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A Temporal Inverse Analysis

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Abstract: Earlier study (Sonis and Hewings, 1998) proposed an alternative tool that can assist in exploiting trends and uncovering tendencies in individual sectors or groups of sectors within the context of an economy-wide system of accounts. In this paper, the methodology, Temporal Leontief Inverse Analysis, is applied to a set of annual input-output tables for the Chicago metropolitan economy during the period of 1980-97. The results are compared to the earlier analysis (Hewings *et al*., 1998, Okuyama *et al*., 2002a, and Okuyama *et al*. 2002b) to examine the method and to investigate further the structural changes of the Chicago economy.

1. Introduction

The analysis of economic structure has created a demand for techniques that can investigate both the nature and changes of the structure over time. Well-known techniques include the familiar multiplicative decomposition associated with the work of Pyatt and Round (1979) and of Round (1985, 1988) and interpretations using structural path analysis as in Defourny and Thorbecke (1984). These approaches were directed towards the evaluation of economies based on the structure of social accounting matrices. Narrowing to the changes of the structure over time, analysis of the evolution of interindustry relations has become a major topic for economic analysis. The traditional approach, introduced by Chenery (1953) and Chenery and Watanabe (1958) was further extended in various studies (for example, Carter, 1970; Harrigan *et al.*, 1980; Deutsch and Syrquin, 1989, among others).

Recent studies (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 manufacturing sectors. While these studies investigated the Chicago economy employing various analytical tools, further explorations focusing on a different side of structural change may reveal not only the different type of changes in interindustrial relationships across sectors t but also more comprehensive picture of 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 these time series and to assist in the extraction of important insights about the nature of technological change and/or of the changes in trading patters (in the case of regional and interregional systems). Employing this tool, impacts and differences 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 derivation 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, then, concludes with a summary and some concluding remarks.

2. Methodology: Temporal Leontief Inverse

Temporal Leontief Inverse was introduced (Sonis and Hewings, 1998) for the need of a tool to analyze and investigate the structural changes of 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. Tiebout's approach was involving a comparison of the structure of a regional economy, *A*, at time *t*+*n* with another economy, *B*, at the present time, *t*, borrowed the structure from *B* as a first estimator of the future structure of region *A*'s economy. Although the Tiebout's idea was ingenious, his method suffers most from a dearth of comparative data.

Dynamic version of input-output model was first introduced by Leontief (1953) and was refined by his 1970 paper (Leontief, 1970). Since Miernyk's system is a derivative from Leontief's (Sonis and Hewings, 1998), only the latter will be discussed here. The dynamic input-output model aims to analyze and determine the structural and the technological changes of an economy (or economies) by including an intertemporal mechanism of capital accumulation. In his first model, Leontief formulated investment as the rate of change in required capital stock as follows:

$$\mathbf{x} = \mathbf{A}\mathbf{x} + \mathbf{C}\dot{\mathbf{x}} + \mathbf{f} \tag{1}$$

where $\mathbf{x}$ is the vector of output, $\mathbf{A}$ is the matrix of input requirement on current account, $\mathbf{C}$ is the matrix of capital requirement, $\mathbf{f}$ is the vector of non-investment final demand, and $\dot{\mathbf{x}}$ is the time derivative of $\mathbf{x}$. Leontief later (1970) developed a discrete approximation of model (1) using a system of difference equations with dated technical matrices reflecting structural change in an economy:

$$\mathbf{x_t} = \mathbf{A_t x_t} + \mathbf{C_{t+1}}\left(\mathbf{x_{t+1}} - \mathbf{x_t}\right) + \mathbf{f_t} \tag{2}$$

where $\mathbf{C_{t+1}}\left(\mathbf{x_{t+1}} - \mathbf{x_t}\right)$ represents the investment requirements in addition to productive stock during t and $t+1$ in order to expand their capacity output from $\mathbf{x_t}$ to $\mathbf{x_{t+1}}$. Forming a system of interlocked balance equations over a period of $m+1$ years, the solution of this system for unknown x's in terms of a given set of the c's:

$$\begin{bmatrix} \mathbf{x_{-m}} \\ \vdots \\ \mathbf{x_{-2}} \\ \mathbf{x_{-1}} \\ \mathbf{x_0} \end{bmatrix} = \begin{bmatrix} \mathbf{G_{-m}^{-1}} \ldots \mathbf{R_{-m}} \ldots \mathbf{R_{-3} R_{-2} G_{-1}^{-1}} & \mathbf{R_{-m}} \ldots \mathbf{R_{-3} R_{-2} R_{-1} G_0^{-1}} \\ \vdots & \vdots \\ \mathbf{R_{-2} G_{-1}^{-1}} & \mathbf{R_{-2} R_{-1} G_0^{-1}} \\ \mathbf{G_{-1}^{-1}} & \mathbf{R_{-1} G_0^{-1}} \\ & \mathbf{G_0} \end{bmatrix} \begin{bmatrix} \mathbf{f_{-m}} \\ \vdots \\ \mathbf{f_{-2}} \\ \mathbf{f_{-1}} \\ \mathbf{f_0} \end{bmatrix} \tag{3}$$

where $\mathbf{R_t} = \mathbf{G_t^{-1} C_{t+1}} = \left(\mathbf{I} - \mathbf{A_t} + \mathbf{C_{t+1}}\right)^{-1} \mathbf{C_{t+1}}$.

The mathematical properties of this dynamic model have been studied by many (for example, Zaghini, 1971; Schinnar, 1978; de Mesnard, 1992; and Guangzhen, 1993). However, the model has been used in few empirical works due to various problems involved: first, the implementation of the dynamic model requires the assembly of capital requirement matrices that distinguish between replacement and expansion of the capital; and second, the model could produce implausible results due to its structure[1].

