The Regional Economics Applications Laboratory (REAL) of the University of Illinois focuses on the development and use of analytical models for urban and regional economic development. The purpose of the **Discussion Papers** is to circulate intermediate and final results of this research among readers within and outside REAL. The opinions and conclusions expressed in the papers are those of the authors and do not necessarily represent official positions of the University of Illinois. All requests and comments should be directed to Geoffrey J. D. Hewings, Director, Regional Economics Applications Laboratory, 607 South Matthews, Urbana, IL, 61801-3671, phone (217) 333-4740, FAX (217) 244-9339.
Web page: www.uiuc.edu/unit/real

Typology of Structural Change in a Regional Economy: A Temporal Inverse Analysis

by

Yasuhide Okuyama, Michael Sonis
And Geoffrey J. D. Hewings

REAL 04-T-12 October, 2004

Typology of Structural Change in a Regional Economy: A Temporal Inverse Analysis[1]

Yasuhide Okuyama

Regional Research Institute, West Virginia University, 511 N. High Street Morgantown, WV 26506-6825, USA

Michael Sonis

Regional Economics Applications Laboratory, University of Illinois, Urbana, IL 61801-3671, USA, and Bar Ilan University, Israel

Geoffrey J.D. Hewings

Regional Economics Applications Laboratory, University of Illinois, Urbana, IL 61801-3671, USA

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), which 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

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

[1] The earlier version of this paper was presented in the 14th International Conference on Input-Output Techniques (2002), the 40th Annual Conference of the Japan Section of Regional Science Association International (2003), the 3rd Meetings of Brazilian Regional Studies (2004), the 41st annual meetings of the Japan Section of Regional Science Association International (2004), and the authors are grateful for the comments by the participants in these conferences.

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 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. 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 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 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 patters (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 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 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. Tiebout's approach involved 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 Tiebout's idea was ingenious, his method suffers most from a dearth of comparative data.

A dynamic version of the input-output model was first introduced by Leontief (1953) and was refined in 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:

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

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:

$$\begin{bmatrix} \mathbf{x}_{-m} \\ \vdots \\ \mathbf{x}_{-2} \\ \mathbf{x}_{-1} \\ \mathbf{x}_0 \end{bmatrix} = \begin{bmatrix} \mathbf{G}_{-m}^{-1} \cdots \mathbf{R}_{-m} \cdots \mathbf{R}_{-3}\mathbf{R}_{-2}\mathbf{G}_{-1}^{-1} & \mathbf{R}_{-m} \cdots \mathbf{R}_{-3}\mathbf{R}_{-2}\mathbf{R}_{-1}\mathbf{G}_0^{-1} \\ \vdots & \vdots \\ \mathbf{R}_{-2}\mathbf{G}_{-1}^{-1} & \mathbf{R}_{-2}\mathbf{R}_{-1}\mathbf{G}_0^{-1} \\ \mathbf{G}_{-1}^{-1} & \mathbf{R}_{-1}\mathbf{G}_0^{-1} \\ & \mathbf{G}_0 \end{bmatrix} \begin{bmatrix} \mathbf{f}_{-m} \\ \vdots \\ \mathbf{f}_{-2} \\ \mathbf{f}_{-1} \\ \mathbf{f}_0 \end{bmatrix} \tag{3}$$

where $\mathbf{R}_t = \mathbf{G}_t^{-1}\mathbf{C}_{t+1} = \left(\mathbf{I} - \mathbf{A}_t + \mathbf{C}_{t+1}\right)^{-1} \mathbf{C}_{t+1}$.

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 secondly, the model could produce implausible results due to its structure.[2]

Using a different approach to introduce a dynamic structure in the static input-output framework, a group of lagged input-output models with distributed activities were proposed. Concerning the time used in the production process and taking into account the time of labor market adjustment, among other things, these lagged input-output models aim to capture the process of impact (or growth) from a production expansion within the input-output framework. The distributed activity model developed by ten Raa (1986) is based on the formulation of the Leontief's dynamic input-output model, solving some of the drawbacks in that framework, such as singular capital structures, unbalanced growth, and different time profiles of investment, while preserving the formal structure and simplicity of the original Leontief dynamic model. ten Raa's

[2] 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.

model is highly theoretical and aggregated, and few empirical applications and analyses based on his formulation have been implemented. Cole's lagged-activity models (Cole, 1988 and 1989) are highly operational and are modeled on the empirical examples of western New York and of Aruba. While Cole's approach is highly practical for simulation-type analysis, in order for it to be used for detailed analysis of structural change, some theoretical and modeling issues of the framework need to be further addressed.[3] A similar approach to these lagged models but with more emphasis on production chronology, Romanoff and Levine (Levine and Romanoff, 1989; Romanoff, 1984; and, Romanoff and Levine, 1977, 1981, 1986, 1990a, 1990b, 1991, and 1993) introduced the Sequential Interindustry Model (SIM) in order to incorporate a more engineering-based flavor to the modeling of the production process, such as large construction projects where the effects on production and employment are transitory. In the SIM, production is not simultaneous as in the static input-output model, but rather occurs sequentially over a period of time, with production processes categorized as either anticipatory or responsive production modes, depending on the response to the stream of demand stimuli. These dynamic frameworks on input-output system tend to place greater emphasis on the modeling aspect of structural change, rather than on the analysis of structural change per se.

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, $\mathbf{A_0}$, $\mathbf{A_1}$,…, $\mathbf{A_t}$, $\mathbf{A_{t+1}}$,…, 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 described in (3). A framework of the temporal Leontief inverse can be shown in the following manner. Consider a sequence of time period, t_0, t_1,…, 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 the 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:

[3] Extensive discussions were made regarding the theoretical underpinning and the formulation of Cole's models in Jackson *et al*. (1997), Cole (1997), Jackson and Madden (1999), Cole (1999), and Oosterhaven (2000).

$$\begin{aligned} \mathbf{A}_s &= \mathbf{A}_{s-1} + \mathbf{E}_s = \mathbf{A}_0 + \mathbf{E}_1 + \mathbf{E}_2 + \cdots + \mathbf{E}_s \\ \mathbf{B}_s &= \left(\mathbf{I} - \mathbf{A}_{s-1} - \mathbf{E}_s\right)^{-1} = \left(\mathbf{I} - \mathbf{A}_0 - \mathbf{E}_1 - \mathbf{E}_2 - \cdots - \mathbf{E}_s\right)^{-1} \end{aligned} \tag{4}$$

