measure of their realization in the actual state. Thus, in a very simple system, each sector would sell its outputs to only one other sector while making purchases from only one sector; most input-output tables have much more sophisticated systems of intermediation with purchases and sales relationships involving multiple sectors. The superposition principle attempts to separate out this complexity into an hierarchically ordered set of relations that at each level, interactions are restricted to the simple set – i.e., each sector has interaction with only one other sector (in either a backward or forward sense).

Let $\mathbf{Y}$ be an admissible solution of the system of linear constraints:

$$\begin{cases} \mathbf{AX} = \mathbf{b} \\ \mathbf{X} \geq 0 \end{cases}$$

and let $f_1(\mathbf{X}), f_2(\mathbf{X}), \cdots, f_s(\mathbf{X})$ be ordered set of linear or concave objective functions. Then, $\mathbf{X}_1, \mathbf{X}_{2,} \cdots, \mathbf{X}_s$ are the optimal solutions to the optimization problem in the form of extreme tendencies:

$$\max f_i(\mathbf{X})$$

subject to constraints:

$$\begin{cases} \mathbf{AX} = \mathbf{b} \\ \mathbf{X} \geq 0 \end{cases}$$

but with additional constraints on coordinates of vector **X**:

$$\mathbf{X}_{k_1} = \mathbf{X}_{k_2} = \cdots = \mathbf{X}_{k_{i-1}} = 0$$

The optimal solution of a linear flow system $\mathbf{Y}$ can be written as the weighted sum of $p_1\mathbf{X}_1 + p_2\mathbf{X}_2 + \cdots + p_k\mathbf{X}_k$, which is also the optimal solution of the same linear flow system according to the superposition principle. Note that $0 \leq p_1 \leq p_2 \leq \cdots \leq p_k \leq 1$, and $\sum_{i=1}^{k} p_k = 1$.

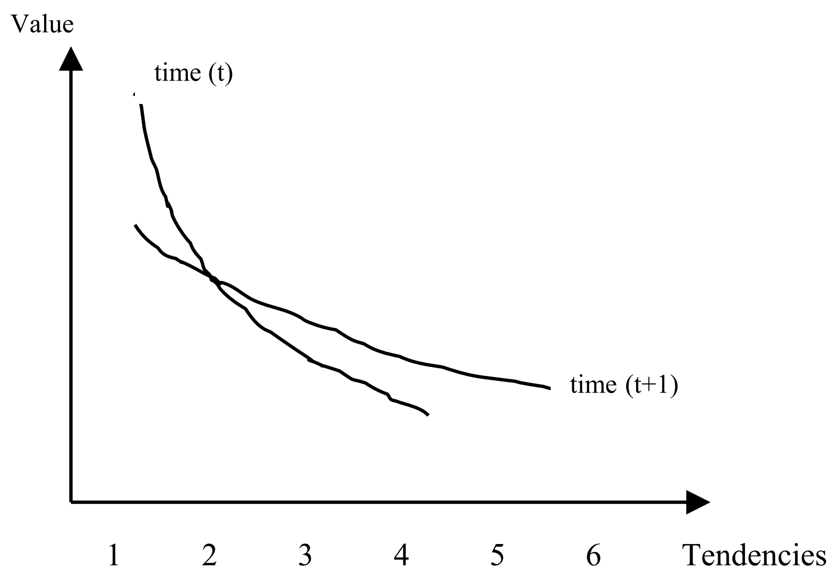

Figure 3 Extreme tendencies: temporal change expectations (Source: Jackson *et al*., 1989)

The superposition principle of linear programming provides an alternative way of decomposing a flow matrix into a hierarchically weighted sum of extreme tendencies by taking into account the degree of its importance. On the other hand, it provides a tool to measure the degree of complexity of an economy, where the degree of complexity reflects the degree of sectoral intermediate production interactions in an economy. The larger the first weight, the less complex the economy; this might also be true up to a certain level, say the third level. A greater proportion of the total flows will be accounted for by the initial levels in a simple economy reflecting the fact that there are fewer interactions among production sectors (Jackson *et al*., 1989). Figure 3 shows the possible changes in the values of the weights for one economy over time as this economy becomes more complicated, in the sense that the degree of intermediation increases.

5. Applications to the Chicago Economy

To explore the structural changes in the Chicago economy, 6-sector annual input-output tables from 1980 to 2000 will be used. The 6 sector tables are aggregated from the 36-sector tables extracted from the region's econometric-input-output model (see Israilevich *et al*., 1997 for details). The sectors' definitions are shown in table 1.

Table 1 Sector definitions in the Chicago input-output tables

Sector	Name	Abbreviation
1	Resources	RES
2	Construction	CNS
3	Manufacturing	MNF
4	Transportation, Trade and FIRE*	TTF
5	Services	SRV
6	Government	GOV

*FIRE: Finance, insurance and real estate.

