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A Miyazawa analysis of interactions between polluting and non-polluting sectors

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Abstract

Interactions between a set of polluting and non-polluting sectors are analyzed using a form of decomposition analysis first proposed by Miyazawa and subsequently modified by Sonis and Hewings. The analysis is applied to a time series set of input–output tables for the Chicago region in an attempt to generate assessments of the internal and external multipliers and their changes over time. The results revealed the important role that structural change will play in determining pollution levels in the region in the future. In addition, significant variations were noted across sectors in terms of the direct and indirect contributions to pollution. © 1998 Elsevier Science B.V. All rights reserved.

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1. Introduction

A companion study (Fritz, 1996a) revealed the importance of a distinction between polluting and non-polluting sectors in an economy. The notions of direct and indirect pollution generation serve to provide the motivation for the present paper that attempts to explore these relationships using a framework initially developed by Miyazawa (1966, 1968, 1971) and extended by Sonis and Hewings (1993, 1995,

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1997). In this paper, the relationship between polluting and non-polluting sectors with respect to industrial emissions will be revealed through an application of Miyazawa's framework of internal and external multipliers. The application of the methodology will be focused on Chicago, drawing on an econometric-input–output model of the Metropolitan Region's economy.

Since the late sixties and early seventies, the input–output framework has been used to model and study the relationship between economic activities and the environment.[1] An early contribution was made by Leontief (1970), who suggested adding a row to the interindustry table to account for sectoral pollution generation and adding a column representing inputs for pollution abatement activities. Authors like Flick (1974), Steenge (1978), Lowe (1979); Lee (1982), Rhee and Miranowski (1984), and more recently Qayum (1991) and Arrous (1994), among others, have modified and extended this approach to analyze the effects of exogenous pollution standards on production, prices and other economic variables. Other types of environmental input–output models include economic–ecological systems (e.g. Isard, 1972), where flows between the economic and ecological system are recorded in submatrices that augment the basic input–output framework, and commodity-by-industry models (e.g. Victor, 1972), which incorporate ecological commodities as outputs or inputs of the economic system.

Another approach, followed here, is to apply the standard, non-augmented, interindustry framework and account for the links between the economic system and the environment by a matrix of pollution coefficients, which represents sectoral emissions per unit of output. Furthermore, in this paper abatement activities are not considered and no emission constraints are imposed on production or consumption activities. Instead, the input–output table is partitioned into one set of industries whose production processes emit significant amounts of pollution and another set which includes relatively 'clean' industries, to show the interaction between these two groups. The basic assumption of a linear relationship between sectoral output levels and emission levels is thereby retained. However, since it is not the aim of the paper to estimate total pollution levels, this assumption does not seem crucial to the validity of its results.

In the following section, the partition analysis of input–output systems is introduced and applied to a two-fold division of the economy into polluting and non-polluting sectors. The decomposition is revealed, focusing on the notions of internal and external components and their realization in multipliers. The empirical application on the Chicago region occupies the next section; special attention is paid to pollution multipliers and their decomposition. A set of conclusions in which the analysis is related to some on-going policy concerns completes the paper.

2. Partition analysis of indirect pollution generation

The region's economy is divided into two parts, one a set of clean sectors comprised of industries that have relatively small emissions per unit of output and a set of

[1] See e.g. Miller and Blair (1985) for an overview of different economic–environmental input–output models.

polluting sectors that are characterized by larger emissions per unit of output. The system may be represented by the block matrix, $\mathbf{A}$, of direct inputs:

$$\mathbf{A}=\begin{pmatrix}\mathbf{A}_{cc} & \mathbf{A}_{cp}\\ \mathbf{A}_{pc} & \mathbf{A}_{pp}\end{pmatrix} \tag{1}$$

where, $\mathbf{A}_{cc}$ and $\mathbf{A}_{pp}$ are square matrices accounting for the internal input flows among the clean and polluting industries, respectively, and $\mathbf{A}_{pc}$ and $\mathbf{A}_{cp}$ are rectangular matrices representing input flows between clean and polluting sectors.

The Leontief inverses of the clean and the polluting sectors are referred to as the internal matrix multipliers (Miyazawa, 1966) and are defined as follows:

$$\mathbf{B}_c=(I-\mathbf{A}_{cc})^{-1} \tag{2a}$$

$$\mathbf{B}_p=(I-\mathbf{A}_{pp})^{-1} \tag{2b}$$

Based on Sonis and Hewings (1993) the following definitions of the external multipliers are used:[2]

$$\mathbf{\Delta}_c=(I-\mathbf{A}_{cc}-\mathbf{A}_{cp}\mathbf{B}_p\mathbf{A}_{pc})^{-1} \tag{3a}$$

$$\mathbf{\Delta}_p=(I-\mathbf{A}_{pp}-\mathbf{A}_{pc}\mathbf{B}_c\mathbf{A}_{cp})^{-1} \tag{3b}$$

Thus the Leontief inverse for the polluting sectors includes not only the internal direct and indirect demand for polluting commodities but also the demand induced by inputs from the clean sectors.

The following decomposition of the matrix in Eq. (1) may be obtained (see Sonis and Hewings, 1993) as:

$$(I-\mathbf{A})^{-1}=\begin{pmatrix}\mathbf{\Delta}_c & \mathbf{B}_c\mathbf{A}_{cp}\mathbf{\Delta}_p\\ \mathbf{\Delta}_p\mathbf{A}_{pc}\mathbf{B}_c & \mathbf{\Delta}_p\end{pmatrix} \tag{4}$$

It is this interpretation of the Leontief inverse that will be used to analyze the transactions between the polluting and clean sectors. Since the focus of this paper is on the pollution generation characteristics of different industries, the influence that the polluting sectors exert on the clean sectors will be ignored when irrelevant for pollution generation.

