Typology of Structural Change in the Chicago Economy:
A Temporal Inverse Analysis$^1$

Yasuhide OKUYAMA*, Michael SONIS**
and Geoffrey J.D. HEWINGS***

Abstract

Earlier studies (Hewings et al. 1998, Okuyama et al. 2002a, and Okuyama et al. 2002b) investigated the hollowing-out phenomenon of the Chicago economy, in which the manufacturing sectors in Chicago have decreased their intermediate dependency within the region while the service sectors have increased their dependency. In this paper, a set of annual input-output tables for the Chicago metropolitan economy during the period of 1980-97 was again employed for a further investigation of the structural change, using an alternative tool, the Temporal Leontief Inverse Analysis (Sonis and Hewings 1998), that can assist in exploring trends and uncovering tendencies in individual sectors or groups of sectors within the context of an economy-wide system of accounts. The results are compared with the earlier studies for examining the nature and details of the hollowing-out phenomenon.

1. Introduction

Recent empirical studies on the Chicago economy (such as Israilevich and Mahidhara, 1991; Hewings et al. 1998; Okuyama et al. 2002a; and Okuyama et al. 2002b) have indicated that the Chicago metropolitan economy has experienced a hollowing-out phenomenon, in which the level of dependence on local purchases and sales is declining, especially in the manufacturing sectors. The hollowing-out phenomenon found in these studies reveals that, especially for intermediate goods, intrametropolitan dependence has been replaced by dependence on sources of supply and demand outside the region, and shows that a complex internal transformation of the economic structure, as dependence on locally sourced manufacturing inputs is replaced by dependence on local service activities. While these studies investigated the Chicago economy employing various analytical tools, further explorations focusing more on the structural change over time may reveal not only the temporal path of changes in interindustry relationships across sectors but also a more comprehensive picture of the hollowing-out effect.

This paper utilizes a new approach for investigating the structural changes in the
Chicago economy over the period of 1980–1997. The analytical tool employed is the 
Temporal Leontief Inverse, developed by Sonis and Hewings (1998). One of the advantages 
of the temporal Leontief inverse is the ability to implement and investigate the role of 
structural changes in a time series of input–output tables. Another important feature of this 
technique is its ability to provide a set of techniques to explore the nature of the time series 
and to assist in the extraction of important insights about the nature of technological change 
and/or of the changes in trading patterns (in the case of regional and interregional systems). 
Employing this tool, impacts and patterns of the hollowing-out effect across sectors are 
displayed and analyzed.

In the next section, the concept of temporal Leontief inverse is presented and discussed 
with other dynamic formulations of Leontief inverse. Section 3 briefly describes the deriva 
tion of Chicago input–output tables using the Chicago Region Econometric Input–Output 
Model (CREIM) and summarized the previous studies mentioned above. The fourth section 
presents an analysis of the Chicago economy over the period of 1980–1997. This paper 
concludes with some summary remarks.

2. Methodology: Temporal Leontief Inverse

The Temporal Leontief Inverse was introduced (Sonis and Hewings, 1998) as a tool to 
analyze and investigate structural changes in an economy over time. Some of the earlier 
approaches to the analysis of structural changes can be categorized into the following two: 
those, like Tiebout (1969), used a comparative static approach; and the others, for example 
Leontief (1970) and Miernyk et al. (1970), who attempted to form a discrete time-series 
dynamic system.

