Assessing the regional economic impact of pollution control—A simulation approach*

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INTRODUCTION

This paper presents a computer simulation approach to assessing the major economic dimensions of the regional impact of pollution control technology. The framework for the analysis is a regional economic input-output model. Impact measures are estimated in terms of price, employment, and output in the affected region. A 22-sector input-output model of the St. Louis area** is used as the basis for the demonstration. Summary economic impact measures combining price and employment effects are developed for the region and for the rest of the nation. The simulation model is applicable to any set of wage, price, or technology changes which can be specified as changes to an input-output model, and has been implemented as part of the regional economic impact analysis program of the Office of Emergency Preparedness. The full algorithm has been implemented on MCL's UNIVAC 1108 computer for application with the data base for the multiregional input-output model developed by the Harvard Economic Research Project. The price-change portion of the algorithm has also been implemented for the 1963 OBE 478-order interindustry model of the U. S. economy.

An ideal basis for assessing the economic dimensions of environmental protection would compare costs and benefits; however, public policy is leading economic science in that assessment of benefits is lagging far behind pollution control decisions. The simulation procedure presented here is directed only toward the effects of control expenditures; although, as we shall see, there are often benefits in the form of increased income which accrue as the direct result of control expenditures. A particular advantage of a simulation procedure in this case is that several critical variables, most notably demand elasticities, are not known, or are known only with great uncertainty so that repeated simulation for various "scenarios" adds considerable dimension to an application.

We first present a simulation approach to estimating the major economic effects of significant technology changes brought about by pollution control expenditures in the second section. The use of the simulation procedure is demonstrated for comparing two hypothetical pollution control strategies in the third section. We also show in that section an important difference between regional and national perspectives in the choice of environmental strategy; this is highlighted in the demonstration. Generalizations of the model for other purposes, such as assessing the effects of price or wage changes, are discussed briefly in the fourth section. An appendix describes the mathematical basis of the simulation procedure.

THE SIMULATION PROCEDURE

Simulation procedures for the impact model may be summarized as follows:

Step 1. Represent pollution control (or other regional economic phenomenon) expenditures as changes in interindustry transactions matrix.

Step 2. Estimate new interindustry transactions matrix based on changes introduced in Step 1.

Step 3. Derive estimates of regional price changes from new transactions matrix (an iterative procedure).

Step 4. Derive estimates of new income and consumption patterns from employment changes.

Step 5. Estimate new output levels for regional industries from (a) new regional consumption pattern, and

* The views contained in this article do not necessarily reflect the policy or position of the Office of Emergency Preparedness.

** The model is from Liu.1
activities: payments for labor inputs, state, local, and federal taxes, imports from the regions, profits, etc. In the right hand side, the vector $C$ represents final consumption demand by regional households, the vector $E$ represents external demands (or exports) for output from the region, and the vector $F$ represents all other regional final demands (e.g., investment by regional businesses, purchases by state and local governments, etc.).

The transactions table is constructed so that the row sums (total output for a sector) equal the column sums (total expenditures by a sector) for all $n$ sectors. This balance sheet condition is used in our simulation as a convergence criterion.

The technology of production for an industry is determined by the column vector of its inputs: we simply divide each element in the vector by the column total to obtain

$$a_{ij} = \frac{X_{ij}}{\sum_{k=1}^{n+k} X_{ij}}$$

and $a_{ij}$ is the expenditure on output from industry $i$ required to produce one dollar's worth of output in industry $j$.

**Step 1.** Suppose we wish to study the effects of major environmental protection expenditures in industry 1 in the region; and suppose that these expenditures are used entirely to buy inputs from industry 2. Then in the "first round," we increase industry 1's purchases from industry 2.