Furthermore the Miyazawa external multipliers for the clean and polluting sectors, respectively, are introduced:

$$\mathbf{\Delta}_{cc}=(I-\mathbf{B}_c\mathbf{A}_{cp}\mathbf{B}_p\mathbf{A}_{pc})^{-1} \tag{5a}$$

$$\mathbf{\Delta}_{pp}=(I-\mathbf{B}_p\mathbf{A}_{pc}\mathbf{B}_c\mathbf{A}_{cp})^{-1} \tag{5b}$$

$\mathbf{\Delta}_{pp}$ includes the direct, indirect and induced effects of the polluting sectors' input demand from the clean sector on the polluting sectors' production.

[2]Note that this definition of the external multiplier is different from the one employed by Miyazawa (1966).

The multipliers in Eqs. (3a) and (3b) can then be written as:

$$\boldsymbol{\Delta}_{\mathrm{c}} = \boldsymbol{\Delta}_{\mathrm{cc}}\mathbf{B}_{\mathrm{c}} \tag{6a}$$

$$\boldsymbol{\Delta}_{\mathrm{p}} = \boldsymbol{\Delta}_{\mathrm{pp}}B_{\mathrm{p}} \tag{6b}$$

The first matrix multiplier of interest in the decomposed Leontief inverse of Eq. (4), $\boldsymbol{\Delta}_{\mathrm{p}}\mathbf{A}_{\mathrm{pc}}\mathbf{B}_{\mathrm{c}}$, reveals the influence of the clean sectors' internal propagation[3] on the polluting sectors' output levels. In order to evaluate the clean sectors' impact in terms of pollution, the matrix multiplier is premultiplied by a diagonal matrix of pollution coefficients, $\hat{\mathbf{R}}$, whose off-diagonal elements are all zero, and thus becomes a pollution matrix multiplier:

$$\mathbf{P}_{\mathrm{c}} = \hat{\mathbf{R}}[\boldsymbol{\Delta}_{\mathrm{p}}\mathbf{A}_{\mathrm{pc}}\mathbf{B}_{\mathrm{c}}] \tag{7}$$

where $\mathbf{P}_{\mathrm{c}}$ is a rectangular matrix of pollution multipliers whose elements, $p_{i_{\mathrm{p}}j_{\mathrm{c}}}$, represent the increase in pollution generated by industry i_{p} as a result of a unit increase in final demand in industry, i_{c}. In order to evaluate the total amount of pollution generated by a unit increase in a clean industry's output level, the appropriate column multipliers are calculated:

$$m_{j\mathrm{c}} = \sum_{i\mathrm{p}} p_{i_{\mathrm{p}}j_{\mathrm{c}}} \tag{8}$$

where $m_{j\mathrm{c}}$ is industry j_{c}'s column multiplier with respect to all the polluting industries.

The multipliers of the matrix $\mathbf{P}_{\mathrm{c}}$ result from the interaction of three multiplier matrices, $\boldsymbol{\Delta}_{\mathrm{pp}}$,$\mathbf{B}_{\mathrm{p}}$,$\mathbf{B}_{\mathrm{c}}$ and the matrix $\mathbf{A}_{\mathrm{pc}}$. The sources of pollution induced by the clean sectors' production activities can be unveiled by looking at the column sums of these matrices with respect to the polluting sectors:

- $\hat{\mathbf{R}}\mathbf{A}_{\mathrm{pc}}$ pollution generated by direct input requirements of the clean sectors;
- $\hat{\mathbf{R}}\mathbf{A}_{\mathrm{pc}}\mathbf{B}_{\mathrm{c}}$ pollution caused by direct and indirect input requirements of the clean sectors;
- $\hat{\mathbf{R}}\mathbf{B}_{\mathrm{p}}\mathbf{A}_{pc}\mathbf{B}_{\mathrm{c}}$ pollution caused by internal propagation of clean industries and the induced direct and indirect production of the polluting sectors;
- $\hat{R}\boldsymbol{\Delta}_{\mathrm{pp}}\mathbf{B}_{\mathrm{p}}\mathbf{A}_{\mathrm{pc}}\mathbf{B}_{\mathrm{c}}$ total pollution multiplier of the clean sector with pollution caused by the internal propagation of clean industries and the induced internal and external propagation of polluting industries.

Industry j_{c}'s column sums with respect to these matrices are denoted as: $m^1_{j_{\mathrm{c}}}$,$m^2_{j_{\mathrm{c}}}$,$m^3_{j_{\mathrm{c}}}$,$m_{j_{\mathrm{c}}}$, respectively. The following definitions will be employed in the empirical analysis:

- $m^1_{j_{\mathrm{c}}}/m_{j_{\mathrm{c}}}$ share of direct input requirements in the total multiplier;
- $m^2_{j_{\mathrm{c}}} - m^1_{j_{\mathrm{c}}}/m_{j_{\mathrm{c}}}$ share of indirect input requirements in the total multiplier;
- $m^3_{j_{\mathrm{c}}} - m^2_{j_{\mathrm{c}}}/m_{j_{\mathrm{c}}}$ share of internal propagation of polluting industry in the total multiplier;

[3]Internal propagation is a term employed by Miyazawa (1966) to refer to internal direct and indirect demand.