Decomposition analysis of the intermediate flows in these input-output tables was undertaken to explore the evolution of production structures over time. Figure 4 depicts the weights of hierarchically determined extreme tendencies for each year. The results mirror those presented stylistically in figure 3: the higher the first weights, the simpler the flow structure. The increasing weights of the first tendencies in Chicago's intermediate flows indicate the movement of an economy to a simpler production structure in Chicago over the period 1980 to 2000.

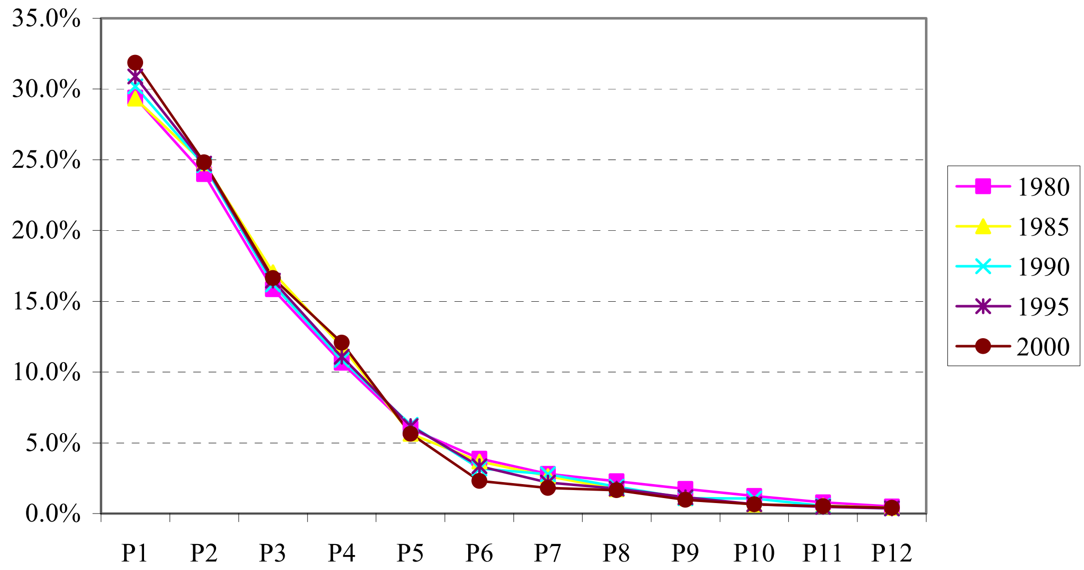

Figure 4 Weights of the tendencies

Figures 5 and 6 show the forward and backward linkage cumulative weights of the first six decomposed levels respectively. Note that the weight of the first decomposed level is increasing from 1980 to 2000; the first six decomposed level accounts for more than 90 per cent of the total flow. Compared with the forward linkage weights, the backward linkage weights in each cumulative level are higher, which implies a more simple production structure than the forward linkage structure. A more simple production structure can be regarded as the result of a declining degree of intermediation in the Chicago's economy. Okazaki (1989) mentioned the same phenomenon in Japan that he referred to as a hollowing out effect. This may provide some evidence of the hollowing-out phenomenon in Chicago (Hewings *et al*. 1998) because the comparatively higher weights in the backward linkage structure suggest that the Chicago economy is sourcing more of its required inputs from outside the regional economy. This seems to be occurring rather than a reduction in total production.