**Step 2.** Two results are immediate:

(a) industry 1 now has a different production process, characterized by greater expenditures per unit of output, and hence a higher price. The new price, relative to the initial price, is simply the ratio of total expenditures after the technology changes to total expenditures before the technology change. That is

$$P^{i}_1 = \frac{\sum_{k=1}^{n+k} X_{i1}^i}{\sum_{k=1}^{n+k} X_{i1}}$$

where $P^{i}_1$ is the price for industry 1 output in round 1 relative to its price in the base period,

$X_{i1}^i$ is the dollar value of sales from industry $i$ to industry 1 in the base period

$X_{i1}$ is the dollar value of sales from industry $i$ to industry 1 in round 1 after the technology change is introduced.

(b) Industry 2 now must produce more output to satisfy the additional demand by industry 1 for inputs; industry 2 must therefore buy more of all inputs according to its own technology to produce more output.

On the next round, we must take into account the two effects: higher price for industry 1 outputs, and greater output and inputs for industry 2.

We do so in the following way: since the first row in the transactions table represents sales from industry 1 to all other industries, we can reflect industry 1 passing along the price increase to its customers by multiplying the dollar
transactions in row 1 by $P_1^i$. (Recall that $P_1^i$ is an index of price change.)

Thus

$$X_{i^j} = X_{i^j} \cdot P_1^i$$

where

$X_{i^j}$ is the dollar value of sales from industry 1 to industry $j$ before the technology change

and

$X_{i^j}^*$ is the dollar value of sales from industry 1 to industry $j$ after the technology change.

Thus we reflect higher prices for industry 1's output.

To reflect the greater output for industry 2, we construct the "production index"

$$R_2^i = \left( \sum_{j=1}^{n} X_{i^j} + C_i + E_i + F_i \right) / \left( \sum_{j=1}^{n} X_{i^j} + C_i + E_i + F_i \right)$$

where

$X_{i^j}$ represents the dollar value of sales from industry 2 to industry $j$ in the base period.

and

$X_{i^j}$ represents the dollar value of sales from industry 2 to industry $j$ in round 1.

In the first round, the only change is in $X_{i^j}$, reflecting the new environmental protection purchases by industry 1.

We now use $R_2^i$ to obtain new purchases by industry 2 to increase its own production:

$$X_{i^j} = R_2^i \cdot X_{i^j}^*$$

where

$X_{i^j}$ in the dollar value of sales from industry 1 to industry 2 in the base period

and

$X_{i^j}$ is the dollar value of sales from industry $i$ to industry 2 in round 2.

In the second round of transactions (or calculations) two kinds of effects are induced on other industries in the region arising from the initial change in a single cell in the transactions matrix:

(a) price changes resulting from higher prices for output from industry 1, affecting all customers of industry 1

and

(b) output changes resulting from greater purchases by industry 2, affecting all suppliers to industry 2.

In general, then, we must account for these possible effects in all industries. We do so by first adjusting for price changes. We form the ratio of price changes for each industry $j$

$$P_j^i = \frac{\sum_{i=1}^{n+k} X_{i^j}^*}{\sum_{i=1}^{n+k} X_{i^j}^*} \quad j=1, \ldots, n$$

and then multiply the corresponding row by the price change index

$$X_{i^j} = X_{i^j} \cdot P_j^i$$

for $i=1, \ldots, n$

Thus each industry is assumed to pass along price increases to its customers.

For simplicity, we suppose that price and quantity changes take place in different rounds. Now we form for each industry the production ratio

$$R_i^3 = \left( \sum_{j=1}^{n+k} X_{i^j} + C_i + E_i + F_i \right) / \left( \sum_{j=1}^{n+k} X_{i^j} + C_i + E_i + F_i \right)$$

and obtain new purchases for each industry by multiplying the corresponding column by the production ratio

$$X_{i^j} = X_{i^j} \cdot R_i^3$$

Step 3. We continue this process until the production ratios and price ratios converge to prespecified tolerances; that is, both

$$R_{p+1} - R_p < d_1$$

and

$$P_{p+1} - P_p < d_2$$

where $d_1$ and $d_2$ represent the convergence criteria selected in advance. At the end of the process, we have a new transaction matrix which reflects higher prices and greater outputs throughout the system, reflecting the initial change in technology in industry 2. Final price indices may be computed from

$$P_t^j = \frac{\sum_{i=1}^{n+k} X_{i^j}^*}{\sum_{i=1}^{n+k} X_{i^j}}$$

where $t$ is the index of the computation round when convergence was achieved.