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

$$\begin{aligned} \mathbf{B}_s &= \left(\mathbf{I} - \mathbf{A}_{s-1} - \mathbf{E}_s\right)^{-1} = \left[\left(\mathbf{I} - \mathbf{A}_{s-1}\right)\left(\mathbf{I} - \mathbf{B}_{s-1}\mathbf{E}_s\right)\right]^{-1} = \left(\mathbf{I} - \mathbf{B}_{s-1}\mathbf{E}_s\right)^{-1}\mathbf{B}_{s-1} \\ \mathbf{B}_s &= \left(\mathbf{I} - \mathbf{A}_{s-1} - \mathbf{E}_s\right)^{-1} = \left[\left(\mathbf{I} - \mathbf{E}_s\mathbf{B}_{s-1}\right)\left(\mathbf{I} - \mathbf{A}_{s-1}\right)\right]^{-1} = \mathbf{B}_{s-1}\left(\mathbf{I} - \mathbf{E}_s\mathbf{B}_{s-1}\right)^{-1} \end{aligned} \tag{5}$$

The matrices, $\mathbf{M}_L^s = \left(\mathbf{I} - \mathbf{B}_{s-1}\mathbf{E}_s\right)^{-1}$ and $\mathbf{M}_R^s = \left(\mathbf{I} - \mathbf{E}_s\mathbf{B}_{s-1}\right)^{-1}$, are called the *left* and *right* temporal multipliers. Obviously:

$$\mathbf{B}_s = \mathbf{M}_L^s\mathbf{B}_{s-1} = \mathbf{B}_{s-1}\mathbf{M}_R^s; \mathbf{M}_L^s = \mathbf{B}_s\left(\mathbf{I} - \mathbf{A}_{s-1}\right); \mathbf{M}_R^s = \left(\mathbf{I} - \mathbf{A}_{s-1}\right)\mathbf{B}_s \tag{6}$$

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

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

The multiplicative representation, model (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:

$$\begin{aligned}\mathbf{B_s} &= \mathbf{B_{s\text{-}1}} + \mathbf{D_s} \\ &= \mathbf{B_{s\text{-}2}} + \mathbf{D_{s\text{-}1}} + \mathbf{D_s} \\ &\vdots \\ &= \mathbf{B_1} + \mathbf{D_2} + \cdots + \mathbf{D_{s\text{-}1}} + \mathbf{D_s} \\ &= \mathbf{B_0} + \mathbf{D_1} + \mathbf{D_2} + \cdots + \mathbf{D_{s\text{-}1}} + \mathbf{D_s}\end{aligned} \tag{10}$$

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

$$\begin{aligned}\mathbf{B_s} &= \underbrace{\mathbf{I} + (\mathbf{B_0} - \mathbf{I})} + (\mathbf{M_L^1} - \mathbf{I})\mathbf{B_0} + (\mathbf{M_L^2} - \mathbf{I})\mathbf{M_L^1}\mathbf{B_0} + \ldots + (\mathbf{M_L^s} - \mathbf{I})\mathbf{M_L^{s\text{-}1}} \cdots \mathbf{M_L^2}\mathbf{M_L^1}\mathbf{B_0} \\ &= \underbrace{\mathbf{B_0} + (\mathbf{M_L^1} - \mathbf{I})\mathbf{B_0}} + (\mathbf{M_L^2} - \mathbf{I})\mathbf{M_L^1}\mathbf{B_0} + \ldots + (\mathbf{M_L^s} - \mathbf{I})\mathbf{M_L^{s\text{-}1}} \cdots \mathbf{M_L^2}\mathbf{M_L^1}\mathbf{B_0} \\ &= \underbrace{\mathbf{B_1} + (\mathbf{M_L^2} - \mathbf{I})\mathbf{M_L^1}\mathbf{B_0}} + \ldots + (\mathbf{M_L^s} - \mathbf{I})\mathbf{M_L^{s\text{-}1}} \cdots \mathbf{M_L^2}\mathbf{M_L^1}\mathbf{B_0} \\ &= \vdots \\ &= \mathbf{B_{s\text{-}1}} + (\mathbf{M_L^s} - \mathbf{I})\mathbf{M_L^{s\text{-}1}} \cdots \mathbf{M_L^2}\mathbf{M_L^1}\mathbf{B_0}\end{aligned} \tag{11}$$

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 $\mathbf{x_s} = \mathbf{B_s}\mathbf{f_s}$, 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 (11), as follows:

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

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, $\left(\mathbf{M}_L^1 - \mathbf{I}\right)\mathbf{B}_0\mathbf{f}_s$, the changes (or deviations from the first period) in indirect impact at the second time period, $\left(\mathbf{M}_L^2 - \mathbf{I}\right)\mathbf{M}_L^1\mathbf{B}_0\mathbf{f}_s$, 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.[4] This system of 250 equations includes both exogenous and endogenous variables. Endogenous coefficient change serves as the mechanism to clear markets in a 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 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 explores 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

[4] In this version of CREIM, the price is fixed at 1987 million dollars.

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 technique. Assessing the time series of direct input coefficient matrices, $\mathbf{A_t}$, 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 quantity of output tend to show greater variance over time whereas sectors with large quantity of output seem to have larger number of r_i values, which 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 evidence of substitution, not across sectors, but in the location of purchases, since the extracted Chicago input-output tables are regional tables. 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 (as seen in direct input coefficient, a_{ij}, and Leontief inverse coefficient, b_{ij}) have declining trends, implying that their interindustry relationship within the Chicago region are weakening. In summary, they claimed that, while the evidence of the hollowing-out process in the Chicago economy is found, the general trends of bi-proportional properties, based on 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*[5], Okuyama *et al*. (2002a) investigated the structural changes of the Chicago economy with the same set of input-output

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

tables. They found that the Chicago economy exhibits little changes in appearance by 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, 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 further evidence of the presence of a *hollowing-out* process in the Chicago economy.

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, $\mathbf{B}_t$, instead of direct input coefficient matrices, $\mathbf{A}_t$, 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. 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 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.