$m_{j_c} - m_{j_c}^3 / m_{j_c}$ share of external propagation of polluting industry in the total multiplier.

The same analysis can be applied to investigate the pollution generation of the polluting industries, using $\mathbf{P}_p = \hat{\mathbf{R}}\boldsymbol{\Delta}_p$.

The following decomposition holds (see Sonis and Hewings, 1993):

$$\boldsymbol{\Delta}_p = \mathbf{B}_p + \mathbf{B}_p\mathbf{A}_{pc}\boldsymbol{\Delta}_c\mathbf{A}_{cp}\mathbf{B}_p \tag{9}$$

This matrix, $\boldsymbol{\Delta}_p$, yields important insights into the sources of pollution originating in the polluting sector. Again, the matrices can be premultiplied by the matrix of pollution coefficients to derive the pollution multipliers:

$$\mathbf{P}_p = \hat{\mathbf{R}}\mathbf{B}_p + \hat{\mathbf{R}}\mathbf{B}_p\mathbf{A}_{pc}\boldsymbol{\Delta}_c\mathbf{A}_{cp}\mathbf{B}_p \tag{10}$$

Column multipliers are computed in the same way as demonstrated in Eq. (8) with respect to the polluting industry j_p. The two parts of Eq. (10) are analyzed separately and then compared to the total multiplier.

$\hat{\mathbf{R}}\mathbf{B}_p$ pollution generated by internal propagation;

$\hat{\mathbf{R}}\mathbf{B}_p\mathbf{A}_{pc}\boldsymbol{\Delta}_c\mathbf{A}_{cp}\mathbf{B}_p$ pollution generated by external propagation, i.e. the demand for clean inputs;

$\hat{\mathbf{R}}\mathbf{B}_p + \hat{\mathbf{R}}\mathbf{B}_p\mathbf{A}_{pc}\boldsymbol{\Delta}_c\mathbf{A}_{cp}\mathbf{B}_p$ total pollution multipliers: pollution generated by internal and external propagation;

Industry j_p's column sums with respect to these matrices are denoted as $m_{j_p}^1, m_{j_p}^2$ *and* m_{j_p}, respectively, and the following ratios are computed:

$m_{j_p}^1 / m_{j_p}$ share of internal propagation in the total multiplier;

$m_{j_p}^2 / m_{j_p}$ share of external propagation in the total multiplier.

3. Empirical application of the partition framework

The regional econometric input–output model developed for Chicago (CREIM) provides the opportunity to derive a consistent time series of input–output tables showing the trading interactions among 36 sectors [see Israilevich et al. (1996, 1997) for a discussion of the methodology used to extract the input–output tables]. Annual input–output tables for the period 1975–2010 are used in this analysis; the coefficients in these tables are regional requirements coefficients so that changes in these coefficients may be attributable to changes in underlying technology, relative prices and changes in the competitive position of industries in the region compared to those outside Chicago.

Data on industrial air emissions were made available for the following pollutants by the Chicago office of the U.S.EPA: CO, PM_{10}, SO_2, NO_x, VOC. Since a consistent time series of airborne emissions is not available, the analysis relies on data for 1992 only so that any changes in direct discharges per unit of output are not considered. In essence, the analysis may be considered to provide an upper bound on pollution emission levels since the processes of technological change over the next 20 years will undoubtedly reduce unit emission rates.

The Chicago economy is divided into two sets of sectors; one set contains thirty industries and these are considered to be non-polluting (no significant airborne discharges). The remaining sectors comprise the set of polluting sectors and these are paper (SIC 26), chemicals (SIC 28), petroleum (SIC 29), stone, clay and glass (SIC 32), primary metals (SIC 33) and utilities (SIC 49). Together, these sectors account for over 86% of total direct industrial air emissions (the aggregate of the five pollutants mentioned above) and produce significantly more pollution per unit of output than the other industries that were allocated to the clean set. Hence, this partition of the economy seems reasonable.

The major findings can be summarized as follows. Over the period analyzed (1975–2010), all pollution multipliers of both the non-polluting and the polluting industries, including all the identified components of the total multipliers and the total multipliers themselves, are decreasing over time. The only exception to this trend is in the forestry and fishing sector, but this is not a very important contributor to economic activity in Chicago. All industries decrease the use of inputs from the polluting sectors per unit of output; this result is derived from the long-run *hollowing-out* of the Chicago economy that has been evaluated by Hewings et al. (1998). Essentially, over time, sectors within the Chicago region have become less dependent on each other as sources of inputs or destinations for outputs but have increased their dependency on sectors outside the region. If the pollution coefficients were really to remain constant over time, the net effect of this process would be to transfer pollution emissions from the Chicago region to other parts of the US or the rest of the world since, in most cases, the level of output in Chicago industries is not forecast to decline.

Only three non-polluting industries (food, textiles and leather) reveal decreasing shares of direct inputs in their total multipliers; for all other non-polluting industries, direct inputs from polluting industries account for an increasing share of their total multipliers. The shares of internal and external propagation of the polluting sectors in the non-polluting sectors' multipliers have declined over time, with the exception of rubber and plastic whose internal propagation share is increasing.