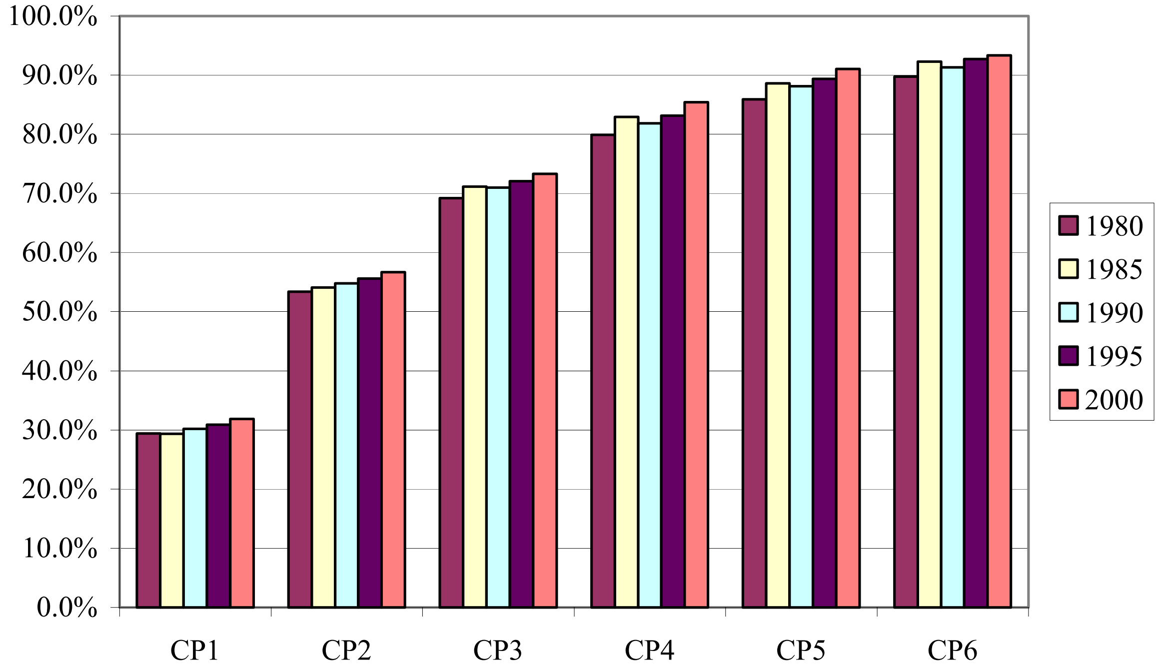

Figure 5 Forward linkage cumulative weights

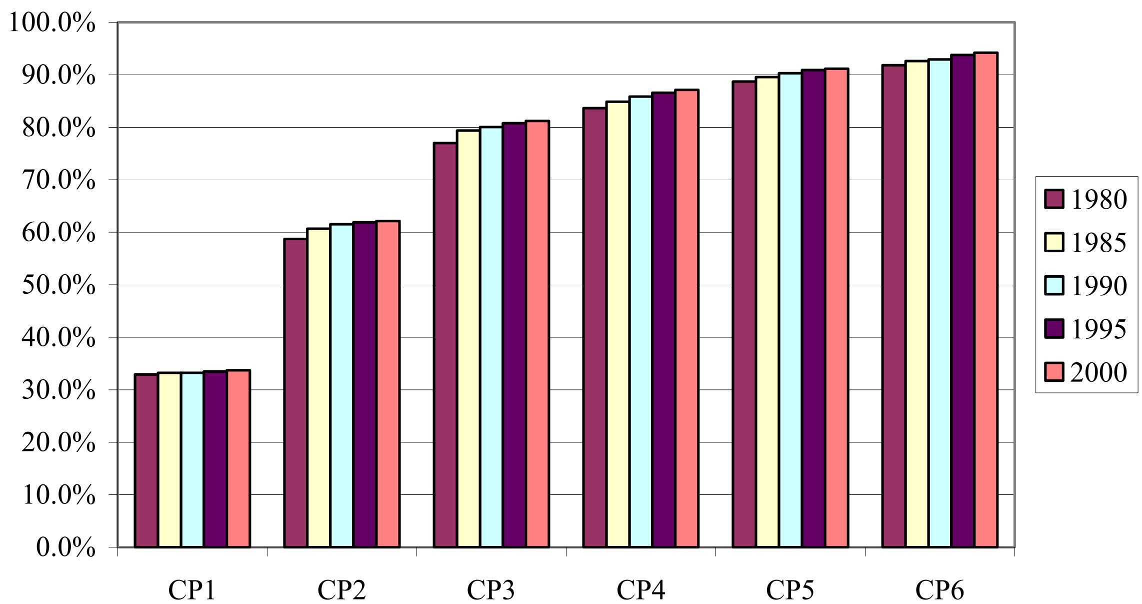

Figure 6 Backward linkage cumulative weights

What is the structure of inter-sectoral relationships in each cumulative decomposed level? First, each cumulative decomposed level will be converted to a binary matrix. Since the first four decomposed levels account for more that 80 per cent of the total flows, attention will be restricted to the sectoral structures up to the fourth cumulative extreme tendencies. In each cumulative decomposed level, the extreme tendency, in a binary structure, shows the sectoral relations. Q-analysis can now explore the deeper structure of the relations in each cumulative decomposed level based on the corresponding cumulative extreme tendency matrixes.

In the case of backward linkage structure of Chicago in 2000, the first four extreme tendencies and their weights can be written as:

$$p_1\mathbf{X}_1 + p_2\mathbf{X}_2 + p_3\mathbf{X}_3 + p_4\mathbf{X}_4 =$$

$$= 0.319\begin{pmatrix} 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 1 \\ 1 & 1 & 1 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 \end{pmatrix} + 0.248\begin{pmatrix} 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 1 & 0 & 0 \\ 1 & 1 & 1 & 0 & 1 & 1 \\ 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 \end{pmatrix} +$$

$$+0.166\begin{pmatrix} 0 & 0 & 0 & 0 & 0 & 0 \\ 1 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 1 \\ 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 1 & 1 & 1 & 1 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 \end{pmatrix} + 0.103\begin{pmatrix} 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 1 & 1 & 0 \\ 0 & 1 & 1 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 \\ 1 & 0 & 0 & 0 & 0 & 1 \\ 0 & 0 & 0 & 0 & 0 & 0 \end{pmatrix}$$