The temporal Leontief inverse, introduced by Sonis and Hewings (1998), is an alternative 
vision for time series analysis of input–output systems. The formulation includes a 
consideration of the sequence of direct input matrices for different periods, \( A_0, A_1, \ldots, A_t, 
A_{t+1}, \ldots \), exploits the notions of discrete time changes and corresponding temporal multipliers, and proposes a temporal Leontief inverse in lieu of the complexities underlying the 
formal structure of dynamic inverses. A framework of the temporal Leontief inverse can be 
shown in the following manner. Consider a sequence of time period, \( t_0, t_1, \ldots, t_T \), such that in 
the initial period, \( t_0 \), there exists a matrix of direct input coefficients, \( A_0 = \| a_{ij}^0 \| \), and the 
associated Leontief inverse matrix, \( B_0 = (I - A_0)^{-1} \). In each period, \( t_s \), there is the matrix of 
changes in direct input coefficients, \( E_s = \| e_{ij}^s \| \), such that the matrix of direct inputs 
coefficients, \( A_s = \| a_{ij}^s \| \), and the Leontief inverse matrix, \( B_s = (I - A_s)^{-1} \) will have the form:

\[
A_s = A_{s-1} + E_s = A_0 + E_1 + E_2 + \cdots + E_s \\
B_s = (I - A_{s-1} - E_s)^{-1} = (I - A_0 - E_1 - E_2 - \cdots - E_s)^{-1} 
\] (1)

Transforming the latter relationship to a multiplicative form, one can obtain:

\[
B_s = (I - A_{s-1} - E_s)^{-1} = [(I - A_{s-1}) + (I - B_{s-1}E_s)]^{-1} = (I - B_{s-1}E_s)^{-1}B_{s-1} \\
B_s = (I - A_{s-1} - E_s)^{-1} = [(I - E_sB_{s-1})(I - A_{s-1})]^{-1} = B_{s-1}(I - E_sB_{s-1})^{-1} 
\] (2)

The matrices, \( M_L = (I - B_{s-1}E_s)^{-1} \) and \( M_R = (I - E_sB_{s-1})^{-1} \), are called the left and right temporal multipliers. Obviously:
\[ B_s = M^\ell_s B_{s-1} = B_{s-1} M^\ell_s, \quad M^\ell_s = B_s (I - A_{s-1}), \quad M^\ell_0 = (I - A_{s-1}) B_s \]  

(3)

Using the left temporal multipliers, the following multiplicative decomposition of the temporal Leontief inverse can be shown as follows:

\[
\begin{align*}
B_s &= M^\ell_s B_{s-1} \\
&= M^\ell_s M^{\ell-1}_s B_{s-2} \\
&= \cdots \cdots \\
&= M^\ell_s M^{\ell-1}_s \cdots M^\ell_2 M^{\ell-1}_1 M^\ell_0 B_0
\end{align*}
\]

(4)

The multiplicative representation, model (3), of the Leontief inverse, \( B_s \), can be converted into the following additive decomposition:

\[
B_s = M^\ell_s B_{s-1} = B_{s-1} + (M^\ell_s - I) B_{s-1}
\]

(5)

Using the former relation:

\[
D_s = B_s - B_{s-1} = (M^\ell_s - I) B_{s-1}
\]

(6)

This, \( D_s \), is called as the temporal increment, and this, in turn, provides the additive decomposition of the temporal Leontief inverse as follows:

\[
B_s = B_{s-1} + D_s = B_{s-2} + D_{s-1} + D_s = \cdots = B_0 + D_1 + \cdots + D_{s-1} + D_s
\]

(7)

Using the left multipliers, \( M^\ell_s \), one can transform the relationship (7) to the following form:

\[
B_s = I + (B_0 - I) + (M^\ell_1 - I) B_0 + (M^\ell_2 - I) M^\ell_1 B_0 + \cdots + (M^\ell_s - I) M^{\ell-1}_s \cdots M^\ell_2 M^{\ell-1}_1 M^\ell_0 B_0
\]

\[
= B_0 + (M^\ell_1 - I) B_0 + (M^\ell_2 - I) M^\ell_1 B_0 + \cdots + (M^\ell_s - I) M^{\ell-1}_s \cdots M^\ell_2 M^{\ell-1}_1 M^\ell_0 B_0
\]

\[
= B_{s-1} + (M^\ell_s - I) M^{\ell-1}_s \cdots M^\ell_2 M^{\ell-1}_1 M^\ell_0 B_0
\]