<<Insert figure 1 here>>

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:

$$\begin{aligned}\mathbf{\Delta x_s} &= \mathbf{B_s \Delta f_s} \\ &= \mathbf{\Delta f_s} + \\ &+ \left(\mathbf{B_0} - \mathbf{I}\right)\mathbf{\Delta f_s} + \\ &+ \mathbf{D_1 \Delta f_s} + \\ &+ \mathbf{D_2 \Delta f_s} + \\ &\vdots \\ &+ \mathbf{D_s \Delta f_s}\end{aligned} \qquad (13)$$

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. Three sectors are chosen to investigate the characteristics of structural change and the evidence of hollowing-out. First, final demand for Sector 27 (Wholesale and Retail Trade; having the largest output and second largest final demand sector throughout the period) is increased $100 million (1987 dollars). Figure 2[6] depicts the trends of temporal indirect impact from the demand increase on the five aggregated sectors (Resources [sectors 1-3]; Construction [sector 4]; Manufacturing (Non-Durable) [sectors 5-15]; Manufacturing (Durable) [sectors 16-23]; and Services [sectors 24-36]) and of the system-wide impact. The system-wide temporal impact has, on average, an upward trend, indicating increasing interindustry relationships between Sector 27 and the entire system, with the negative values throughout the 1980s (with an exception of 1987) and positive values during most of the 1990s. This upward trend appears to characterize each aggregated sector, except the Resource sector which has a flat trend around the value of zero (meaning little change from the previous year). The most notable changes in value can be found with Manufacturing (Durable) sector, which has large negative values in the early 1980s, significant upward shift in the late 1980s, and the steady positive values during the 1990s.

<<*Insert figure 2 here*>>

In order to investigate the relative changes from the initial year (1980) as the erosion of production lost (or the intensification of production gained), each year's temporal indirect impact is integrated (accumulated) from the 1981 value. And, the trends are shown in figure 3. The system wide trends display the initial erosion of production loss during the 1980s, corresponding to the negative values during the same period in figure 2. Then, the trends become flatter in the early 1990s with moderate increasing trends after 1993, regaining the values to some extent. This also reflects the positive values after 1993 in figure 2. The trends of the aggregated sectors, by and large, mirror the trends of the system-wide values. Both manufacturing sectors (non-durable and durable aggregated sectors) exhibit the steady decrease in the 1980s and the flattened trends in the 1990s without having any notable increase in the late 1990s. In sum, Sector 27

---

[6] Direct impact, $\Delta\mathbf{f_s}$, and the base year (1980) indirect impact, $\left(\mathbf{B_0} - \mathbf{I}\right)\Delta\mathbf{f_s}$, are not included in this and following figures in order to emphasize temporal changes between 1981 and 1997.

appears to have gone through some structural changes, with the growing trends with Construction and Services sectors and the moderately decreasing trends with both Manufacturing sectors.

<<Insert figure 3 here>>

Another feature of the 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 and 1997 was ranked 6th over all and is ranked first among manufacturing sectors. Figure 4 shows the trends of the temporal indirect impacts to the entire system and to the aggregated sectors. In contrast to the previous case (figure 2), most of temporal indirect impacts in figure 4 have negative values, except some small positive values in 1984, 1987, 1994, 1995, and 1997 for most of the sectors, indicating steady trends of weakening interindustry relationship relative to the previous year. The general trends over the period can be considered as slightly upward, but it is clearly flatter than the one in figure 2. In addition, the system-wide temporal impacts have more fluctuations, wider variance, than for Sector 27. Manufacturing (Durable) sector, in which Sector 19 is, has the largest negative values than other aggregated sectors in most years and stay negative, except only in a few years, while Sector 19's output appears to be increasing, especially from 1983 to 1994 (figure 1). These findings suggest that the hollowing-out process has been transforming the manufacturing sectors in Chicago to become more dependent on interregional trade.

<<Insert figure 4 here>>

Figure 5 shows the trends of accumulated temporal changes of Sector 19, as in figure 3 for Sector 27. During the 1980s, the trends of system-wide trends indicate a steady decrease throughout the 1980s and continued until 1993, with a flattening after that point. The degree of decrease (erosion) in this sector has been much more severe than in the previous case (Sector 27), indicating the considerable decline in interindustry relationship between Sector 19 and the system as a whole. This observation also reflects the trends that the values of temporal indirect impacts are mostly negative for this sector, as shown in figure 4. In addition, the recovery trends in the late 1990s observed for Sector 27 do not appear for Sector 19. As for the trends of the aggregated sectors, both Manufacturing (Durable) and Services sectors exhibit steady decline, while other aggregated sectors (Resources, Construction, and Manufacturing (Non-Durable)) show less significant changes. Together with the observation in figure 1, in which the trends of Sector 19's output indicate moderate but steady increases, this result documents clearer evidence of the hollowing-out process in this particular sector with in the Chicago economy. While the output of a sector increases, the intermediate transactions within the region decrease as a result of interregional competition.

<<Insert figure 5 here>>

Hewings *et al*. (1998) found that Construction (sector 4) in the Chicago economy exhibits significant changes in the hierarchy of backward and forward linkages (pages 226-227), based on their 9-sector model. In order to investigate the temporal changes of interindustry relationships with Construction sector, the temporal indirect impacts are calculated using a $100 million increase of final demand in 1997. Figure 6 displays the trends in temporal indirect impacts of system-wide and five aggregated sectors. The general trends of temporal indirect impacts look more like the ones of Sector 27 (figure 2) than the one of Sector 19 (figure 4): the trends of the system-wide impact and of the five aggregated sectors exhibit a slight upward trend, flatter than of Sector 27 but steeper than of Sector 19, while the trends here tend downward during 1996 and 1997. As with the previous two cases, Manufacturing (Durable) has the lowest values throughout the 1980s, but the trend turns to a steady increase after 1989 until 1996. Other aggregated sectors have the very similar trends to the ones of Sector 27, except, again, with the downward trend during 1996 and 1997.

<<Insert figure 6 here>>

Figure 7 displays the trends of accumulated temporal impacts for Sector 4, as in Figures 3 and 5. The trends of the system-wide accumulated temporal impacts appear very similar to the ones of Sector 27 (figure 3); the declining trend during the 1980s and the early 1990s and the regaining trend after 1993. The trends of five aggregated sectors also mirror the ones of Sector 27, while the trends of Manufacturing (Durable) have a steeper decline than the ones in figure 3, indicating severe erosion of interindustry relationship between the Construction sector and the

Manufacturing (Durable) sector. Considering the output trends of the Construction sector in figure 1 and Construction sector's output is strictly local, this observation also suggests the hollowing-out process in which Construction sector has come to rely more on the interregional trade for intermediate inputs and less on local purchases.