Based on our assumptions up to this point in the simulation algorithm, we have estimates of payments to labor in row $n+1$ of the new transactions table. Suppose that employment is proportional to expenditures on labor. Then we may calculate the relative increase in employment as the ratio

$$W_j = X_{n+1,j} / X_{n+1,j}^*$$

Incomes to regional households have increased in the proportion

$$Y = \frac{\left( \sum_{i=1}^{n+k} X_{n+1,i} + C_{n+1,i} + E_{n+1,i} + F_{n+1,i} \right)}{\left( \sum_{i=1}^{n+k} X_{n+1,i} + C_{n+1,i} + E_{n+1,i} + F_{n+1,i} \right)}$$

Step 4. In the process of adjusting outputs of each industry by the production ratios, we have changed purchases of all inputs, including labor, based on the assumptions that (a) final demand $(C, E, F)$ remain unaffected by price changes, and (b) that the changes in labor (household) incomes result in no changes in final demands. We now successively relax these assumptions.
The elasticity of demand measures the response in quantity demanded by a commodity to a change in price. Analytically,

\[ e = \frac{\Delta Q}{Q} \div \frac{\Delta P}{P} \]

Thus, for known (or assumed) values of \( e \), we can derive relative quantity changes from the relative price changes derived in Step 2. The simplest assumption, and that which we adopt here, is that \( e = 1 \) for each element of \( C \), \( E \), and \( F \); consequently, the dollar values of \( C \), \( E \), and \( F \) remain unchanged in response to the price increases brought about by environmental protection expenditures. Because prices have increased, the same level of expenditures by final purchasers will result in lower physical quantities of output. In other terms, total expenditures by each industry will now exceed total receipts; column sums will exceed row sums. Under these circumstances, we would expect producers to scale down their production; we simulate this effect by forming for each industry the ratio of receipts to expenditures

\[ S_j = \frac{\sum_{i=1}^{n} X_{ij} + C_j + E_j + F_j}{\sum_{m=1}^{n} X_{mj}} \]

(For simplicity, we now reindex successive rounds of computations \( s+1, \ldots, t \))

On the other hand, increases in household incomes within the region will generate increased consumption, so that we compute

\[ C_i = C^{p} \cdot Y^{1} \quad \text{for all } i \]

where \( Y^{1} \) is computed as in Step 3 above. Our procedure corresponds to the simple assumption that consumers spend additional income in the same pattern as before.

Step 5. We now construct a new sequence of operations which adjust at each round of computations for both of these effects.

First, we adjust for the excess of expenditures over receipts. For each industry \( j \), we compute

\[ S_j = \frac{\sum_{i=1}^{n} X_{ij} + C_j + E_j + F_j}{\sum_{m=1}^{n} X_{mj}} \quad j = 1, \ldots, n \]

This differs from the expression in Step 4 only in that we replace \( C \) with \( C^{p} \). Because we have done so, \( S_j \) may be greater than or less than 1. We then scale purchases by industry \( j \)

\[ X_{ij} = X_{ij} \cdot S_j \quad i = 1, \ldots, n+k \]

In so doing, we create new income patterns, from which we compute

\[ Y = \frac{\sum_{i=1}^{n} X_{i+nj} + C_{i+nj} + E_{i+nj} + F_{i+nj}}{\sum_{j=1}^{n} X_{ij} + C_j + E_j + F_j} \]