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[1] Leontief (1970) implemented his dynamic model using 1947 and 1958 US data, and it revealed the two major inherent drawbacks of the model, which could produce implausible results. Leontief solved the model employing the backward-looking way--determine the final impacts first, and then solve the model for the requirements in previous years. This backward-looking solution is stable, yet unrealistic, since it assumes that the economy has a perfect foresight of the future. Although the forward-looking solution has been studied [Szyld (1985), Steenge (1990a), Heesterman (1990), and Steenge (1990b)], it has been found that a set of non-negative solutions for $\mathbf{x_t}$ exists only if the initial conditions lie on the "balanced growth path". This drawback comes from the assumption of full capacity utilization: the entire physical productive capacity will be utilized. Another difficulty to derive the solution of the Leontief dynamic model is the singularity of the capital matrix, $\mathbf{C}$. As Duchin and Szyld (1985) pointed out, most theoretical works have been carried out based on the assumption that the $\mathbf{C}$ matrix is invertible, whereas the $\mathbf{C}$ matrix may be invariably singular, with rows of zeros corresponding to the sectors not producing durable goods. In order to overcome these problems, Duchin and Szyld (1985) proposed the new formulation of the dynamic input-output model, and this formulation was used in Leontief and Duchin (1986) study. More recently, Campisi and his colleagues developed a series of models based on the Duchin-Szyld formulation, with an extension

Temporal Leontief inverse, proposed by Sonis and Hewings (1998), is an alternative vision for time series analysis of input-output system. The formulation includes only consideration of the sequence of direct input matrices for different periods, $\mathbf{A_0}$, $\mathbf{A_1},\dots,$ $\mathbf{A_t}$, $\mathbf{A_{t+1}},\dots,$ exploits the notions of discrete time changes and corresponding temporal multipliers, and proposes temporal Leontief inverse in lieu of the complexities underlying the formal structure of dynamic inverses described in (3). A definition of the temporal Leontief inverse can be introduced in the following manner:

Consider a sequence of time period, t_0, $t_1,\dots,$ t_T, such that in the initial period, t_0, there exists a matrix of direct input coefficients, $\mathbf{A_0} = \left\| a_{ij}^0 \right\|$, and an associated Leontief inverse matrix, $\mathbf{B_0} = \left(\mathbf{I} - \mathbf{A_0}\right)^{-1}$. In each period, t_s, there is the matrix of changes in direct input coefficients, $\mathbf{E_s} = \left\| e_{ij}^s \right\|$, such that the matrix of direct inputs coefficients, $\mathbf{A_s} = \left\| a_{ij}^s \right\|$, and the Leontief inverse matrix, $\mathbf{B_s} = \left(\mathbf{I} - \mathbf{A_s}\right)^{-1}$ will have the form:

$$\begin{aligned} \mathbf{A_s} &= \mathbf{A_{s-1}} + \mathbf{E_s} = \mathbf{A_0} + \mathbf{E_1} + \mathbf{E_2} + \dots + \mathbf{E_s} \\ \mathbf{B_s} &= \left(\mathbf{I} - \mathbf{A_{s-1}} - \mathbf{E_s}\right)^{-1} = \left(\mathbf{I} - \mathbf{A_0} - \mathbf{E_1} - \mathbf{E_2} - \dots - \mathbf{E_s}\right)^{-1} \end{aligned} \tag{4}$$

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

$$\begin{aligned} \mathbf{B_s} &= \left(\mathbf{I} - \mathbf{A_{s-1}} - \mathbf{E_s}\right)^{-1} = \left[\left(\mathbf{I} - \mathbf{A_{s-1}}\right)\left(\mathbf{I} - \mathbf{B_{s-1}E_s}\right)\right]^{-1} = \left(\mathbf{I} - \mathbf{B_{s-1}E_s}\right)^{-1}\mathbf{B_{s-1}} \\ \mathbf{B_s} &= \left(\mathbf{I} - \mathbf{A_{s-1}} - \mathbf{E_s}\right)^{-1} = \left[\left(\mathbf{I} - \mathbf{E_sB_{s-1}}\right)\left(\mathbf{I} - \mathbf{A_{s-1}}\right)\right]^{-1} = \mathbf{B_{s-1}}\left(\mathbf{I} - \mathbf{E_sB_{s-1}}\right)^{-1} \end{aligned} \tag{5}$$

The matrices, $\mathbf{M_L^s} = \left(\mathbf{I} - \mathbf{B_{s-1}E_s}\right)^{-1}$ and $\mathbf{M_R^s} = \left(\mathbf{I} - \mathbf{E_sB_{s-1}}\right)^{-1}$, are called the *left* and *right* temporal multipliers. Obviously:

$$\mathbf{B_s} = \mathbf{M_L^sB_{s-1}} = \mathbf{B_{s-1}M_R^s}; \mathbf{M_L^s} = \mathbf{B_s}\left(\mathbf{I} - \mathbf{A_{s-1}}\right); \mathbf{M_R^s} = \left(\mathbf{I} - \mathbf{A_{s-1}}\right)\mathbf{B_s} \tag{6}$$

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

to multiregional context, and applied to the Italian economy (Campisi *et al*., 1990; Campisi, Nastasi, and Bella, 1992; and Campisi and Nastasi. 1993).

$$\begin{aligned}\mathbf{B}_s &= \mathbf{M}_L^s \mathbf{B}_{s-1} \\ &= \mathbf{M}_L^s \mathbf{M}_L^{s-1} \mathbf{B}_{s-2} \\ &\vdots \\ &= \mathbf{M}_L^s \mathbf{M}_L^{s-1} \ldots \mathbf{M}_L^2 \mathbf{M}_L^1 \mathbf{B}_0\end{aligned} \tag{7}$$