<<Insert figure 7 here>>

Typology of Trends of Accumulated Temporal Impact

Based on the findings of the previous studies (Hewings *et al.* 1998; 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.

<<Insert table 1 here>>

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

<u>Tilted L (TL):</u> 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 5 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.

<u>Flattened U (FU):</u> 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 regaining 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.

<u>Flat (F):</u> 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 8 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.

<<*Insert figure 8 here*>>

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 9 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 at 1992 and afterwards. 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 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.

<<*Insert figure 9 here*>>

In order to investigate whether there is any relationship between this typology of sectors and the growth rate of sectoral output and/or the changes in rank, the comparison between the type and the growth and rank trends across sectors during the period of 1980-1997 is made in table 2. For Tilted L (TL) type, the growth rates of sectoral output in this type vary considerably, from negative growth (-38% in sector 21) to strong increase (102% in sector 14), and the distribution appears to be dispersed without having a clear center. The change in their ranks is either almost no change (sectors 5, 7, 8, 10, 19, 22, 25) or decline (sectors 17, 20, 21, 23), except sector 14 with a slight gain. Flattered U (FU) type also exhibits a similar pattern: their output growth rates vary in a wide range, from -21% (sector 1) to 108% (sector 2); however, the distribution of the growth rates tend more towards positive value, although the shape of distribution remains flat without any clear center with high frequency. The rank in this type is almost unchanged for most of the sectors, except sector 9 (slight decline) and sectors 12, 16, 33 (gain). Flat (F) type also has a wide spread distribution of growth rate, ranging from -48% (sector 3) to 100% (sector 32). In contrast with the FU type, the distribution of growth rate for F type is rather skewed to the negative side—4 out of 7 sectors have negative values. The change in ranks in this type shows a wider variety of trends—significant decline (sectors 3, 13, 26) and significant gain (sector 32). The sectors in TL and F are relatively small in size (with small output share); thus, their trends may be more volatile than the sectors in other type (Okuyama *et al.*, 2002b). On the other hand, the sectors in Tilted J (TJ) type appear more stable or increasing in terms of their growth trends and the changes in rank. Their growth rates are all positive values and relatively large, and the changes in rank are all gain. These observations suggest that the hollowing-out process in the Chicago economy is very complex; using only the trends of output growth rate and of rank to classify which sector is gaining (or losing) with in the regional economy may be misleading. For example, sector 14 increased its output by 104% during 1980-1997, but the trend of interindustry dependence is declined as classified in TL. At the same time, sector 34 increased its output moderately, by 50%, while it also increased the interindustry relationship within the Chicago economy over the period, as classified in TJ. It is clear that the results from temporal Leontief inverse analysis can provide additional and more detailed information of the hollowing-out process.

<<Insert table 2 here>>

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 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. The typology of sectors created in this study provides a more detailed view of the hollowing-out process in Chicago, illustrating complex yet clearly divided trends of the structural change among sectors. 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 done for more robust investigation of the differences in structural change of an economy.

References

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.

Cole, Sam. (1988) "The Delayed Impacts of Plant Closures in a Reformulated Leontief Model." Papers in Regional Science Association. 65: 135-149.

Cole, Sam. (1989) "Expenditure Lags in Impacts Analysis." Regional Studies. 23 (2): 105-116.

Cole, Sam. (1997) "Closure in Cole's Reformulated Leontief Model: A Response to R.W. Jackson, M. Madden, and H.A. Bowma," Papers in Regional Science. 76 (1): 29-42.

Cole, Sam. (1999) "The Phantom of the Matrix: Inverting the Case on Closure in Cole's Model," Papers in Regional Science. 78 (4): 429-436.

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

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

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

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.

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

Jackson, Randall W., and Moss Madden. (1999) "Closing the Case on Closure in Cole's Model," Papers in Regional Science. 78 (4): 423-427.

Jackson, Randall W., Moss Madden, and Harry A. Bowman. (1997) "Closure in Cole's Reformulated Leontief Model," Papers in Regional Science. 76 (1): 21-28.

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.

Levine, Stephen H., and Eliahu Romanoff. (1989) "Economic Impacy Dynamics of Complex Engineering Project Scheduling, " IEEE Transactions Systems, Man and Cybernetics. 19: 232-240.

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.

Oosterhaven, Jan. (2000) "Lessens from the Debate on Cole's Model Closure," Papers in Regional Science. 79 (2): 233-242.

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

Romanoff, Eliahu. (1984) "Interindustry Analysis for Regional Growth and Development: The Dynamics of Manpower Issues." Socio-Economic Planning Sciences 18 (5): 353-363.

Romanoff, Eliahu., and Stephen H. Levine. (1977) "Interregional Sequential Interindustry Modeling: A Preliminary Analysis of Regional Growth and Decline in a Two Region Case," Northeast Regional Science Review. 7: 87-101.

Romanoff, Eliahu., and Stephen H. Levine. (1981) "Anticipatory and Responsive Sequential Interindustry Models" IEEE Transactions on Systems, Man, and Cybernetics SMC 11 (3): 181-186.

Romanoff, Eliahu., and Stephen H. Levine. (1986) "Capacity Limitations, Inventory, and Time-Phased Production in the Sequential Interindustry Model." Papers of the Regional Science Association 59; 73-91.

Romanoff, Eliahu., and Stephen H. Levine. (1990a) "Combined Regional Impact Dynamics of Several Construction Megaprojects," Regional Science Review. 17: 85-93.

Romanoff, Eliahu., and Stephen H. Levine. (1990b) "Technical Change in Production Processes of the Sequential Interindustry Model." Metroeconomica 41 (1): 1-18.

Romanoff, Eliahu., and Stephen H. Levine. (1991) "Technical Change and Regional Development: Some Further Developments with the Sequential Interindustry Model," in David E. Boyce, Peter Nijkamp, and D. Shafer eds. Regional Science: Retrospect and Prospect. Berlin: Springer-Verlag: 251-275.

Romanoff, Eliahu., and Stephen H. Levine. (1993) "Information, Interindustry Dynamics, and the Service Industries" Environmental and Planning A 25: 305-316.

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 (1998) “Temporal Leontief Inverse,” *Macroeconomic Dynamics*, 2, 89-114.

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.

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.

ten Raa, Thijs. (1986) “Dynamic Input-Output Analysis with Distributed Activities.” Review of Economics and Statistics. 68 (2): 300-310.