At each subsequent round we obtain

\[ C^{s} = C^{s-1} \cdot Y^{t-1} \]

which is entered into

\[ S_j^{t} = \left( \frac{\sum_{i=1}^{n} X_{ij}^{t-1} + C_j^{p} + E_j^{p} + F_j^{p}}{\sum_{m=1}^{n} X_{mj}^{t-1}} \right) / \frac{\sum_{i=1}^{n} X_{ij}^{t-1} + C_j^{p} + E_j^{p} + F_j^{p}}{\sum_{m=1}^{n} X_{mj}^{t-1}} j+1, \ldots, n \]

to obtain

\[ X_{ij} = X_{ij}^{t-1} \cdot S_j^{t} \]

We iterate these procedures until convergence for \( Y^{t} \) and \( S_j^{t} \) is obtained in terms of prespecified tolerances. When convergence is achieved, we have obtained the following information:

1. A new interindustry transactions matrix which reflects the new technology, and consequent new levels of output, income, employment and consumption demands for each industry and for the region as a whole.
2. A set of price indices which show the effects of the new technology on prices throughout the interindustry model.

Step 6. We can use this information to summarize the effects on the region in terms of impact multipliers based on the original technology change and our assumed values of the elasticities of demand:

1. A vector of indices of relative (or absolute) production changes for each industry;
2. A vector of indices of relative price changes for each industry;
3. A vector of relative (or absolute) employment changes for each industry;
4. A vector of relative (or absolute) changes in consumption for each industry.

These measures, together with the new technology and Leontief inverse matrices, whose derivations are described in the Appendix, provide a complete description of the regional economic impacts brought about by whatever set of changes are initially put into the transactions matrix.

Policy-makers are likely to be most interested in the effects of policy decisions on incomes (or employment—which in this example is proportional to income) and—perhaps to a lesser extent—on prices. We can readily construct summary measures of these impacts at the expense of industry detail, although this use should be considered only indicative.

The dollar value of the change in regional income may be expressed as

\[ W_{t} = \sum_{j=1}^{n} (X_{i+nj} - X_{i+nj}^{p}) \]

where \( t \) represents the final iteration in Step 5 and \( 0 \) represents the original transactions matrix.

Price indices may be computed for each component of final demand (in this case \( C \), \( E \), \( F \)) by

\[ P_{t} = y_{t} \cdot p^{p} \]
That is, base period weights are used to measure the effect of price increases. The effects of income changes and price changes may be compared by expressing both in dollar terms. For regional consumption

\[ W_2 = \sum_{i=1}^{n+k} (P_i^t - 1) C_i, \]

Estimates of the effects of the technology change on the rest of the nation can be derived from (a) changes in "import" from outside the region and (b) changes in the price of goods shipped outside the region. Changes in imports from the rest of the nation affect incomes elsewhere; a dollar measure of this effect may be obtained by

\[ W_4 = \sum_{i=1}^{n} (P_i^t - 1) E_i, \]

where \( t \) is the index of the final iteration in Step 5 and 0 represents the initial transactions matrix. \( K \) is the income multiplier for the nation at large; that is, each dollar of final demand in a national model generates \( K \) dollars of income throughout the system. (The value is about 2 for the 1963 OBE interindustry model of the U.S. economy.)

Finally, we may construct a dollar measure of the effect of price changes for goods shipped outside the region:

\[ W_3 = \sum_{i=1}^{n+k} (P_i^t - 1) \cdot K \]

These summary measures, although crude and heavily dependent on assumed values of elasticities, may be useful in determining the distribution of the effects of a given policy between the region under study and the rest of the nation. It can be argued, for example, that a regional authority will, because of its narrow constituency, tend to favor policies which raise prices of "exported" goods and thereby generate greater incomes within the region, whereas a different policy which raises prices of "exported" goods and thereby generate greater incomes within the region, whereas a different policy with less favorable local results would have lower national costs.

A DEMONSTRATION OF THE MODEL

The model has been used to demonstrate the difference between regional and national perspectives in environmental pollution control, based on hypothetical alternative strategies for two industrial sectors. Some of the results are reproduced and briefly discussed here.

Table II summarizes the industries defined for the St. Louis region.

* These results are taken from a longer study, Norsworthy and Teller.