Changes in the shares of indirect inputs are positive for some non-polluting industries and negative for others. This suggests that the structural changes within the non-polluting sector results in some industries demanding successively more from sectors with large direct pollution inputs but with other industries demanding a smaller volume. Finally, the shares of the external multipliers are declining for all the polluting industries.

4. Pollution multipliers

The total pollution multipliers were estimated for the non-polluting industries (computed as the column sums of the non-polluting industries across the rows of the polluting industries) for 1975, 1988 and 2000. While 1975 represents an early period in the CREIM time series, 1988 is the last year for which an impact analysis can be based on historical data and 2000 is based entirely on forecasts. The largest

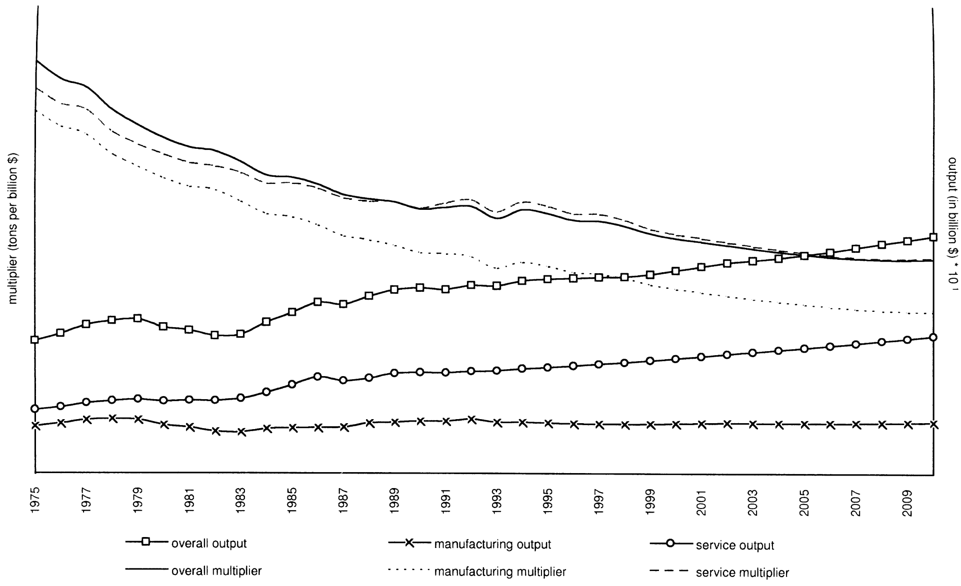

Fig. 1. Change in output and mean pollution multipliers of non-polluting sectors, 1975–2010.

multipliers are those for state and local government enterprises (since this includes air and water resource and solid waste management), forestry and fishing, construction and electrical machinery. The average pollution multipliers are persistently higher than those of the non-polluting manufacturing industries, and the average rank of the service sector is increasing over time while that for manufacturing is decreasing. This leads to the conclusion that the already significant share of services in indirect pollution generation is likely to expand further. This conclusion is supported by the fact that the output of the Chicago service sectors is growing while, for most manufacturing sectors, output growth is modest or stagnating.[4] Overall, the pollution multipliers are decreasing over time, as revealed in Fig. 1. This implies that past and future structural changes in the Chicago economy will work towards a reduction in indirect pollution generation (see Fig. 2).

Since the pollution multipliers of large sectors should be more important than the multipliers of small sectors, all multipliers were weighted by gross output levels. The ranking order changes accordingly with larger sectors like wholesale and retail, eating and drinking establishments moving up and smaller sectors, such as forestry and fishing, moving down in rank. The average weighted multiplier over all sectors is fairly stable over time with the one for manufacturing decreasing slightly and the one for services exhibiting an upward trend. This finding suggests that even though the sectoral multipliers are decreasing over time, the changes in the sectoral mix of

[4]All output values are expressed in constant $1987.

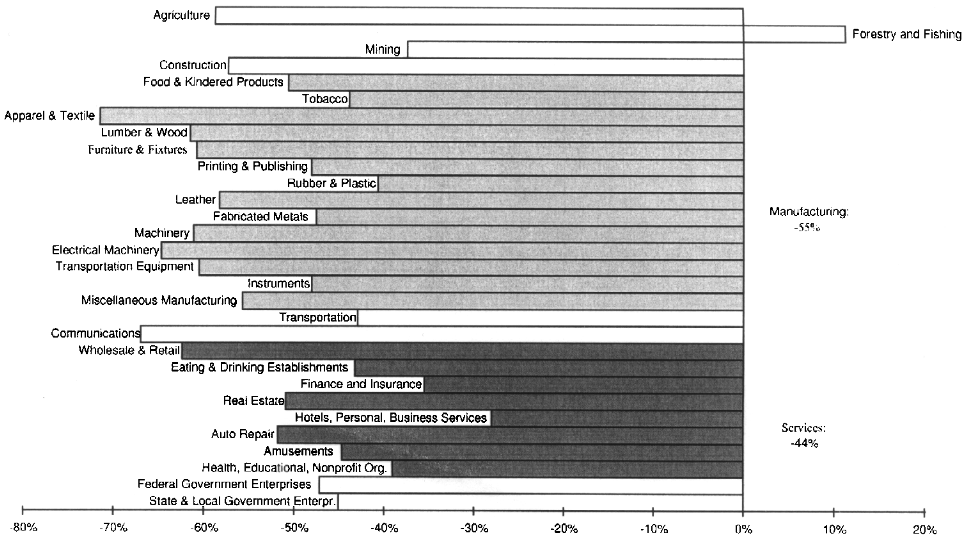

Fig. 2. Change in pollution multipliers of non-polluting sectors, 1975–2010.

the Chicago economy favors sectors with higher pollution multipliers and thus the total pollution from polluting sectors is increasing.[5]

The time series of multipliers of polluting industries reveals that the pollution multipliers are decreasing as well even though the decrease is smaller if the multipliers are weighted by gross output. The paper industry shows the largest decrease while, in terms of output growth, paper, chemicals and petroleum are growing at positive rates while stone, clay and glass, primary metals, and utilities are declining (see Fig. 3).