(8)

Together with temporal multipliers and temporal increments, this form can serve as the basis for temporal analysis of an evolving input-output system. For example, if \( f_s \) is the final demand vector in the \( s \)th period, the corresponding gross output vector, \( x_s \), can be derived as \( x_s = B_s f_s \), and then can be decomposed into a sum of the effects of the first time period, the second time period, through to the \( s \)th time period increments, using the relationship (8), as follows:
More specifically, this formulation can decompose the impact from the final demand change into the direct impact, \( f_s \), the indirect impact at the base year, \((B_0 - I)f_s\), the changes (or the deviations from the base year) in indirect impact at the first time period, \((M_1 - I)B_0f_s\), the changes (or deviations from the first period) in indirect impact at the second time period, \((M_2 - I)M_1B_0f_s\), and so forth. In this way, the manner in which each year’s change contributes to the total impact in gross output change can be traced.

3. Data and Previous Findings

In order to analyze structural changes of the Chicago economy, the Chicago input–output tables are extracted from the Chicago Region Econometric Input–Output Model (CREIM), which consists of 36 industrial sectors (see Appendix), during the period of 1980–1997.\(^2\) The input–output coefficient matrix is not observed directly; however, it is possible to derive analytically a Leontief inverse matrix and, through inversion, the estimated direct coefficient matrix. An important assumption here is that the error terms in the derived input–output coefficients from the CREIM are normally distributed, and are independent and identically distributed; thus, the coefficients, while not “real” observations, can be treated as such, since they are derived by a quantity adjustment general equilibrium process.

Israilevich and Mahidhara (1991) and Hewings et al. (1998) used a time series of input–output tables for the period 1975–2011, extracted from the CREIM, for investigating the transformation in the economic structure of Chicago. While these studies employed the aggregated industrial sectors (7 and 9 sectors, respectively), they explored the nature of the structural changes through examination of the changes in the composition of the Leontief multipliers and changes in the economic landscapes interpreted through the application of the multiplier product matrix. The results of these studies, especially in Hewings et al. (1998), revealed that intrametropolitan dependence has been replaced by dependence on sources of supply and demand outside the region, indicating the evidence of a hollowing-out process. In addition, their analysis shows a complex internal transformation, as dependence on locally sourced manufacturing inputs is replace by dependence on local service activities.

One concern that might be raised is the degree to which the coefficient estimation is devolved to a bi-proportional adjustment process. Using the same series of input–output tables for the Chicago economy, Okuyama et al. (2002b) investigated the way that the exogenous changes included in CREIM are manifested in the input–output coefficients and the degree to which these input–output coefficients are predictable through the bi-proportional properties of input–output table, under the usual conditions associated with the RAS tech-

\(^{2}\) In this version of CREIM, the price is fixed at 1987 million dollars.
nique. Assessing the time series of direct input coefficient matrices, $A_t$, they found a greater volatility over time in the values of "substitution effects" $r_i$, than in the entries of "fabrication effects" $s_j$, in the RAS procedure. In addition, sectors with small output values tend to show greater variance over time whereas sectors with large output values seem to have a larger number of $r_i$ values, which are less than unity, than in the case of $s_j$ values.

Using a new analytical technique of Fields of Influence\(^3\), Okuyama et al. (2002a) investigated the structural changes of the Chicago economy with the same set of input-output tables. They found that the Chicago economy exhibits little change in the appearance of the economic landscape (multiplier product matrix); however, changes in the hierarchy of forward and/or backward linkages illustrate some underlying changes in the structure of the Chicago economy. In addition, focusing on the cross-structure of the direct (first order) fields of influence, the stability of some Leontief inverse coefficients and the instability of some other coefficients are revealed. Moreover, their further analysis indicates that the trends and the types of changes in forward and backward linkages differ considerably across sectors.