The multiplicative representation, (6), of the Leontief inverse, $\mathbf{B}_s$, can be converted into the following *additive* decomposition:

$$\begin{aligned}\mathbf{B}_s &= \mathbf{M}_L^s \mathbf{B}_{s-1} = \mathbf{B}_{s-1} + \left(\mathbf{M}_L^s - \mathbf{I}\right)\mathbf{B}_{s-1} \\ \mathbf{B}_s &= \mathbf{B}_{s-1}\mathbf{M}_R^s = \mathbf{B}_{s-1} + \mathbf{B}_{s-1}\left(\mathbf{M}_R^s - \mathbf{I}\right)\end{aligned} \tag{8}$$

Using the former relation:

$$\mathbf{D}_s = \mathbf{B}_s - \mathbf{B}_{s-1} = \left(\mathbf{M}_L^s - \mathbf{I}\right)\mathbf{B}_{s-1} \tag{9}$$

This, $\mathbf{D}_s$, is called as the temporal increment, and this, in turn, provides the *additive* decomposition of the temporal Leontief inverse as follows:

$$\begin{aligned}\mathbf{B}_s &= \mathbf{B}_{s-1} + \mathbf{D}_s \\ &= \mathbf{B}_{s-2} + \mathbf{D}_{s-1} + \mathbf{D}_s \\ &\vdots \\ &= \mathbf{B}_1 + \mathbf{D}_2 + \ldots + \mathbf{D}_{s-1} + \mathbf{D}_s \\ &= \mathbf{B}_0 + \mathbf{D}_1 + \mathbf{D}_2 + \ldots + \mathbf{D}_{s-1} + \mathbf{D}_s\end{aligned} \tag{10}$$

Using left multipliers, $\mathbf{M}_L^s$, one can transform the relationship (10) to the following form:

$$\begin{aligned}\mathbf{B}_s &= \underbrace{\mathbf{I} + \left(\mathbf{B}_0 - \mathbf{I}\right)} + \left(\mathbf{M}_L^1 - \mathbf{I}\right)\mathbf{B}_0 + \left(\mathbf{M}_L^2 - \mathbf{I}\right)\mathbf{M}_L^1\mathbf{B}_0 + \ldots + \left(\mathbf{M}_L^s - \mathbf{I}\right)\mathbf{M}_L^{s-1}\cdots\mathbf{M}_L^2\mathbf{M}_L^1\mathbf{B}_0 \\ &= \underbrace{\mathbf{B}_0 + \left(\mathbf{M}_L^1 - \mathbf{I}\right)\mathbf{B}_0} + \left(\mathbf{M}_L^2 - \mathbf{I}\right)\mathbf{M}_L^1\mathbf{B}_0 + \ldots + \left(\mathbf{M}_L^s - \mathbf{I}\right)\mathbf{M}_L^{s-1}\cdots\mathbf{M}_L^2\mathbf{M}_L^1\mathbf{B}_0 \\ &= \underbrace{\mathbf{B}_1 + \left(\mathbf{M}_L^2 - \mathbf{I}\right)\mathbf{M}_L^1\mathbf{B}_0} + \ldots + \left(\mathbf{M}_L^s - \mathbf{I}\right)\mathbf{M}_L^{s-1}\cdots\mathbf{M}_L^2\mathbf{M}_L^1\mathbf{B}_0 \\ &= \qquad \vdots \\ &= \mathbf{B}_{s-1} + \left(\mathbf{M}_L^s - \mathbf{I}\right)\mathbf{M}_L^{s-1}\cdots\mathbf{M}_L^2\mathbf{M}_L^1\mathbf{B}_0\end{aligned} \tag{11}$$

Sonis and Hewings (1998) claim that this representation provides for an interpretation of the temporal Leontief inverse that shares a common feature with its dynamic cousin; the inverse depends on its *evolutionary tail* of changes and this dependence is highly non-linear. 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 $\mathbf{f_s}$ is the final demand vector in the *s*th period, the corresponding gross output vector, $\mathbf{x_s}$, can be derived as $\mathbf{x_s} = \mathbf{B_s f_s}$, and then can be decomposed in to 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 (11), as follows:

$$\begin{aligned} \mathbf{x_s} &= \mathbf{B_s f_s} \\ &= \mathbf{f_s} \\ &+(\mathbf{B_0} - \mathbf{I})\mathbf{f_s} \\ &+(\mathbf{M_L^1} - \mathbf{I})\mathbf{B_0 f_s} \\ &+(\mathbf{M_L^2} - \mathbf{I})\mathbf{M_L^1 B_0 f_s} \\ &\vdots \\ &+(\mathbf{M_L^s} - \mathbf{I})\mathbf{M_L^{s-1}} \cdots \mathbf{M_L^2 M_L^1 B_0 f_s} \end{aligned} \tag{12}$$

More specifically, this formulation can decompose the impact from the final demand change into the direct impact, $\mathbf{f_s}$, the indirect impact at the base year, $(\mathbf{B_0} - \mathbf{I})\mathbf{f_s}$, the changes (or the deviations from the base year) in indirect impact at the first time period, $(\mathbf{M_L^1} - \mathbf{I})\mathbf{B_0 f_s}$, the changes (or deviations from the first period) in indirect impact at the second time period, $(\mathbf{M_L^2} - \mathbf{I})\mathbf{M_L^1 B_0 f_s}$, and so forth. In this way, how 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. This system of 250 equations includes both exogenous and endogenous variables. Endogenous coefficient change serves as the mechanism to clear markets in the quantity-adjustment process (see Israilevich *et al.*, 1997, for more details). 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 derived input-output coefficients from the CREIM are normally distributed, and are independent and identically distributed; thus, the coefficients can be not "real" observations but treated as such.