5. Decomposition of pollution multipliers

The total multipliers for non-polluting industries are decomposed into direct input requirements, internal propagation of the non-polluting sectors, internal propagation

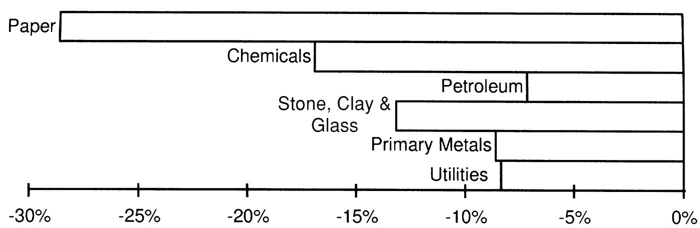

Fig. 3. Change in pollution multipliers of polluting sectors, 1975–2010.

[5]According to the assumption of constant pollution coefficients, total pollution is strictly proportional to the total output of the polluting sectors.

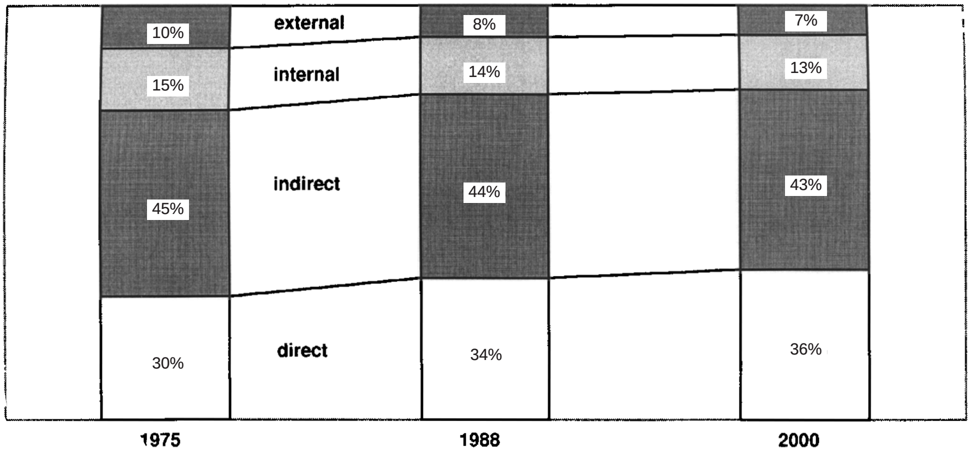

Fig. 4. Shares in mean pollution multipliers of non-polluting sectors.

of the polluting sectors stimulated by the non-polluting sectors' input requirements and finally, external propagation. The time series of total pollution multipliers and their components reveal the characteristics of past and future structural changes as far as indirect air pollution and its sources are concerned.

Examination of the overall shares of individual multipliers (Fig. 4) of the non-polluting sectors demonstrates that the share of direct input requirements in total multipliers is increasing rather significantly, from 30% in 1975 to 36% in 2000, while the shares of all other components are decreasing. The absolute values of the components declines as well: −37% for direct inputs, −50% for indirect inputs, −55% for internal propagation and −64% for external propagation. This evidence suggests that industries are not only reducing their demand for polluting industries production (relative to the value of their output) but are even shifting their demand away from industries with large shares of polluting inputs. This conclusion holds for both the non-polluting and polluting sector, since the shares of internal and external propagation are declining as well. There are several possible explanations for this development. First, the regulatory abatement requirements of polluting industries, especially in metropolitan areas that are considered to be non-attainment regions as far as air quality regulations are concerned, may tend to increase the local price of polluting inputs and cause industries to substitute these inputs either for less polluting inputs or inputs from other regions. In addition, technological changes that are independent of environmental regulation may cause intermediate demand to shift away from polluting industries. Finally, the level of aggregation at which the analysis was conducted, essentially two-digit, may obscure some important, sectorally specific transformations in demand for inputs across three-, four- and even six-digit industries.

Fig. 5 shows how the composition of the total multiplier differs significantly across sectors; direct inputs account for more than half of the value of the total pollution multiplier of the fabricated metals industry but only 19% for the hotels, personnel

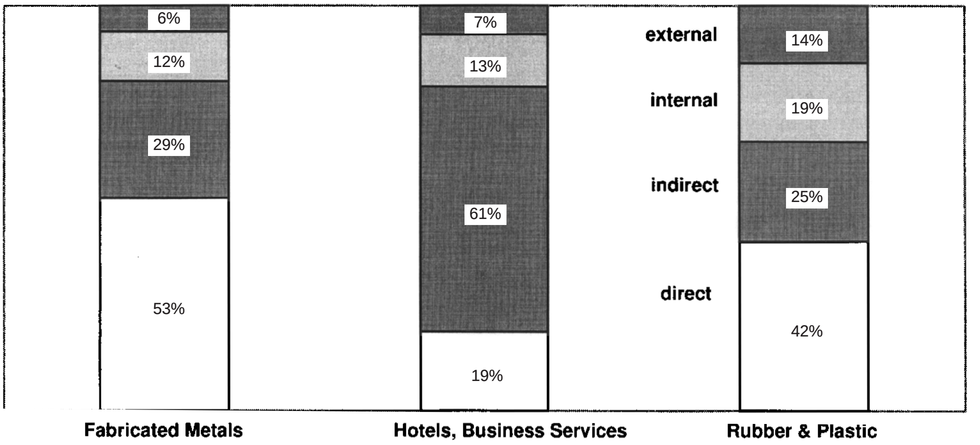

Fig. 5. Shares in total pollution multipliers of selected non-polluting sectors.