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	

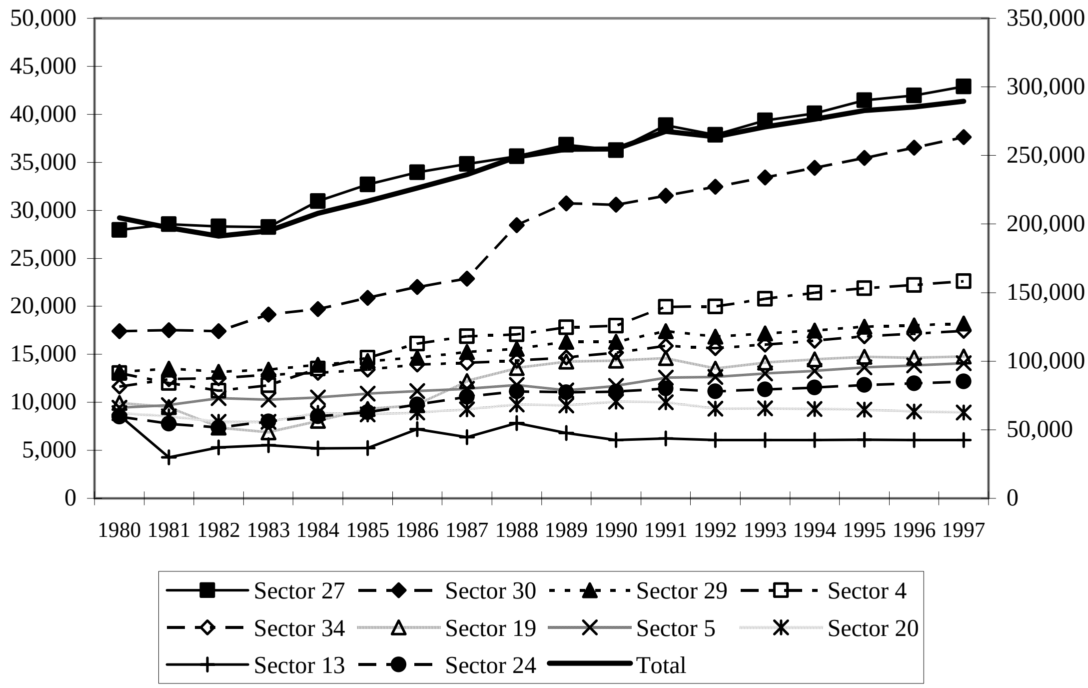

Figure 1. Changes in Total and Sector Outputs (Left Axis for Sector Output; and Right Axis for Total Output; $ 1987 million)

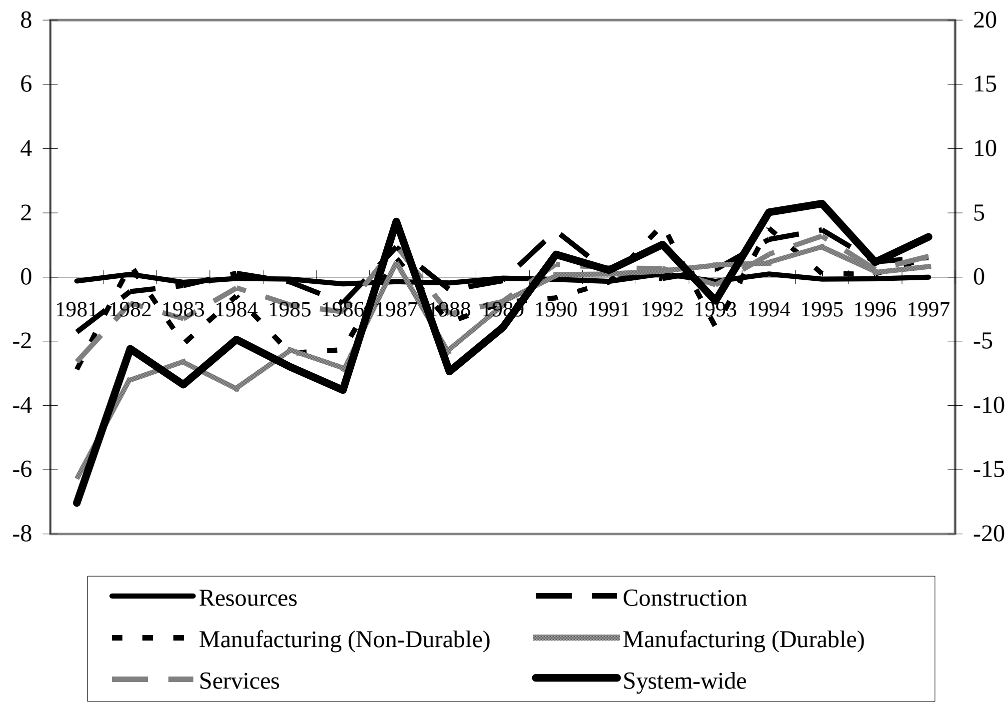

Figure 2. Trends of Temporal Impact of the Demand Increase in Sector 27 (Left Axis for Sector Impact; and Right Axis for System-wide Impact)