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 technique. Assessing the time series of direct input coefficient matrices, $\mathbf{A}$, they found that a greater volatility in the values of "*substitution effects*", $\mathbf{r_i}$ in RAS procedure, than in the entries of "*fabrication effects*", $\mathbf{s_j}$ in RAS. In addition, smaller out put sectors tend to show greater variance over time whereas the larger sectors seem to have more r_i values that are less than unity than in the case of s_j values. They concluded that these results coincide with the '*hollowing-out*' process in the Chicago economy, reported by Hewings *et al*. (1998). In the hollowing-out process, the level of dependence on local purchases and sales is declining, especially between manufacturing sectors. Therefore, the tendency of the sectors with larger output to have $r_i < 1$ can be considered as the evidence of substitution, not across sectors, but in the location of purchase, since the extracted Chicago input-output tables are regional tables. And, the smaller volatility in the s_j entries indicates that the fabrication effect (technological change) is relatively insignificant. They also found that some of the interactions between manufacturing sectors (direct input coefficient, a_{ij}, and Leontief inverse coefficient, b_{ij}) have declining trends, implying that their relationship within the Chicago region becomes weakening. In conclusion, they claimed that, while the evidence of the hollowing-out process in the Chicago economy is found, the trends of bi-proportional properties, based the direct input matrices over the period of 1980 – 1997, can be considered as random movements.

Using a new analytical technique of *Fields of Influence*[2], 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 appearance by the

[2] The details of fields of influence can be found in Sonis and Hewings (1991) and Sonis and Hewings (1992).

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, by 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. These results indicate that the manufacturing sectors have experienced significant structural changes in the period of 1980-1997, while the service sectors have been rather stable in terms of field of influence; this also can be considered as another evidence of the presence of a *hollowing-out* process in the Chicago economy.

In this paper, the structural change of the Chicago economy is further investigated using the technique of Temporal Leontief Inverse, investigating a time series of inverse matrices, $\mathbf{B}$, instead of direct input coefficient matrices, $\mathbf{A}$, employed in Okuyama *et al*. (2002b). Furthermore, the decomposition of temporal inverse can examine numerically in which year temporal change has more significant impact on the system-wide economic structure than in other years, whereas the qualitative analysis of ranks and hierarchies of interindustry relationships were implemented in Okuyama *et al*. (2002a). Consequently, temporal inverse can analyze changes in the system-wide impact of the changes in a particular sector and can illustrate the trends of changes in indirect impact.

4. Analysis of Structural Change Using Temporal Inverse

In this section, the general observation of changes in the Chicago economy was 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 shows the trends of total output of the Chicago economy and the top 10 sectors with largest output in 1980. The output of most 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. 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 grows at the similar to or slightly higher rate than the ones of total output, after 1989. Sector 19 (Industrial Machinery and Equipment) has a smaller but still significant output increase during 1987 and 1989; however, the growth of the output in other periods is 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 in1980 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.

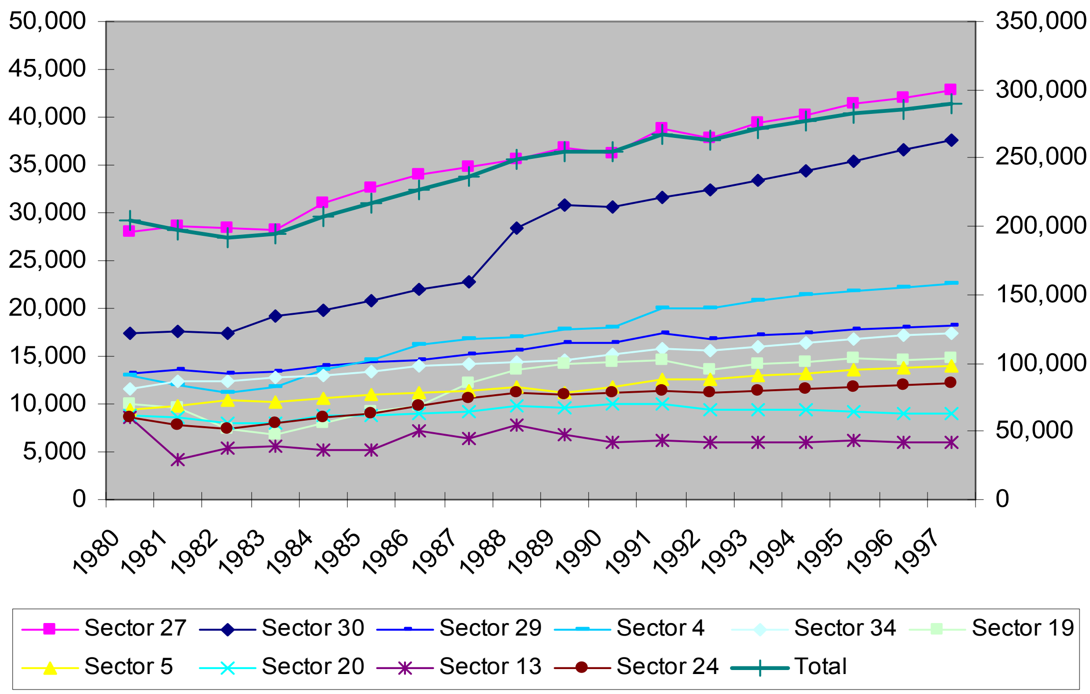

Figure 1. Changes in Total and Sector Outputs
(Left Axis for Sector Output; and Right Axis for Total Output; $ 1987 million)

Temporal Inverse Analysis

As indicated earlier, Equation (12) 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 (8) and (9), Equation (12) can be simplified for numerical calculation as follows:

$$\begin{aligned}\Delta\mathbf{x}_s &= \mathbf{B}_s\Delta\mathbf{f}_s \\ &= \Delta\mathbf{f}_s \\ &+(\mathbf{B}_0-\mathbf{I})\Delta\mathbf{f}_s \\ &+\mathbf{D}_1\Delta\mathbf{f}_s \\ &+\mathbf{D}_2\Delta\mathbf{f}_s \\ &\vdots \\ &+\mathbf{D}_s\Delta\mathbf{f}_s\end{aligned} \tag{13}$$