and business services industries. On the other hand, this latter industry has the largest share of indirect inputs in its pollution multiplier. Rubber and plastic reveal a more even distribution in the composition of the multiplier elements; its shares of internal and external propagation are the highest of all non-polluting industries.

The changes in the shares of the multiplier components are presented in Figs. 6–9. As mentioned before, shares of direct inputs are generally increasing (except for food and kindred products, apparel, and textile and leather, whose input shares are only increasing slightly) while shares of internal and external propagation are declin-

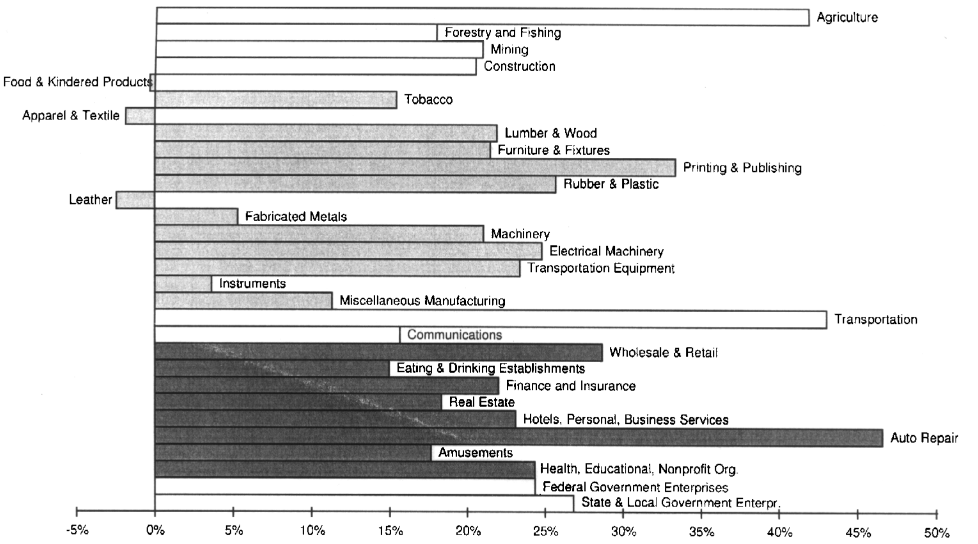

Fig. 6. Changes in shares of direct inputs in pollution multipliers of non-polluting sectors, 1975–2010.

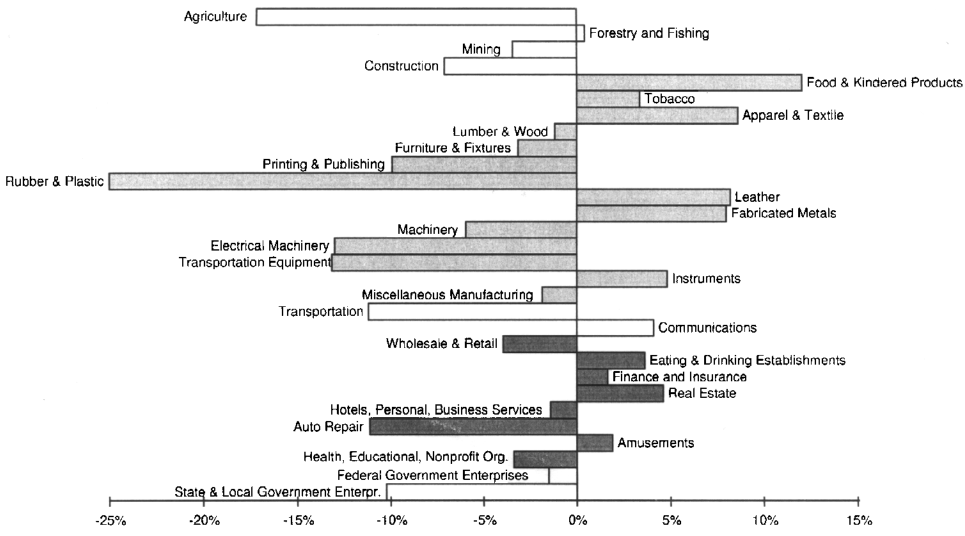

Fig. 7. Changes in shares of indirect inputs in pollution multipliers of non-polluting sectors, 1975–2010.