with the first four corresponding incidence matrixes being:

$$\Lambda^1 = \begin{pmatrix} 0&0&0&0&0&0 \\ 0&0&0&0&0&1 \\ 1&1&1&0&1&0 \\ 0&0&0&1&0&0 \\ 0&0&0&0&0&0 \\ 0&0&0&0&0&0 \end{pmatrix}, \quad \Lambda^2 = \begin{pmatrix} 0&0&0&0&0&0 \\ 0&0&0&0&0&1 \\ 1&1&1&1&1&0 \\ 1&1&1&1&1&1 \\ 0&0&0&0&0&0 \\ 0&0&0&0&0&0 \end{pmatrix}, \quad \Lambda^3 = \begin{pmatrix} 0&0&0&0&0&0 \\ 1&0&0&0&0&1 \\ 1&1&1&1&1&0 \\ 1&1&1&1&1&1 \\ 0&1&1&1&1&0 \\ 0&0&0&0&0&0 \end{pmatrix},$$

$$\text{and}\ \Lambda^4 = \begin{pmatrix} 0&0&0&0&0&0 \\ 1&0&0&1&1&1 \\ 1&1&1&1&1&1 \\ 1&1&1&1&1&1 \\ 1&1&1&1&1&1 \\ 0&0&0&0&0&0 \end{pmatrix}.$$

The first four tendencies account for 83.6% of the total transaction flows and indicate a connectivity pattern of backward linkage shown in figure 7. Each extreme tendency represents a sectors' connection pattern with the weight. In this 6-sector case, it is much easier to describe the pattern. In case of a more complicated input-output table, interpretation is a greater challenge and for this reason, Q-analysis can be applied.

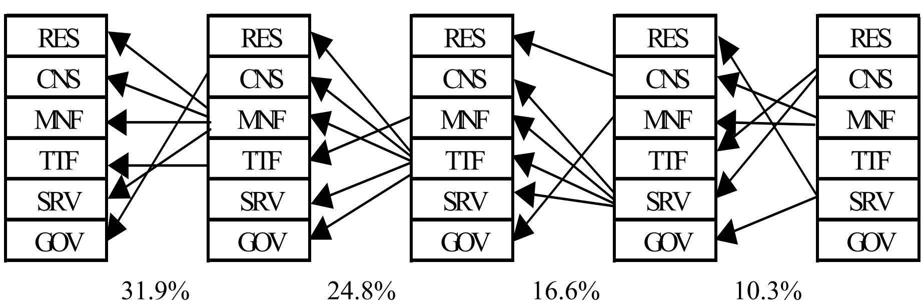

Figure 7: The backward linkage structure for the first four tendencies in Chicago, 2000

The corresponding sectoral dependence pattern in each cumulative tendency can be shown by the Q-analysis, in which the Q-chain and structural vector will be show as following. For example, Q_4^1 reveals that {MNF} connects with four sectors (q=3) in the economy (in addition, it also connects with 3 (q=2) , 2(q=1) and 1(q=0) sector(s)). Sector CNS connects with one sector (q=0). Sectors MNF and TTF are connected with each other (q=0). The Q-chain shows the number for each connection. In this case, for each value of q from 3 to 1, there is one chain, while when q=0, there are two chains .

$$Q_q^1 = \begin{cases} q=3:\{MNF\} \\ q=2:\{MNF\} \\ q=1:\{MNF\} \\ q=0:\{CNS\},\{MNF,TTF\} \end{cases}, \quad Q^1 = \begin{Bmatrix} 3 & & & 0 \\ 1 & 1 & 1 & 2 \end{Bmatrix}$$

$$Q_q^2 = \begin{cases} q=5:\{TTF\} \\ q=4:\{MNF,TTF\} \\ q=3:\{MNF,TTF\} \\ q=2:\{MNF,TTF\} \\ q=1:\{MNF,TTF\} \\ q=0:\{CNS,MNF,TTF\} \end{cases}, \quad Q^2 = \begin{Bmatrix} 5 & & & & & 0 \\ 1 & 1 & 1 & 1 & 1 & 1 \end{Bmatrix}$$

$$Q_q^3 = \begin{cases} q=5:\{MNF,TTF\} \\ q=4:\{MNF,TTF\} \\ q=3:\{MNF,TTF,SRV\} \\ q=2:\{MNF,TTF,SRV\} \\ q=1:\{CNS,MNF,TTF,SRV\} \\ q=0:\{CNS,MNF,TTF,SRV\} \end{cases}, \quad Q^3 = \begin{Bmatrix} 5 & & & & & 0 \\ 1 & 1 & 1 & 1 & 1 & 1 \end{Bmatrix}$$

$$Q_q^4 = \begin{cases} q=5:\{MNF,TTF,SRV\} \\ q=4:\{MNF,TTF,SRV\} \\ q=3:\{CNS,MNF,TTF,SRV\} \\ q=2:\{CNS,MNF,TTF,SRV\} \\ q=1:\{CNS,MNF,TTF,SRV\} \\ q=0:\{CNS,MNF,TTF,SRV\} \end{cases}, \quad Q^4 = \begin{Bmatrix} 5 & & & & & 0 \\ 1 & 1 & 1 & 1 & 1 & 1 \end{Bmatrix}$$