In this paper, the structural changes of the Chicago economy are further investigated using the technique of Temporal Leontief Inverse, investigating a time series of inverse matrices, $B_t$, instead of direct input coefficient matrices, $A_t$, employed in Okuyama et al. (2002b). In this way, the trends of system-wide structural change in the Chicago economy can be evaluated over time. Furthermore, the decomposition of temporal inverse can examine numerically in which year temporal change had more significant impacts on the system-wide economic structure than in other years, whereas the qualitative analysis of ranks and hierarchies of interindustry relationships were identified in Okuyama et al. (2002a). Therefore, by using the temporal inverse, one can analyze changes in the system-wide impact of the changes in a particular sector as well as illustrate the trends of changes in indirect impact.

4. Analysis of Structural Change Using Temporal Inverse

In this section, some general observations of temporal changes in the Chicago economy are made and analyzed, followed by the analysis using the temporal inverse and the comparison with the findings summarized in the previous section.

General Trends of the Chicago Economy

Figure 1 displays the trends of total output of the Chicago economy and the top 10 sectors with largest output in 1980. The output of the top 10 sectors, except Sector 20 (Electronic and Electric Equipment) and Sector 13 (Petroleum and Coal Products), increased in real terms over the period of 1980-1997. The rate of growth among these sectors varies; for example, the largest output sector, Sector 27 (Wholesale and Retail Trade), has a steady growth of output, mirroring the growth pattern of the total output of the region. On the other hand, the second largest output sector, Sector 30 (Lodging, Business, Engineering, Management, and Legal Services), had a significant increase between 1987 and 1988, and continuously grew at the same or slightly higher rate than that of total output, after 1989.

\(^3\) The details of fields of influence analysis can be found in Sonis and Hewings (1991) and Sonis and Hewings (1992).
Sector 19 (Industrial Machinery and Equipment) has a smaller but still significant output increase between 1987 and 1989; however, the growth of the output in the other periods appears rather flat. Sector 4 (Construction), the fourth ranked in 1980, has growth trends almost parallel to the ones of total output. The rank order among these sectors also changed; Sector 4 (Construction) moved up from fourth in 1980 to third in 1997; Sector 20 (Electronic and Electric Equipment) moved down from eighth to eleventh; more significantly, Sector 13 (Petroleum and Coal Products) moved down from ninth to 15th.

Temporal Inverse Analysis

As indicated earlier, equation (9) can be used to analyze changes in the impact path from the increase or decrease in final demand at a particular time period. Using equations (5) and (6), equation (9) can be simplified for numerical calculation as follows:

$$
\Delta x_s = B_s \Delta f_s \\
= \Delta f_s + \\
+ (B_0 - I) \Delta f_s + \\
+ D_1 \Delta f_s + \\
+ D_2 \Delta f_s + \\
\vdots \\
+ D_s \Delta f_s
$$

(10)

Using this formulation of the temporal inverse, an impact of final demand increase in 1997 to a specific sector can be decomposed into the temporal impact (each year's contribution to the total impact), so that structural changes in each year, in terms of interindustry relationship, can be traced. Based on the findings of the previous studies (Hewings et al. 1998; 

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4 The direct impact, $\Delta f_s$, and the base year (1980) indirect impact, $(B_0 - I) \Delta f_s$, are not included in this and following figures in order to emphasize temporal changes between 1981 and 1997.
Okuyama et al. 2002a; and Okuyama et al. 2002b) and the observations documented earlier, differences in trends of structural change among sectors appear prevalent; in addition, some common types of structural change may be created so that sectors can be categorized into several groups of structural change trends. In order to investigate how a hollowing-out process affects sectors differently, a typology of sectors based on the shape of the trends of accumulated temporal impacts to the entire system (system-wide trends in the above figures) was developed. The results are shown in Table 1.