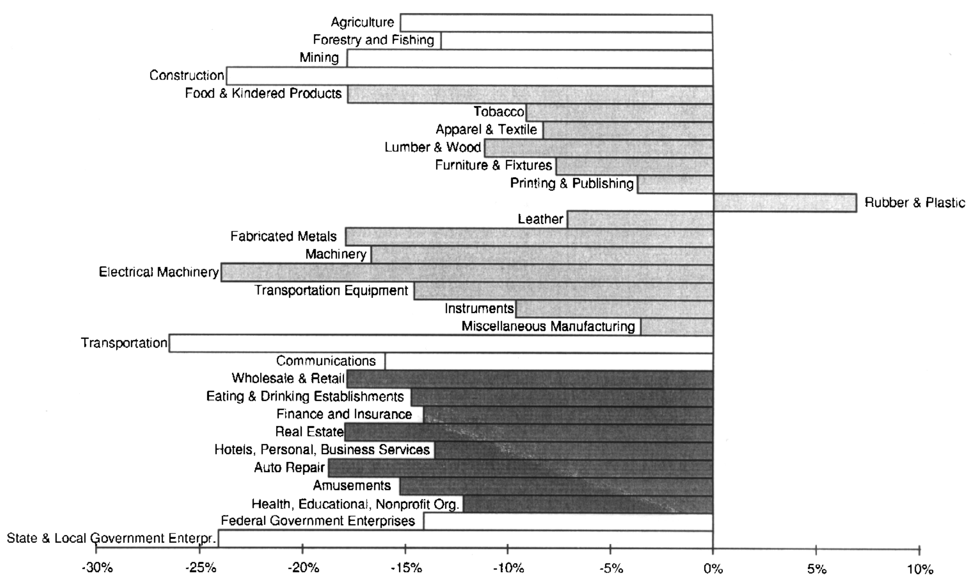

Fig. 8. Changes in shares of internal propagation in pollution multipliers of non-polluting sectors, 1975–2010.

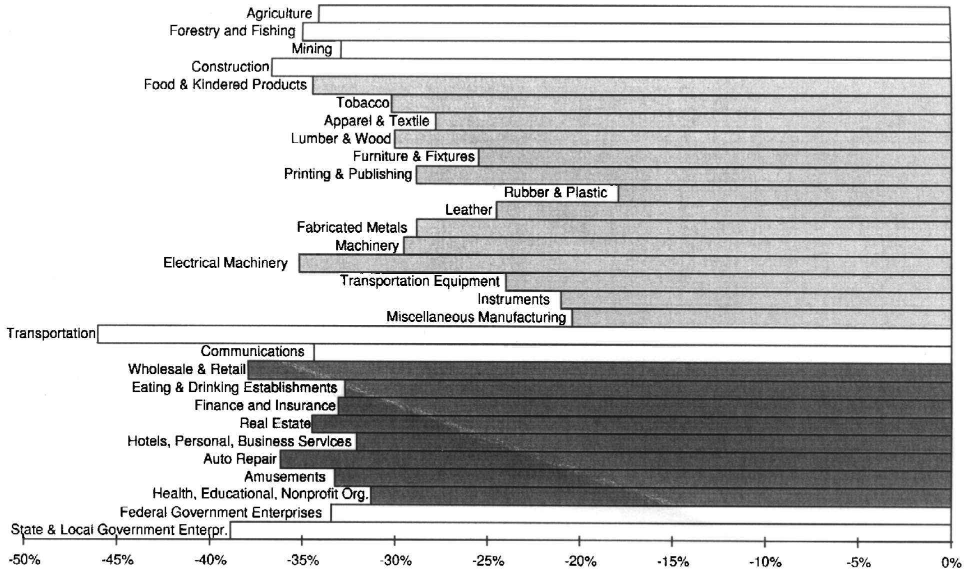

Fig. 9. Changes in shares of external propagation in pollution multipliers of non-polluting sectors, 1975–2010

Fig. 10. Shares of external multipliers in total pollution multipliers of polluting sectors, 1975–2010

ing (with the exception of the rubber and plastic industry). Changes in the shares of indirect inputs are positive for 12 out of 30 non-polluting sectors, with food and kindred products showing the highest increase and agriculture and rubber and plastic, the largest declines.

The polluting industries indirect pollution generation is decomposed into only two elements, internal and external propagation. The share of external propagation is decreasing in all industries, most significantly in the paper and chemical industries but only slightly for utilities (Fig. 10).

The analysis reveals that focusing attention only on polluting sectors in a regional economy may miss some of the more important interactions in the generation of pollution. The complex interplay between supply and demand among industries generates forces that are often significant contributors, through indirect pollution generation, in the volume of pollution that is ultimately created in a region. Equally importantly, structural changes in the economy can play both a positive and negative role in pollution generation; in the Chicago case, declines in the output levels of manufacturing sectors results in a decrease in levels of pollution but this is offset in some cases by increases generated in nonmanufacturing sectors. Furthermore, the decrease in the level of intermediation in the economy (reduction in the volume and strength of interindustry interactions) creates a further source of change. The Miyazawa decomposition offers the possibility to view each of the components of these changes in turn and to build a more useful and accurate picture of the economic–environment interactions. Changes in the shares of indirect inputs, internal and external propagation in the non-polluting sectors play a very important role in the determination of pollution levels over the period 1975–2010. These findings would not have been revealed through a more classical approach to pollution determination.

6. Conclusions

While only a small set of industries generates most of the direct pollution in an economy, the interdependence between the different parts of the economic system requires consideration of the sources of demand for the goods and services provided by these polluting sectors. In this paper, the pollution generation process has been decomposed, using some of the initial ideas of Miyazawa (1966) and subsequent modifications by Sonis and Hewings (1993). The methodology was then applied to a time series of input–output tables for the Chicago region over the period 1975–2010. One of the most important findings was that structural change manifests itself in the form of an economy that is less pollution intensive at the end of the time period. All sectoral multipliers as well as direct pollution coefficients decline; furthermore, a substitution of inputs away from local polluting industries and industries with large shares of polluting inputs also takes place.