The Q-analysis results for forward linkage and backward linkage sectoral structure in Chicago from 1980 to 2000 are listed in tables 2 and 3. In the backward linkage results, note that in the first two decomposed levels, the structure of 1980 is different from 1985 to 2000. In the first decomposed level, MNF provides its output to five out of six sectors (q=4) in 1980, while since 1985, MNF just supplies four out of six sectors in the economy. In the first two decomposed levels, MNF and TTF provide inputs to all six sectors in 1980 (*q*=5), while since 1985 only TTF provides inputs to all the six sectors, and MNF provides its output to five sectors with the connection with TTF (*q*=4). The first three and four decomposed levels show that SRV begins to appear as an important input provider since 1990 when four sectors obtain their inputs from SRV (*q*=3).

Table 2 Backward linkage sectoral structure

	1980	1985	1990	1995	2000
q=4	{MNF}	--	--	--	--
q=3	{MNF}	{MNF}	{MNF}	{MNF}	{MNF}
q=2	{MNF}	{MNF}	{MNF}	{MNF}	{MNF}
q=1	{MNF}	{MNF}	{MNF}	{MNF}	{MNF}
q=0	{MNF}, {TTF}	{CNS}, {MNF}, {TTF}	{MNF}, {TTF}, {CNS}	{MNF}, {TTF}, {CNS}	{MNF}, {TTF}, {CNS}
CP1	0.294	0.293	0.302	0.309	0.319
q=5	{MNF, TTF}	{TTF}	{TTF}	{TTF}	{TTF}
q=4	{MNF, TTF}	{MNF, TTF}	{MNF, TTF}	{MNF, TTF}	{MNF, TTF}
q=3	{MNF, TTF}	{MNF, TTF}	{MNF, TTF}	{MNF, TTF}	{MNF, TTF}
q=2	{MNF, TTF}	{MNF, TTF}	{MNF, TTF}	{MNF, TTF}	{MNF, TTF}
q=1	{MNF, TTF}	{MNF, TTF}	{MNF, TTF}	{MNF, TTF}	{MNF, TTF}
q=0	{MNF, TTF}	{CNS, MNF, TTF}	{CNS, MNF, TTF}	{CNS, MNF, TTF}	{CNS, MNF, TTF}
CP2	0.534	0.541	0.548	0.556	0.567
q=5	{MNF, TTF}	{MNF, TTF}	{MNF, TTF}	{MNF, TTF}	{MNF, TTF}
q=4	{MNF, TTF}	{MNF, TTF}	{MNF, TTF}	{MNF, TTF}	{MNF, TTF}
q=3	{MNF, TTF}	{MNF, TTF}	{MNF, TTF, SRV}	{MNF, TTF, SRV}	{MNF, TTF, SRV}
q=2	{MNF, TTF, SRV}	{MNF, TTF, SRV}	{MNF, TTF, SRV}	{MNF, TTF, SRV}	{MNF, TTF, SRV}
q=1	{CNS, MNF, TTF, SRV}	{CNS, MNF, TTF, SRV}	{CNS, MNF, TTF, SRV}	{CNS, MNF, TTF, SRV}	{CNS, MNF, TTF, SRV}
q=0	{CNS, MNF, TTF, SRV}	{CNS, MNF, TTF, SRV}	{CNS, MNF, TTF, SRV}	{CNS, MNF, TTF, SRV}	{MNF, TTF, SRV, CNS}
CP3	0.692	0.711	0.710	0.721	0.733
q=5	{MNF, TTF}	{MNF, TTF, SRV}	{MNF, TTF, SRV}	{MNF, TTF, SRV}	{MNF, TTF, SRV}
q=4	{MNF, TTF, SRV}	{MNF, TTF, SRV}	{MNF, TTF, SRV}	{MNF, TTF, SRV}	{MNF, TTF, SRV}
q=3	{MNF, TTF, SRV}	{MNF, TTF, SRV}	{MNF, TTF, SRV}	{CNS, MNF, TTF, SRV}	{CNS, MNF, TTF, SRV}
q=2	{CNS, MNF, TTF, SRV}	{CNS, MNF, TTF, SRV}	{CNS, MNF, TTF, SRV}	{CNS, MNF, TTF, SRV}	{CNS, MNF, TTF, SRV}
q=1	{CNS, MNF, TTF, SRV}	{CNS, MNF, TTF, SRV}	{CNS, MNF, TTF, SRV}	{CNS, MNF, TTF, SRV}	{CNS, MNF, TTF, SRV}
q=0	{CNS, MNF, TTF, SRV}	{CNS, MNF, TTF, SRV}	{CNS, MNF, TTF, SRV}	{CNS, MNF, TTF, SRV}	{CNS, MNF, TTF, SRV}
CP4	0.799	0.829	0.819	0.832	0.854