The typology of sectors consists of four types: Tilted L, Flattened U, Flat, and Tilted J. The description of each type is as follows:

- **Tilted L (TL):** this type has the shape of temporal impact trend that the accumulated impact decreases monotonically during all or most of the period with a flat or slightly elevated tail (mostly after 1993). Sector 19 in figure 2 has the typical shape of the trends. This shape indicates that a sector in this type has consistently decreased its intraregional interindustry relationships with the system as a whole and with most of the other sectors. This tendency may be due to the increasing reliance on interregional trade for intermediate purchases, and this is one of the features of a hollowing-out process. Included in this category are: Food Products (5), Textile (7), Wood Products (8), Paper Products (10), Rubber Products (14), Primary Metal (17), Industrial Machinery (19), Electronics (20), Transportation Equipment (21), Instruments (22), Miscellaneous Manufacturing (23), and Communications (25) sectors.
These sectors are mostly manufacturing sectors (the only exception is Communications), from both Non-Durable and Durable sub-categories. This type coincides with the observations found in the previous studies that most of manufacturing sectors have decreased the interindustry relationship with the region and have increased interregional trade for their production.

**Flattened U (FU)**: the shape of curve in this type starts with moderate decrease during the 1980s, usually flatter than in TL, but starts to regain the slope upward in the 1990s. Sector 27 in figure 3 has the typical shape of these trends. A difference between TL's slightly recovering tail and FU's moderate recovery during the 1990s is defined that the range of recovery (the difference between the lowest value and the 1997 (end of period) value) is greater than one third of the total decline (the difference between the highest value during
the 1980s and the lowest value). Thus, this type has the flattened U shape with more noticeable and larger recovery on the right hand side (during the 1990s) than in TL that has a much more modest recovery. This shape implies that the sectors in this type decreased the interindustry relationships within the region during the 1980s, but they regained them to some extent during the 1990s. The sectors in this type include: Agricultural Products (1), Agriculture (2), Construction (4), Furniture (9), Chemicals (12), Leather Products (15), Stone Products (16), Fabricated Metal (18), Transportation Services (24), Wholesale and Retail Trade (27), Entertainment (33), and State and Local Government (36). As most of these sectors have increased their output level continually and visibly during the period, this shape may imply that during the 1980s these sectors decreased the interindustry relationships within the region, similar to the sectors in TL, but their increased output level may have necessitated to regain the intraregional interindustry relationships in addition to the increased interregional relationships. In fact, the sectors in this type are a mixture of Resources, Construction, Manufacturing, and Services sectors.

**Flat (F)**: the name of the type describes the shape of trends: flat, having few changes over the period. The typical shape in this type is shown in figure 4 for Sector 29 (Real Estate). The sectors in this type include: Mining (3), Tobacco (6), Printing and Publishing (11), Petroleum Products (13), Utility (26), Real Estate (29), and Auto Services and Parking (32). These sectors have either very small output levels (Mining and Tobacco), or are strictly local activity (Utility, Real Estate, and Auto Services and Parking). Printing and Petroleum Products are the final two sectors in this group.

**Tilted J (TJ)**: the shape of this type looks like a vertical reverse display of TL: initial decrease ends by the mid 1980s, followed by the flat trend in the late 1980s and the shape turns to upward throughout the 1990s, with the value in 1997 (end of the period) greater than any prior time point. The most extreme case of the shape is shown in figure 5 for Sector 28 (Finance and Insurance). In figure 9, the shape is mostly upward after 1986 and the value of accumulated temporal impact turns positive in 1992 and thereafter. Sector 28 is the only
sector having all positive values with system-wide impact. Even with this Sector 28, however, Manufacturing (Durable) sector has negative accumulated values during the entire period. This observation implies that Sector 28 increased the interindustry relationships within the region considerably during the 1990s, except with the sectors in the Manufacturing (Durable) category. The sectors in this type are all Services sector, and this result is very much consistent with the findings in the previous studies, in which Services sectors increased intraregional dependency.

5. Summary and Conclusions

In this section, major findings in this paper are evaluated and compared to previous studies. Some discussions about the analytical technique and concluding remarks are also provided.