The analysis developed here may be seen as the first step in a more complete evaluation of the interactions between economy and environment. Future research will need to address the issues of environmental regulation and its impact on: (1)

changing firms' input composition; and (2) reduction of emission rates per unit of output. The interdependence in the economy makes it imperative that attention is not focused exclusively at the individual sectoral level. Furthermore, it will be important to examine the issues in a two or *n*-region context, as Briassoulis (1986) has argued. For example, to what degree is the shift in demand noted for Chicago one that is characterized by a substitution of cleaner inputs for polluting inputs or merely a substitution of polluting inputs from Chicago with equally polluting inputs from other regions? In the first case, the economy as a whole moves towards a cleaner structure while in the second case, the problem is merely transferred to another region. However, it should be stated that even this move can be welfare enhancing if additional emissions in the other regions do not cause a significant deterioration in air quality but help ease the environmental problems of non-attainment areas.

The final issue that needs to be considered is the role that analysis, of the kind presented in this paper, plays in industrial retention activities that are now one of the major policy initiatives adopted by many urban and regional planning agencies. If market forces operate to reduce the volume of activity in a region and, concomitantly, the level of pollution, should steps be taken to retain the polluting activities within the region? Here, attention needs to be focused on an analytical framework of the kind suggested by Fritz (1996b) in which a portfolio variance theoretical notion was posited for explicitly addressing the tradeoffs between economic characteristics and pollution.

Appendix

The chicago model and the data extraction process[6]

The Chicago region econometric input–output model (CREIM) generates forecasts of the Chicago economy on an annual basis, with the forecast horizon extending up to 25 years. The model is comprises two major components: an input–output module and an econometric module. The modeling system is one designed and implemented for the state of Washington by Conway (1990, 1991); the reader is referred to Conway's papers for more complete descriptions of the model. The input–output structure is derived from the whole system and is not a separable entity that is abstracted without reference to the rest of the economic interactions. The model is a system of linear and nonlinear equations formulated to predict the behavior of 151 endogenous variables, and consists of 123 behavioral equations, 28 accounting identities, and 68 exogenous variables. CREIM identifies 36 industries and three government sectors. For each industry, there are projections of output, employment, and earnings. Thus, out of 150 equations, only 36 relate to the linear input–output components. Many of the non input–output equations are nonlinear

[6]This section draws heavily on Israilevich et al. (1997)

and estimated in a recursive fashion (usually, incorporating autoregressive lags of order one or two). As a result, the relationships of one sector to another include the formal input–output link as well as a set of complex linkages through a chain of actions and reactions that could potentially involve the whole economy. However, the output of one industry can be related to the output of another industry; in CREIM, this is specified through first derivatives. It would be very difficult to derive these derivatives analytically due to the nonlinearity of many of the equations and their incorporation of autoregressive components; in the solution to the model, these derivatives are calculated numerically. Then, the whole system is tested to ensure that these numerical derivatives are stable with respect to the shocks that were used in the process of estimating the derivatives.

The input–output module

This module was constructed from establishment-level data obtained from the U.S. Bureau of the Census. Three models have been developed, based on 1982, 1987 and 1992 data. Thirty-six sectors were identified for Chicago — essentially, the two-digit SIC manufacturing sectors and somewhat more aggregated sectors for non-manufacturing. While data are available at the individual establishment level, Federal Disclosure Rules preclude the publication of data that would reveal the transactions of individual firms or would enable reasonable estimation from information presented.

Extracting the input–output tables

The method of extracting the input–output tables is described in detail in Israilevich et al. (1996). The input–output coefficients provide the endogenous mechanism that enables markets to clear. The original formulation of the system (Conway, 1990, 1991) that was utilized in Chicago, equilibrates outputs demanded by both intermediate and final sectors with the supply of output. Hence, to draw on Takayama (1985), the dynamic output adjustment equation for this system of markets can be presented as:

$$\dot{q}=\tilde{k}[D(q)-S(q)] \tag{A1}$$

where both demand, $D(q)$ and supply $S(q)$ are expressed as functions of output and $\tilde{k}$ is the speed of adjustment of the market. The process described above may be referred to as an adjustment along the lines of a Marshallian output adjustment process (see Takayama, 1985 p. 295ff).[7] Takayama (1985) noted that there has been some confusion about the differences between Walrasian and Marshallian adjustment processes; he notes that

> …the Marshallian adjustment is better suited (for the case in which) the adjustment of output is explicitly considered. It is important to note that the Marshallian output adjustment process is…perfectly relevant for a competitive market.

In CREIM, there is an underlying (though not observed) price adjustment process

[7]As Takayama (1985) notes, the Walrasian equilibrium system would solve $\dot{p}=k[D(p)-S(p)]$ where demand and supply are functions of prices, p.

but the operation of the model focuses on the market clearing quantity adjustment mechanisms. Hence, the system shares more of a Marshallian character in the terms defined by Takayama (1985). Since regional price differentials for goods and services are generally unavailable, Marshallian equilibrium adjustment is easier to model than a Walrasian process.

From this system of extraction, input–output tables for the period 1975–2018 can be derived; these tables reflect the dynamics of changes in the region's economy and thus may be thought of as reflecting the changes in the region's internal complexity.

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