Table 3 shows the Q-analysis of forward linkage sector structure. In the first two decomposed levels, the number of sectors providing MNF for inputs are decreasing since 1980; in 1980, all the six sectors supplied MNF's input (*q*=5), but by 1985, the number decreases to five (*q*=4), and since 1990, only four sectors provides MNF's input inside the Chicago regional economy. The service sector (SRV) derives inputs from more and more sectors, increasing from only one sector in 1980 to two in 1985 and three after 1990.

Table 3 Forward sectoral structure

	1980	1985	1990	1995	2000
q=3	{TTF}	{TTF}	{TTF}	{TTF}	{TTF}
q=2	{TTF}	{TTF}	{TTF}	{TTF}	{TTF}
q=1	{TTF} {MNF}	{TTF} {MNF}	{TTF} {MNF}	{TTF} {MNF}	{TTF} {MNF}
q=0	{TTF} {MNF}	{TTF} {MNF}	{TTF} {MNF}	{TTF} {MNF}	{TTF} {MNF}
CP1	0.329	0.332	0.332	0.335	0.337
q=5	{MNF}				
q=4	{MNF}	{MNF}			
q=3	{MNF, TTF}	{MNF}, {TTF}	{MNF}, {TTF}	{MNF}, {TTF}	{MNF}, {TTF}
q=2	{MNF, TTF}	{MNF, TTF}	{MNF}, {TTF}, {SRV}	{MNF}, {TTF}, {SRV}	{MNF}, {TTF}, {SRV}
q=1	{MNF, TTF}	{MNF, TTF}, {SRV}	{MNF, TTF, SRV}	{MNF, TTF, SRV}	{MNF, TTF, SRV}
q=0	{MNF, TTF, SRV}	{MNF, TTF, SRV}	{MNF, TTF}, {SRV}	{MNF, TTF, SRV}	{MNF, TTF, SRV}
CP2	0.587	0.607	0.615	0.619	0.621
q=5	{MNF, TTF}	{MNF, TTF}	{MNF, TTF}	{MNF, TTF}	{MNF, TTF}
q=4	{MNF, TTF, SRV}	{MNF, TTF, SRV}	{MNF, TTF, SRV}	{MNF, TTF, SRV}	{MNF, TTF, SRV}
q=3	{MNF, TTF, SRV}	{MNF, TTF, SRV}	{MNF, TTF, SRV}	{MNF, TTF, SRV}	{MNF, TTF, SRV}
q=2	{MNF, TTF, SRV}	{MNF, TTF, SRV}	{MNF, TTF, SRV}	{MNF, TTF, SRV}	{MNF, TTF, SRV}
q=1	{MNF, TTF, SRV}	{MNF, TTF, SRV}	{MNF, TTF, SRV}	{MNF, TTF, SRV}	{MNF, TTF, SRV}
q=0	{MNF, TTF, SRV}	{MNF, TTF, SRV}	{MNF, TTF, SRV}	{MNF, TTF, SRV}	{MNF, TTF, SRV}
CP3	0.770	0.794	0.801	0.808	0.812
q=5	{MNF, TTF}	{MNF, TTF}	{MNF, TTF}	{MNF, TTF, SRV}	{MNF, TTF, SRV}
q=4	{MNF, TTF, SRV}	{MNF, TTF, SRV}	{MNF, TTF, SRV}	{MNF, TTF, SRV}	{MNF, TTF, SRV}
q=3	{MNF, TTF, SRV}	{CNS, MNF, TTF, SRV}	{MNF, TTF, SRV}	{MNF, TTF, SRV}	{CNS, MNF, TTF, SRV}
q=2	{CNS, MNF, TTF, SRV}	{CNS, MNF, TTF, SRV}	{CNS, MNF, TTF, SRV}	{CNS, MNF, TTF, SRV}	{CNS, MNF, TTF, SRV}
q=1	{CNS, MNF, TTF, SRV}	{CNS, MNF, TTF, SRV}	{CNS, MNF, TTF, SRV}	{CNS, MNF, TTF, SRV}	{CNS, MNF, TTF, SRV}
q=0	{CNS, MNF, TTF, SRV}	{CNS, MNF, TTF, SRV}	{CNS, MNF, TTF, SRV}	{CNS, MNF, TTF, SRV}	{CNS, MNF, TTF, SRV}
CP4	0.836	0.849	0.858	0.866	0.871

While the earlier decomposed method suggested that the production structure in Chicago's economy was becoming simpler, the analysis of sectoral structure explored a more detailed picture of structure changes, showing the relationships of the sectoral structure in different levels of transaction flow. In about 50 per cent of the total transaction flow, manufacturing and service sectors have the most noticeable changing features in that manufacturing has less and less connections with other sectors, while the service sectors, on the other hand, expanded its connections with other sectors inside the economy, further indicating their growing importance in the economy.