Using this formulation of the temporal inverse, an impact of final demand increase in 1997 to a specific sector can be decomposed to the temporal impact (each year's contribution to the total system-wide impact), so that structural changes in each year, in terms of interindustrial relationship, can be traced. First, final demand for Sector 27 (Wholesale and Retail Trade; the largest output sector during 1980 and 1997) is increased \$100 million (1987 dollars), and the temporal impacts to the sectors (five largest indirect impact recipient sectors) and to the entire system are shown in Figure 2[3]. Notice that the negative numbers in this figure are the relative decline in interindustrial relationship comparing to the previous year. In general, the trends of the temporal indirect impact to the system and these sectors are, on average, rising, implying that the relationships between Sector 27 and these five sectors (and the entire system) are becoming stronger. There are a few years when a sudden change occurred, such as 1987, 1988, and 1993. While any significant changes in the trends of gross output, shown in Figure 1, are not found to total output or to Sector 27, some sizable changes in interindustrial relationship might have occurred in these years. The trends of most large impact sectors in Figure 2 mirrors the ones of system-wide impact, except Sector 4 (Construction). The trends of temporal indirect impact to Sector 4 traces the ones of other sectors and system-wide; however, at a few positive spikes, such as 1984, 1990, 1994 and 1995, the impacts to Sector 4 are magnified—Sector 4 receives larger

[3] Direct impact, $\Delta\mathbf{f}_s$, and the base year (1980) indirect impact, $(\mathbf{B}_0-\mathbf{I})\Delta\mathbf{f}_s$ are not included in this and following figures in order to emphasize temporal changes between 1981 and 1997.

indirect impact than the other sectors do relative to the previous year. In addition, the range of changes in temporal indirect impact is the largest in Sector 4. This may be resulted from the fact that Construction sector is responsive in terms of production process—constructing the production facilities, capital, for other sectors.

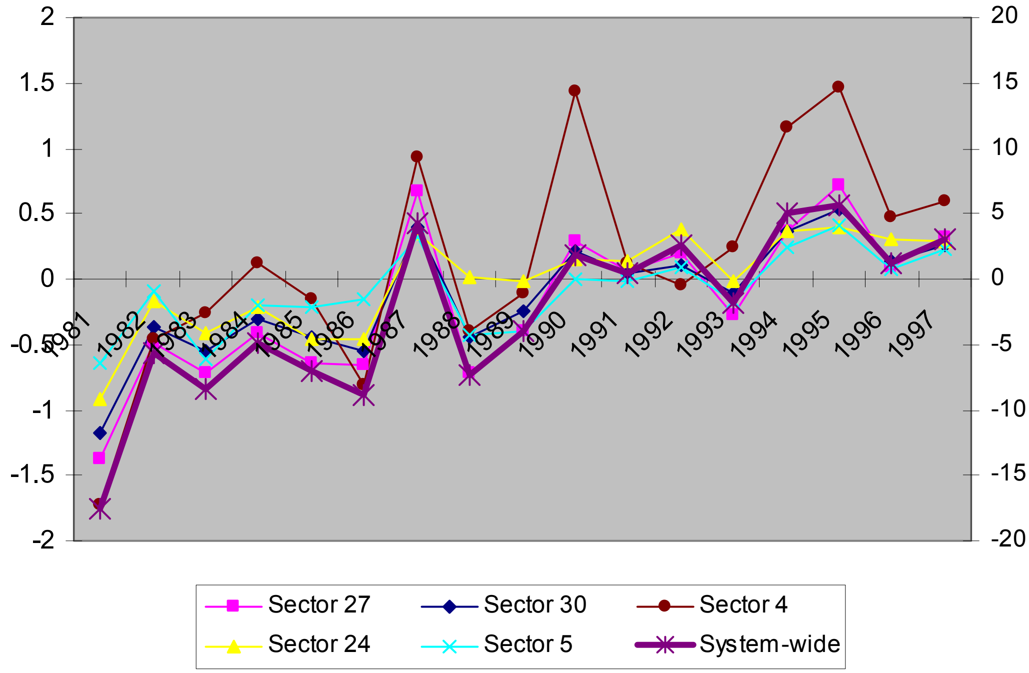

Figure 2. Trends in Temporal Impacts of the Demand Increase in Sector 27
(Left Axis for Sector Impact; and Right Axis for System-wide Impact)

One of the common observations of a hollowing-out process is that, especially for manufacturing sectors, the level of dependence on local purchases and sales is declining. In order to analyze the trends in one of the manufacturing sectors in Chicago, a similar stimulus ($100 million increase in final demand) was injected into Sector 19 (Industrial Machinery and Equipment). Sector 19's output in 1980 is ranked 6th over all and is ranked first among manufacturing sectors. Figure 3 shows the temporal indirect impacts to the entire system and to the five largest impact recipient sectors. In contrast to the Sector 27 (Wholesale and Retail Trade) case, most of temporal indirect impacts for Sector 19 have negative values, except 1987, and 1994 and 1995 for most of the sectors, indicating decreasing interindustry relationship relative to the previous year. The general trends over the period can be considered as upward, but it is clearly flatter than the one in Figure 2. The trends of temporal indirect impacts for each of the five sectors appear to be similar to the ones of the system-wide impact; however, the trends of intraindustry impact (impact to own sector, in this case to Sector 19) seem to have a narrower range of changes, comparing to the system-wide impacts and to the other sectors, except Sector 24 (Railroad Transportation and Transportation Services); in addition, during 1992-1995, the directions of change in temporal indirect impact to the previous year are opposite from the ones for the system-wide and for the other sectors. This may be an indication of complexity of structural change.