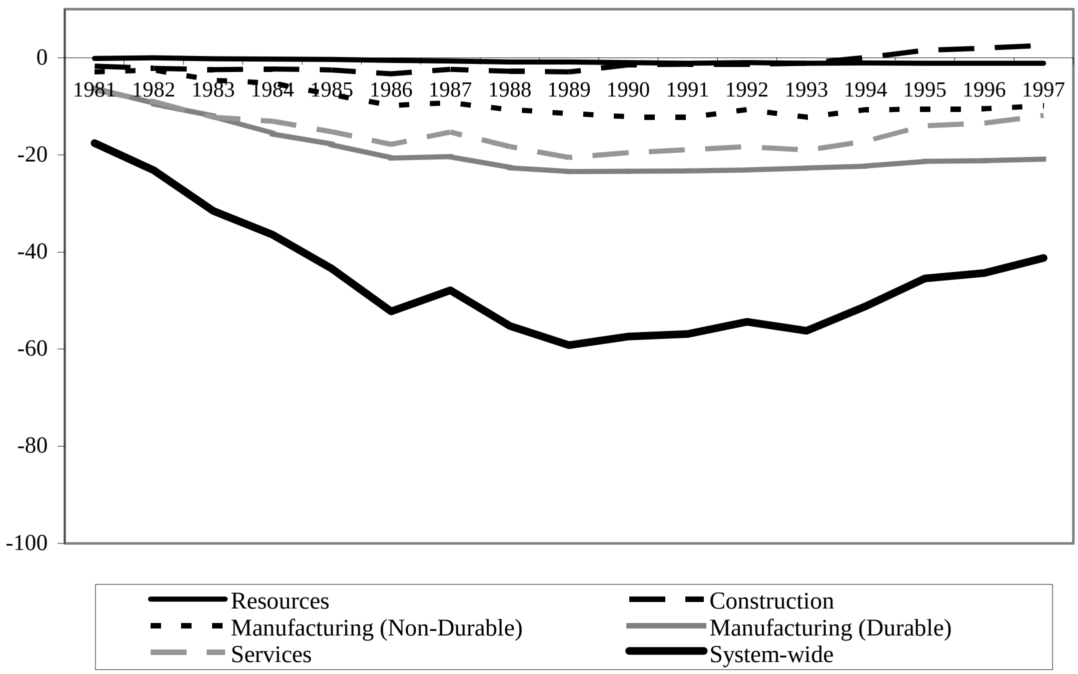

Figure 3. Trends in Accumulated Temporal Impacts of the Demand Increase in Sector 27

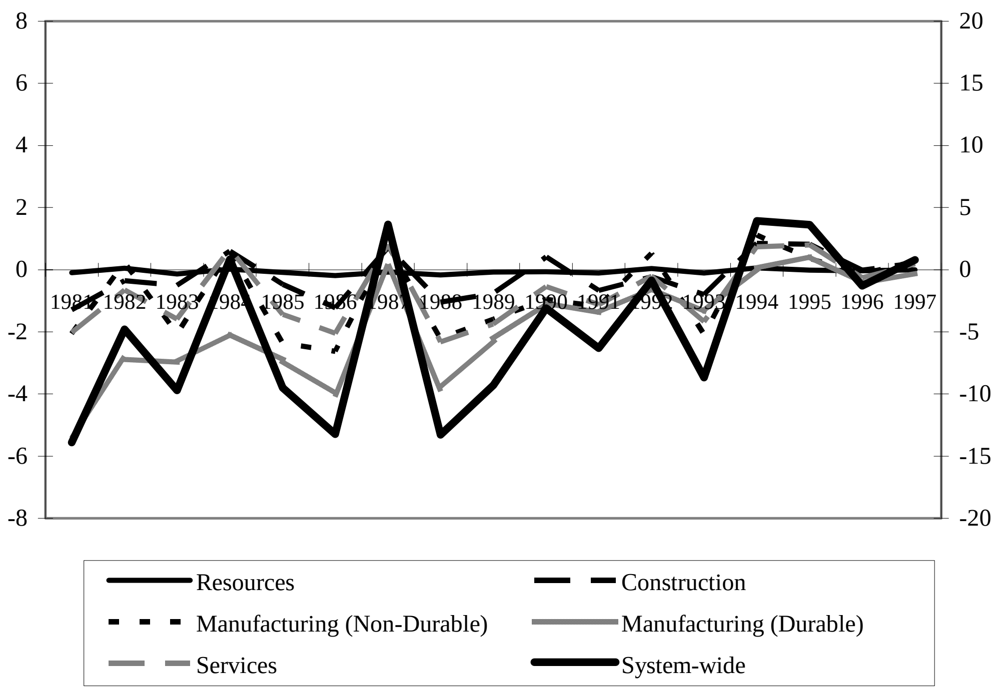

Figure 4. Trends of Temporal Impact of the Demand Increase in Sector 19 (Left Axis for Sector Impact; and Right Axis for System-wide Impact)

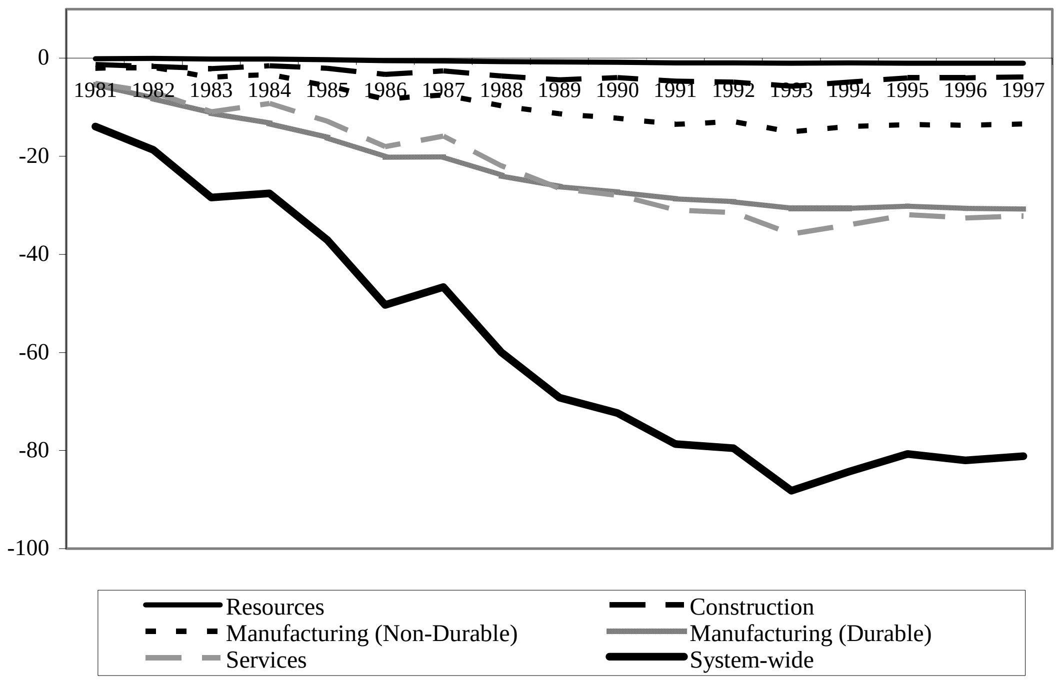

Figure 5. Trends in Accumulated Temporal Impacts of the Demand Increase in Sector 19