Even though manufacturing in Chicago provides inputs to and derives inputs from fewer sectors inside the economy since 1980, its total output did not decrease. Figures 8 and 9 shows the inputs by sector and output by sectors in Chicago from 1980 to 2010. Clearly, the inputs to manufacturing are decreasing while that to service is increasing. On the other hand, the total outputs of both manufacturing and services are increasing. The implications for the regional economy are a reduction in the multiplier value for the manufacturing sector over time; however, since total production continues to increase in real terms, the volume of goods and services circulating in the economy as a result of the manufacturing sector may not have changed a great deal. The ratio of sectoral intermediate output to total output is declining as shown in figure 10.

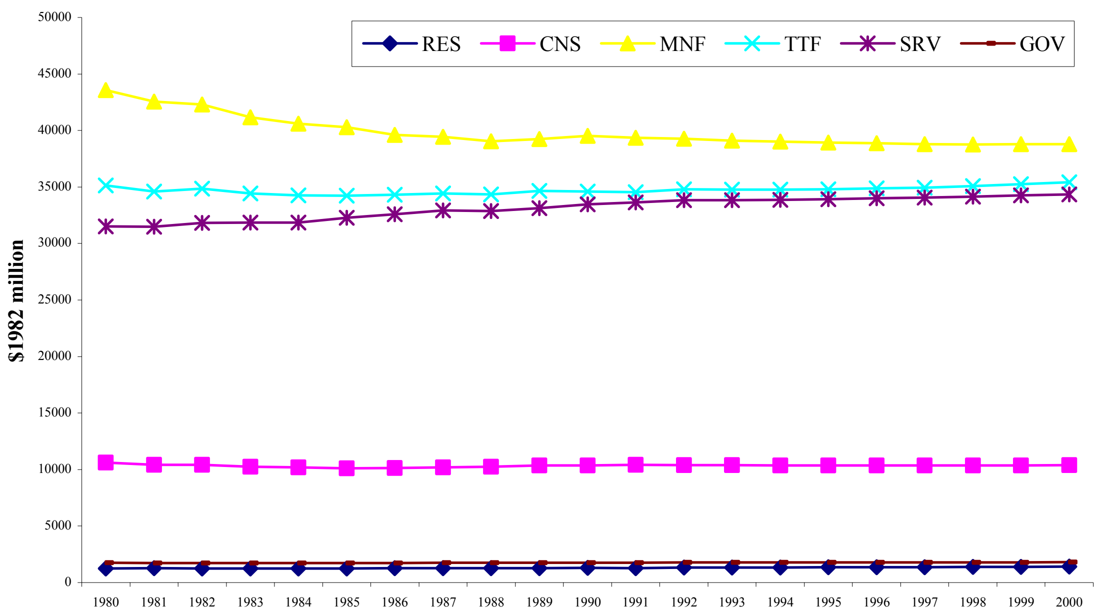

Figure 8 Input by sector in Chicago from 1980 to 2000

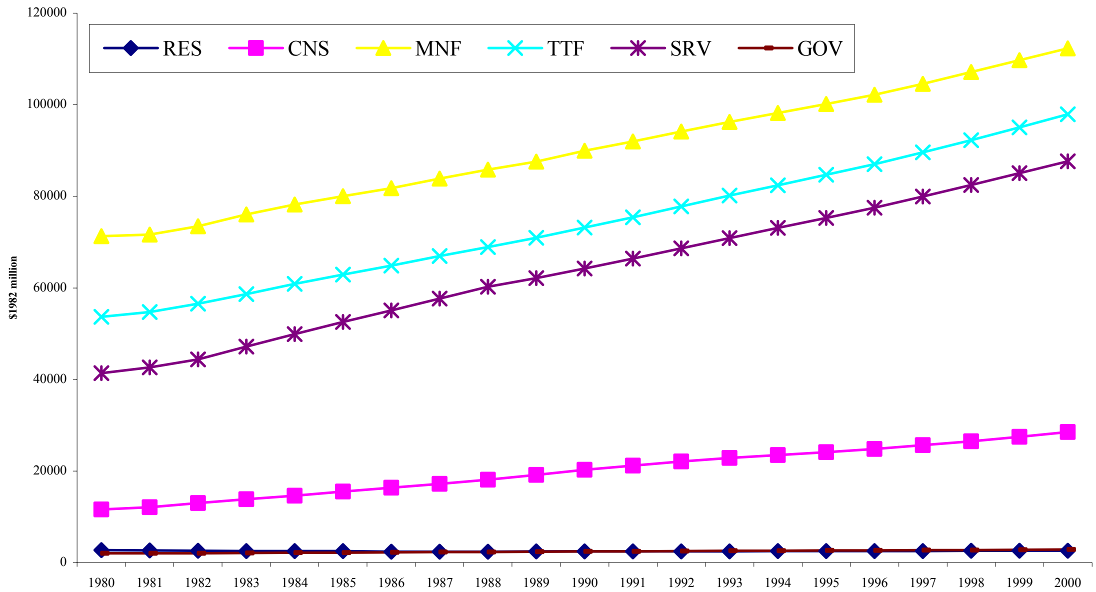

Figure 9 Output by sector in Chicago from 1980 to 2000

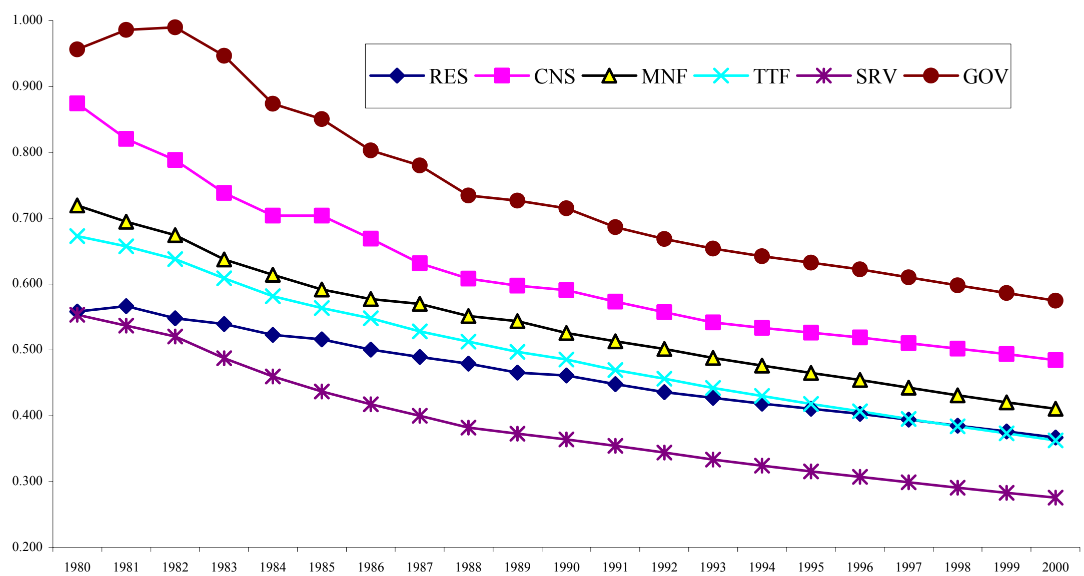

Figure 10 Ratio of sectoral intermediate output to total output by sector from 1980 to 2000

The analysis reveals some features of the structure of Chicago's economy in the last two decades that can be summarized as follows. The structure has become simpler; there has been a declining degree of interactions between sectors, but with increasing total outputs, especially in manufacturing and service sectors. Further, the strengthened interaction of services with more sectors in the economy has occurred while the reverse has been the case for manufacturing. These findings clearly suggest some evidence of hollowing out and/or fragmentation of production. The results indicate that the production process in Chicago is increasingly becoming more dependent in a backward