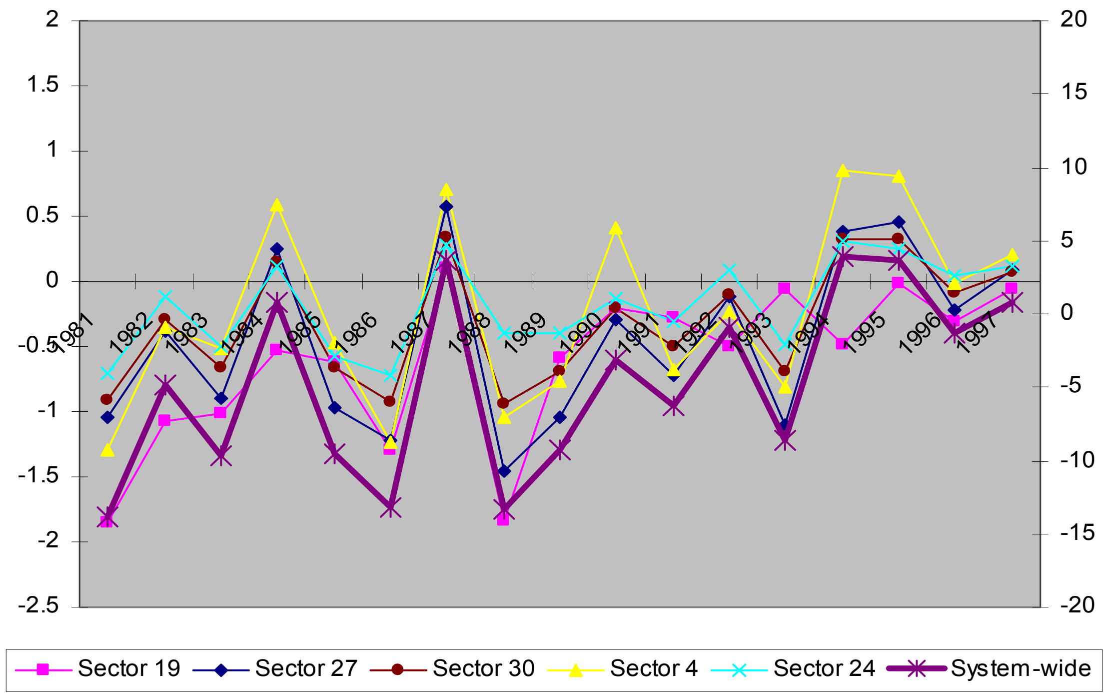

Figure 3. Trends in Temporal Impacts of the Demand Increase in Sector 19
(Left Axis for Sector Impact; and Right Axis for System-wide Impact)

Hewings *et al*. (1998) found that Construction sector (Sector 4) in the Chicago economy exhibits significant changes in backward and forward linkage hierarchies (pages 226-227). During the period of 1980-1995, Construction sector climbed up the backward linkage ranking from 6th to 4th, while its forward linkage dropped from second to seventh. In order to investigate the indirect impact from the increase in final demand for Construction sector, the temporal indirect impacts are calculated based on $100 million increase of final demand in 1997. Figure 4 displays the trends of temporal indirect impacts. The general trends of temporal indirect impacts are comparable to the ones in Figure 2. The system-wide impacts and most of the top five impact-recipient sectors exhibit the upward trend, although the trends ended downward during 1996 and 1997. Intraindustry indirect impacts (impact to Sector 4 itself) indicate the similar tendency found for Sector 4 in Figure 2—a wider range of changes and signified impacts when the positive spike in the system-wide impact occurred. One exception is the trends of Sector 19 (Industrial Machinery and Equipment). The temporal indirect impacts to Sector 19 in Figure 4 are mostly negative values, except 1987 (year with a large positive spike), 1990 and 1991, 1993, and 1995. In general, the interindustry relationship between Sector 4 and Sector 19 is declining during 1980's and become steady during 1990's. This tendency is different from the interindustry relationship between Sector 4 and service sectors (Sectors 24, 27, and 30 in Figure 4)—declining during 1980's but increasing during 1990's. This may be another evidence of a hollowing-out process; however, the trends of the process seem different between 1980's and 1990's.