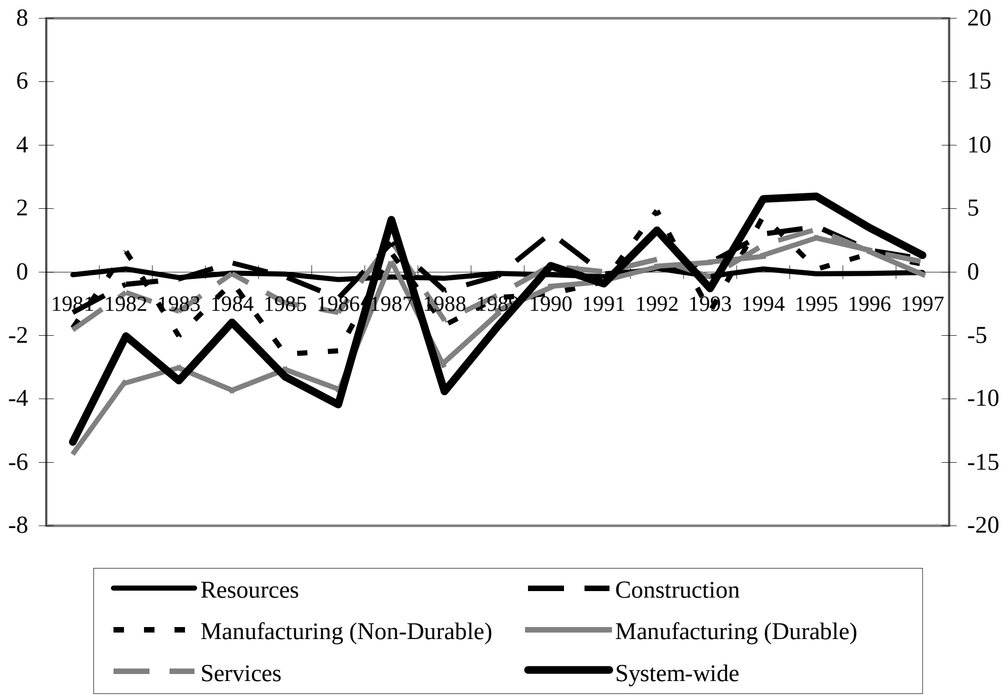

Figure 6. Trends of Temporal Impacts of the Demand Increase in Sector 4 (Left Axis for Sector Impact; and Right Axis for System-wide Impact)

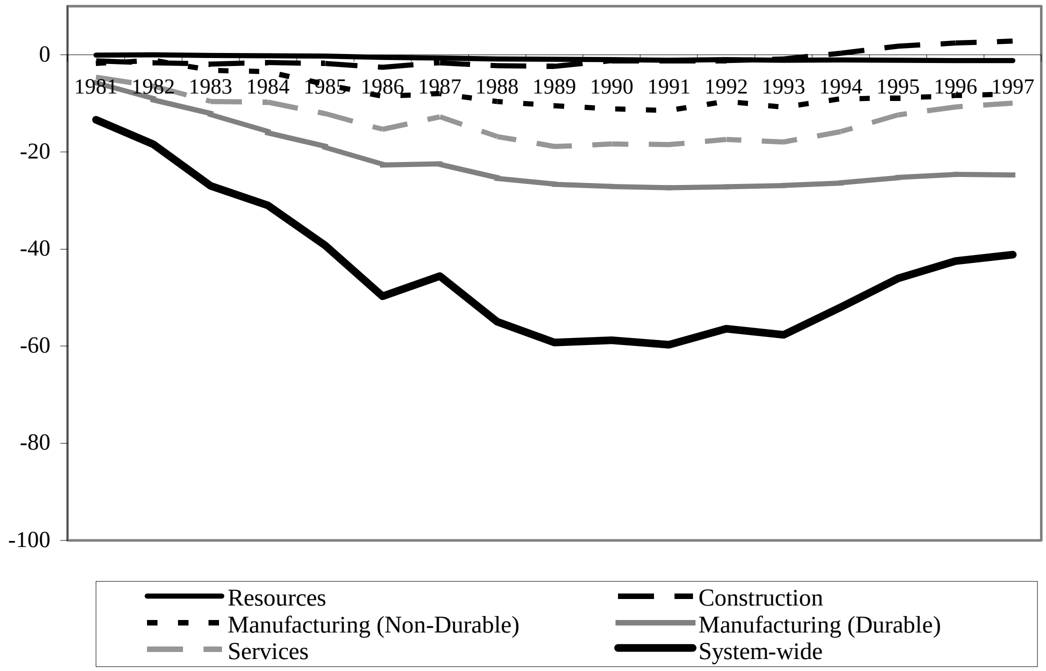

Figure 7. Trends in Accumulated Temporal Impacts of the Demand Increase in Sector 4