Evaluation

The results in this paper indicate that the evidence of different types of temporal change exists. With the typology of sectors presented in the previous section, it is quite clear that sectors can be grouped into a few types, in which each type has a distinguishable path of structural change. In this regard, the findings in this paper confirm the conclusions of previous studies that used actual transaction volumes (Hewings et al. 1998); yearly analysis of Leontief inverse matrix using the fields of influence technique (Okuyama et al. 2002a); and the time series (econometric) analysis of direct input coefficient matrices (Okuyama et al. 2002b), over the similar period of time. The results in this paper can offer an analysis of temporal changes in the Leontief Inverse, by which relative changes in system-wide structure of an economy can be traced and investigated and thus may be seen to complement and deepen the understanding of the processes of structural change in a regional economy. Combining these results, we now have a more complete picture of the hollowing-out process in the Chicago Metropolitan economy: Manufacturing sectors have experienced sizable structural changes during the period of 1980–1997 with weakening interindustry relationships.
within the region and becoming more dependent on interregional trade, while Services sectors have been rather stable and increasing relative significance in interindustry relationships within the region. Careful examination and comparison of the findings of the previous studies may provide further depth in understanding of the structural change in an economy.

Concluding Remarks

While the methodology and associated properties of the temporal Leontief inverse do not provide the rich theoretical foundations that the Leontief dynamic system and its extended and modified models offer, the technique provides the capability for implementation and for exploration of the analysis of structural changes in a time series of input-output tables. Although the formal linkages between the methodologies remain to be developed, this paper presented the usefulness and clear advantages of the temporal Leontief inverse analysis and the evidence of the hollowing-out process in the Chicago Metropolitan economy. If a greater number of data points (years) becomes available, the statistical analysis of trends based on this type of analysis can be conducted for more robust investigation of the differences in structural change of an economy. For more empirical implications, as Hewings et al. (1998) indicated, if the hollowing-out processes investigated for the Chicago economy are the common trends in many other regions, then the U.S. economy has been experiencing a significant structural change, shifting the dominance from Manufacturing sector to Services sector in more complex ways than that revealed by shares of total employment or value added accounted for by these two macro sectors.

References


## Appendix

### Sectoring Scheme in the CREIM Model

<table>
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<tr>
<th>Sector</th>
<th>Title</th>
<th>SIC</th>
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<tbody>
<tr>
<td>1</td>
<td>Livestock, Livestock Products, and Agricultural Products</td>
<td>01, 02</td>
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<tr>
<td>2</td>
<td>Agriculture, Forestry, and Fisheries</td>
<td>07, 08, 09</td>
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<tr>
<td>3</td>
<td>Mining</td>
<td>10, 12, 13, 14</td>
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<td>4</td>
<td>Construction</td>
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<td>5</td>
<td>Food and Kindred Products</td>
<td>20</td>
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<tr>
<td>6</td>
<td>Tobacco</td>
<td>21</td>
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<tr>
<td>7</td>
<td>Apparel and Textile Products</td>
<td>22, 23</td>
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<tr>
<td>8</td>
<td>Lumber and Wood Products</td>
<td>24</td>
</tr>
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<td>9</td>
<td>Furniture and Fixtures</td>
<td>25</td>
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<tr>
<td>10</td>
<td>Paper and Allied Products</td>
<td>26</td>
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<td>11</td>
<td>Printing and Publishing</td>
<td>27</td>
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<td>12</td>
<td>Chemicals and Allied Products</td>
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<td>13</td>
<td>Petroleum and Coal Products</td>
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<td>14</td>
<td>Rubber and Misc. Plastics Products</td>
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<td>15</td>
<td>Leather and Leather Products</td>
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<td>16</td>
<td>Stone, Clay, and Glass Products</td>
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<td>Primary Metals Industries</td>
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<td>Instruments and Related Products</td>
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<td>Railroad Transportation and Transportation Services</td>
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