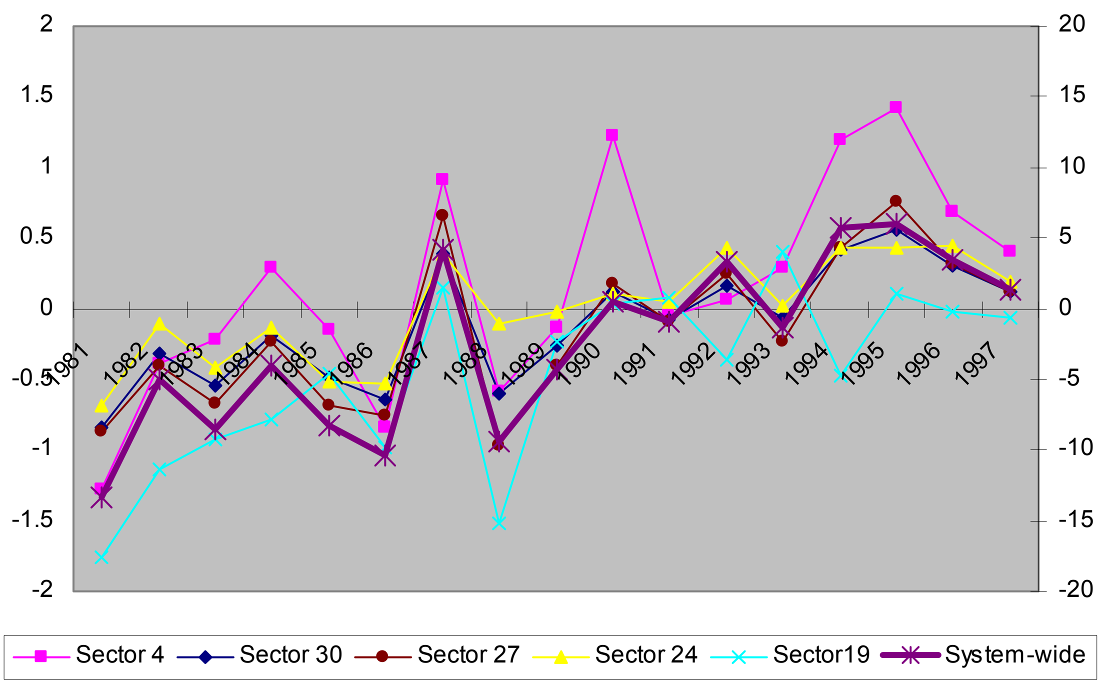

Figure 4. Trends in Temporal Impacts of the Demand Increase in Sector 4 (Left Axis for Sector Impact; and Right Axis for System-wide Impact)

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

Although further analyses of temporal impacts are necessary, the results in this paper indicate that the evidence of different types of contribution from temporal change exists. In this regard, the findings in this paper confirm the conclusions of previous studies, while the previous studies use actual transaction volume (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. What complement the results in this paper can offer is an analysis of temporal inverse by which relative changes in system-wide structure of an economy can be traced. It is obvious that each method and technique can analyze the different side of one phenomenon. Careful examination and comparison of the findings may provide further depth in understanding the structural change of an economy.

Over all, the analysis in this paper confirms the presence of a *hollowing-out* process in the Chicago economy. The manufacturing sectors have experienced sizable structural changes during the period of 1980-1997, while the service sectors have been rather stable and increasing relative significance in interindustry relationship.

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, there are some alternative formulations that share similar perspectives with the notion of temporal changes and can be used for a comparative analysis. As Okuyama *et al*. (2002b) indicated, an alternative way to exploit a time series of input-output tables draws on Markov properties:

$$\mathbf{A_t} = \mathbf{R_L A_{t-1}} \tag{14}$$

$$\mathbf{A_t} = \mathbf{A_{t-1} S_R} \tag{15}$$

Although these formulation utilizes a time series of direct input coefficient matrices, $\mathbf{A}$, rather than Leontief inverse matrices, $\mathbf{B} = (\mathbf{I} - \mathbf{A})^{-1}$, these formulations share the structure of left and right temporal multipliers in Section 2 of this paper. While Equations (14) and (15) are also analogous to RAS technique, employed in Okuyama *et al*. (2002b), this adoption of Markov adjustments would exploit a full matrix adjustment process. This type of analysis using Markov matrices is similar to the causative matrices of Jackson *et al*. (1990). Comparing and linking the findings from these three formulations may provide more comprehensive analysis of structural changes in an economy.

References

Campisi, Domenico. and Alberto Nastasi. (1993) "Capital Usage and Output Growth in Multiregional Multisectoral Models: An Application to the Italian Case," *Regional Studies*, 27 (1): 13-27.

Campisi, Domenico., Alberto Nastasi, and Agostino La Bella. (1992) "Balanced Growth and Stability of the Leontief Dynamic Model: An Analysis of the Italian Economy," *Environmental and Planning A*, 24 (4): 591-600.

Campisi, Domenico., Agostino La Bella, Massimo Gastaldi, Bruna Ludovici, and Gustav Schachter. (1990) "A Multi-Regional Multi-Sectoral Input-Output Model for Italy," in Luc Anselin and Moss Madden ed. *New Directions in Regional Analysis*, New York, NY: Belhaven Press, 187-210.

Carter, A.P. (1980) "Changes in Input-Output Structure Since 1972." *Interindustry Review* 1980: Summer.

Chenery, H.B. (1953) "Regional Analysis." in H.B. Chenery, P.G. Clark and V. Cao-Pinna eds. *The Structure and Growth of the Italian Economy*.

Chenery, H.B. and T. Watanabe. (1958) "International Comparisons of the Structure of Production." *Econometrica* 26:487-521.

Defourny, J. and E. Thorbecke. (1984) "Structural Path Analysis and Multiplier Decomposition within a Social Accounting Framework" *Economic Journal* 94: 111-36.

de Mesnard, Louis. (1992) "The Asynchronous Leontief Model," *Economic Systems Research*, 4 (1): 25-34.

Deutsch, J. and M. Syrquin. (1989) "Economic Development and the Structure of Production" *Economic Systems Research* 1: 447-64.

Duchin, Faye. and Daniel B. Szyld. (1985) "A Dynamic Input-Output Model with Assured Positive Output," *Metroeconomica*, 37 (3): 269-282.

Guangzhen, Sun. (1993) "Economic Impact of the Structural Changes of Production Technology: A Robust Approach," *Economic Systems Research*, 5 (3): 235-242

Harrigan, F., J.W. McGilvay and I. McNicoll. (1980) "A Comparison of Regional and National Technical Structures." *Economic Journal* 90: 795-810.

Heesterman, A.R.G. (1990) "The Instability of the Dynamic Input-Output Model," *Economic Systems Research*, 2 (4): 351-355.

Hewings, Geoffrey J.D., Michael Sonis, Jiemin Guo, Philip R. Israilevich, and Graham R. Schindler. 1998. "The Hollowing-out Process in the Chicago Economy, 1975-2015," *Geographical Analysis* , 30, 217-233.

Israilevich, Philip R., Geoffrey J.D. Hewings, Michael Sonis, and Graham R. Schindler. 1997. "Forecasting Structural Change with a Regional Econometric Input-Output Model," *Journal of Regional Science*, 37, 565-590.

Israilevich, Philip R., and R. Mahidhara (1991) "Hog Butchers No Longer: Twenty Years of Employment Change in Metropolitan Chicago." *Economic Perspectives* 15: 2-13.