and forward sense on regions outside the Chicago economy. This result is especially true for manufacturing; the fragmentation of production has been facilitated by the fast growth of the service sectors, especially transportation and communications, that have made it possible to source inputs from distant sources and to serve markets that are more geographically diverse. This kind of production process is observed internationally nowadays because of the tremendous development of services in the world (Jones and Kierzkowski, 2001a, 2001b). Even though fragmentation of production may happen domestically and internationally, the process has not been documented at the regional level.

6. Conclusion

Returning to the issue of structural decomposition analysis, this paper provides a new perspective by emphasizing intermediate flows decomposition by employing two methods: superposition flow decomposition and Q-analysis. The objective of the flow decomposition is stressed by taking account of the importance of the decomposed sub-flows in a system; while Q-analysis is to explore the detailed structure in each decomposed level.

The applications to Chicago's economic structure analysis in the period of 1980 to 2000 have shown several features of Chicago's economy, such as the simpler production structure inside the region, the declining interactions of manufacturing with other sectors in the region while the increasing interactions of service with other sectors. With the total output of manufacturing did not decrease, all these features provide another evidence of hollowing-out effect in Chicago's economy found by others (Hewings *et al.*, 1998). Also, it reveals production fragmentation patterns at the regional level, paralleling findings of similar processes at the international level.

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