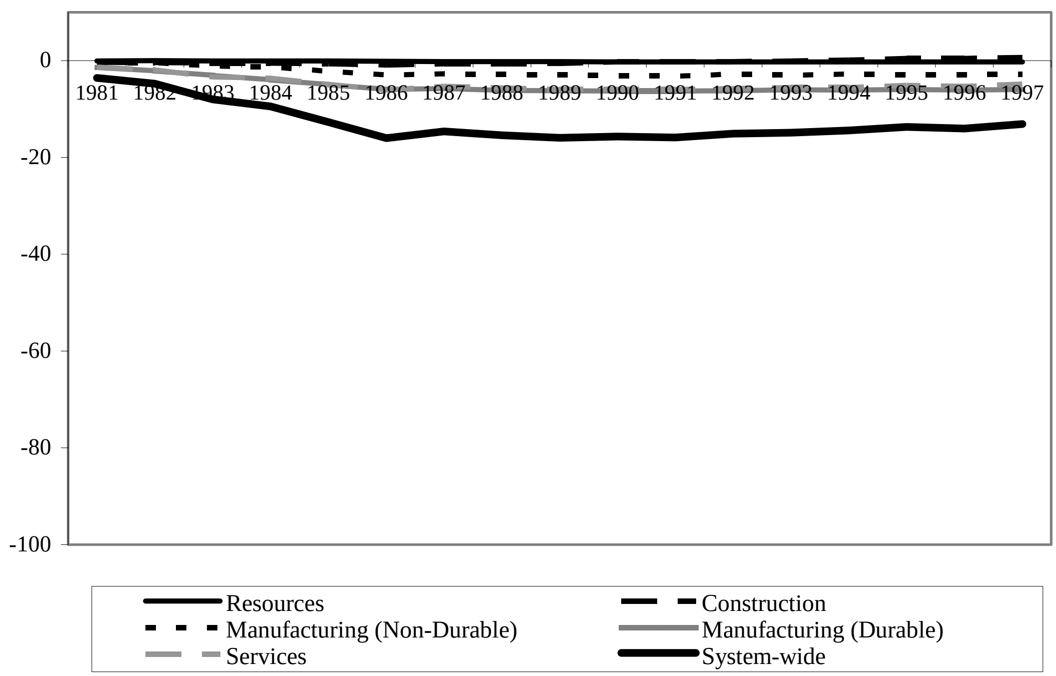

Figure 8. Shape of Flat Type – Sector 29

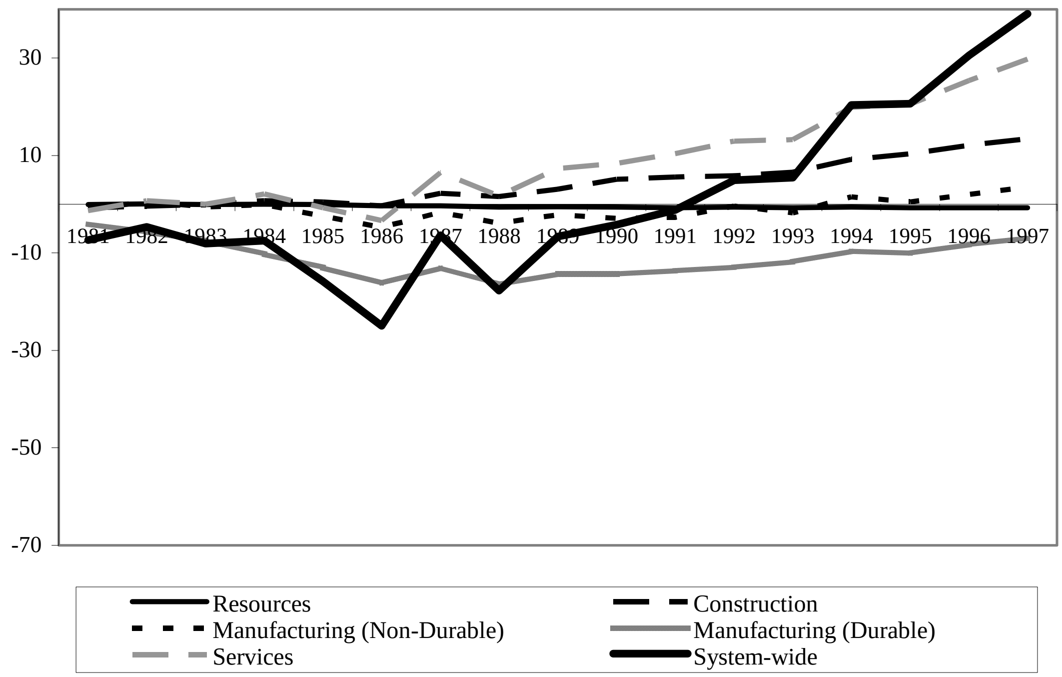

Figure 9. Shape of Tilted J Type – Sector 28

Table 1. Typology of Trends of Temporal Impact (System-wide Impact)

Aggregated Sector	Sector No.		Aggregated Sector	Sector No.	
Resources	1	Agricultural Products	Manufacturing (Durable)	19	Industrial Machinery and Equipment
	2	Agriculture, Forestry, and Fisheries		20	Electronic and Electric Equipment
	3	Mining		21	Transportation Equipment
Construction	4	Construction		22	Instruments and Related Products
Manufacturing (Non-Durable)	5	Food and Kindred Products		23	Miscellaneous Manufacturing
	6	Tobacco	Services	24	Transportation Services
	7	Apparel and Textile Products		25	Communications
	8	Lumber and Wood Products		26	Electric, Gas, and Sanitary Services
	9	Furniture and Fixtures		27	Wholesale and Retail Trade
	10	Paper and Allied Products		28	Finance and Insurance
	11	Printing and Publishing		29	Real Estate
	12	Chemicals and Allied Products		30	Lodging, Business, Engineering, Management, and Legal Services
	13	Petroleum and Coal Products		31	Eating and Drinking Places
	14	Rubber and Misc. Plastics Products		32	Auto Repair, Services, and Parking
	15	Leather and Leather Products		33	Entertainment
Manufacturing (Durable)	16	Stone, Clay, and Glass Products		34	Other Services (Health, Education, Social, etc.)
	17	Primary Metals Industries		35	Federal Government Enterprises
	18	Fabricated Metal Products		36	State and Local Government Enterprises

Tilted L (TL)
Flattened U (FU)
Flat (F)
Tilted J (TJ)

Table 2. Comparison of Growth Trends and Types across Sectors

Sector	Growth Rate of Total Output (1980-1997)	Rank of Sectoral Output in 1980	Rank of Sectoral Output in 1997	Output Share in 1997	Type
1	-21%	34	35	0.09%	FU
2	108%	33	33	0.25%	FU
3	-48%	21	28	0.49%	F
4	74%	4	3	7.81%	FU
5	49%	7	7	4.86%	TL
6	-2%	36	36	0.05%	F
7	32%	30	30	0.40%	TL
8	74%	32	32	0.33%	TL
9	-23%	27	31	0.38%	FU
10	26%	22	22	1.11%	TL
11	16%	15	13	2.42%	F
12	71%	14	10	3.73%	FU
13	-30%	9	15	2.10%	F
14	102%	23	19	1.52%	TL
15	27%	35	34	0.09%	FU
16	55%	28	24	0.72%	FU
17	-37%	16	21	1.14%	TL
18	5%	11	12	2.81%	FU
19	49%	6	6	5.11%	TL
20	1%	8	11	3.08%	TL
21	-38%	17	23	1.09%	TL
22	85%	20	18	1.85%	TL
23	-3%	24	27	0.56%	TL
24	43%	10	9	4.20%	FU
25	58%	19	17	2.05%	TL
26	-21%	12	16	2.09%	F
27	53%	1	1	14.81%	FU
28	76%	13	8	4.38%	TJ
29	38%	3	4	6.29%	F
30	116%	2	2	12.99%	TJ
31	50%	18	14	2.30%	TJ
32	100%	25	20	1.15%	F
33	52%	29	26	0.66%	FU
34	50%	5	5	6.02%	TJ
35	37%	31	29	0.40%	TJ
36	22%	26	25	0.66%	FU