Jackson, R., P. Rogerson, D. Plane, and O'hUallachain. 1990. "A Causative Matrix Approach to Interpreting Structural Change," *Economic Systems Research*, 2, 259-269.

Leontief, Wassily. (1953) "Dynamic Analysis," in W. Leontief, H.B. Chenery, P.G. Clark, J.S. Duesenberry, A.R. Ferguson, A.P. Grosse, R.N. Grosse, and M. Holzman ed. *Studies in the Structure of the American Economy: Theoretical and Empirical Explorations in Input-Output Analysis*. New York, NY: Oxford University Press.

Leontief, Wassily. (1970) "The Dynamic Inverse." in A. P. Carter and A. Brody eds. *Contributions to Input-Output Analysis*. Amsterdam, Netherlands: North-Holland Publishing; 17-46.

Leontief, Wassily. and Faye Duchin. (1986) *The Future Impact of Automation on Workers*, New York, NY: Oxford University Press.

Miernyk, W.H., K.L. Shellhammer, R.L. Coccari, W.H. Wineman, C.J. Gallagher, and D.M. Brown (1970) *Simulating Economic Development, Lexington*, MA: Lexington Books.

Okuyama, Yasuhide., Geoffrey J.D. Hewings, Michael Sonis, and Philip R. Israilevich (2002a) "Structural Changes in the Chicago Economy: A Field of Influence Analysis" in Geoffrey J.D. Hewings, Michael Sonis, and David Boyce eds. *Trade, Network and Hierarchies: Modeling Regional and Interregional Economies*, Berlin, Germany: Springer-Berlag; 201-224.

Okuyama, Yasuhide., Geoffrey J.D. Hewings, Michael Sonis, and Philip R. Israilevich (2002b) "An Econometric Analysis of Biproportional Properties in an Input-Output System," *Journal of Regional Science*, 42: (2), 361-388.

Pyatt, G. and J.I. Round. (1979) "Accounting and Fixed Price Multipliers in a Social Accounting Matrix Framework." *Economic Journal* 89: 850-73.

Round, J.I. (1985) "Decomposing Multipliers for Economic Systems Involving Regional and World Trade." *Economic Journal* 95: 383-99.

Round, J.I. (1988) "Incorporating the International, Regional and Spatial Dimension into a SAM: Some Methods and Applications." in F.J. Harrigan and P.G. McGregor eds. *Recent Advances in Regional Economic Modeling*, London: Pion.

Schinnar, Arie P. (1978) "The Leontief Generalized Inverse," *The Quarterly Journal of Economics*, 92 (4): 641-52

Sonis, Michael., and Geoffrey J.D. Hewings (1991) “Fields of Influence and Extended Input-Output Analysis: A Theoretical Account,” in John J.Ll. Dewhurst, Geoffrey J.D. Hewings, and Rodney C. Jensen eds. *Regional Input-Output Modeling: New Developments and Interpretations*, Aldershot, Avebury.

Sonis, Michael., and Geoffrey J.D. Hewings (1992) “Coefficient Changes in Input-Output Models: Theory and Applications,” *Economic Systems Research*, 4: 143-57.

Sonis, Michael. and Geoffrey J.D. Hewings (1998) “Temporal Leontief Inverse,” *Macroeconomic Dynamics*, 2, 89-114.

Steenge, Albert E. (1990a) "On the Complete Instability of Empirically Implemented Dynamic Leontief Models," *Economic Systems Research*, 2 (1): 3-16

Steenge, Albert E. (1990b) "Instability Problems in the Dynamic Leontief Model: an Economic Explanation," *Economic Systems Research*, 2 (4): 357-361.

Szyld, Daniel B. (1985) "Conditions for the Existence of a Balanced Growth Solution for the Leontief Dynamic Input-Output Model," *Econometrica*, 53 (6): 1411-1419.

Tiebout, C.M. (1969) “An Empirical Regional Input-Output Projection Model: the State of Washington, 1980,” *Review of Economics and Statistics*, 51, 334-340.

Zaghini, Enrico. (1971) "Solow Prices and the Dual Stability Paradox in the Leontief Dynamic System," *Econometrica*, 39 (3): 625-632.

Appendix

Sectoring Scheme in the CREIM Model

Sector	Title	SIC
1	Livestock, Livestock Products, and Agricultural Products	01, 02
2	Agriculture, Forestry, and Fisheries	07, 08, 09
3	Mining	10, 12, 13, 14
4	Construction	15, 16, 17
5	Food and Kindred Products	20
6	Tobacco	21
7	Apparel and Textile Products	22, 23
8	Lumber and Wood Products	24
9	Furniture and Fixtures	25
10	Paper and Allied Products	26
11	Printing and Publishing	27
12	Chemicals and Allied Products	28
13	Petroleum and Coal Products	29
14	Rubber and Misc. Plastics Products	30
15	Leather and Leather Products	31
16	Stone, Clay, and Glass Products	32
17	Primary Metals Industries	33
18	Fabricated Metal Products	34
19	Industrial Machinery and Equipment	35
20	Electronic and Electric Equipment	36
21	Transportation Equipment	37
22	Instruments and Related Products	38
23	Miscellaneous Manufacturing Industries	39
24	Railroad Transportation and Transportation Services	40-47
25	Communications	48
26	Electric, Gas, and Sanitary Services	49
27	Wholesale and Retail Trade	50-57, 59
28	Finance and Insurance	60-64, 66, 67
29	Real Estate	65
30	Lodging, Business, Engineering, Management, and Legal Services	70, 73, 81, 87, 89
31	Eating and Drinking Places	58
32	Auto Repair, Services, and Parking	75
33	Motion Pictures, and Amusement and Recreation Services	78, 79
34	Other Services (Health, Education, Social, etc.)	
35	Federal Government Enterprises	
36	State and Local Government Enterprises	