### TABLE II-Sectors in the St. Louis Input/Output Model

<table>
<thead>
<tr>
<th>Sector No.</th>
<th>Description</th>
<th>Total Production*</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Food, Tobacco &amp; Kindred Products</td>
<td>21,723,957</td>
</tr>
<tr>
<td>2</td>
<td>Textiles &amp; Apparel</td>
<td>197,447</td>
</tr>
<tr>
<td>3</td>
<td>Lumber and Furniture</td>
<td>83,800</td>
</tr>
<tr>
<td>4</td>
<td>Paper and Printing</td>
<td>506,653</td>
</tr>
<tr>
<td>5</td>
<td>Chemicals, Petroleum &amp; Rubber</td>
<td>1,584,148</td>
</tr>
<tr>
<td>6</td>
<td>Leather Products</td>
<td>106,859</td>
</tr>
<tr>
<td>7</td>
<td>Stone, Clay and Glass</td>
<td>219,986</td>
</tr>
<tr>
<td>8</td>
<td>Primary Metals</td>
<td>851,358</td>
</tr>
<tr>
<td>9</td>
<td>Fabricated Metals</td>
<td>535,675</td>
</tr>
<tr>
<td>10</td>
<td>Machinery (Except Electrical)</td>
<td>439,483</td>
</tr>
<tr>
<td>11</td>
<td>Electrical Machinery</td>
<td>386,357</td>
</tr>
<tr>
<td>12</td>
<td>Transportation Equipment</td>
<td>3,555,904</td>
</tr>
<tr>
<td>13</td>
<td>Ordnance &amp; Miscellaneous Manufacturing</td>
<td>298,573</td>
</tr>
<tr>
<td>14</td>
<td>Agriculture</td>
<td>88,291</td>
</tr>
<tr>
<td>15</td>
<td>Mining</td>
<td>78,659</td>
</tr>
<tr>
<td>16</td>
<td>Construction</td>
<td>922,382</td>
</tr>
<tr>
<td>17</td>
<td>Transportation, Communication &amp; Utilities</td>
<td>1,481,926</td>
</tr>
<tr>
<td>18</td>
<td>Wholesale Trade Services</td>
<td>870,227</td>
</tr>
<tr>
<td>19</td>
<td>Retail Trade Services</td>
<td>1,350,862</td>
</tr>
<tr>
<td>20</td>
<td>Finance, Insurance &amp; Real Estate</td>
<td>1,056,675</td>
</tr>
<tr>
<td>21</td>
<td>Business, Personal &amp; Other Services</td>
<td>1,462,304</td>
</tr>
<tr>
<td>22</td>
<td>Households</td>
<td>8,052,260</td>
</tr>
<tr>
<td>23</td>
<td>Local Government</td>
<td>601,655</td>
</tr>
<tr>
<td>24</td>
<td>Other Exogenous Payments</td>
<td>5,511,801</td>
</tr>
<tr>
<td>25</td>
<td>Imports</td>
<td>6,097,453</td>
</tr>
</tbody>
</table>

* Thousands of 1967 dollars.

The scenario on which this demonstration is based may be described as follows: A regional air pollution control authority must decide between two pollution control strategies of equivalent effectiveness for the local chemical, petroleum, and rubber industries (sector 5 in the St. Louis input-output model). The sector serves an external market: only 5 percent of total output is sold within the region. Table III shows the distribution of expenditures among input-output sectors for the two strategies. Strategy 1, while more expensive, results...

### TABLE III-Hypothetical Technology Change for Pollution Control in Sector 5*

<table>
<thead>
<tr>
<th>Sector No.</th>
<th>Expenditure Change**</th>
</tr>
</thead>
<tbody>
<tr>
<td>10</td>
<td>Machinery</td>
</tr>
<tr>
<td>16</td>
<td>Construction</td>
</tr>
<tr>
<td>17</td>
<td>Utilities</td>
</tr>
<tr>
<td>22</td>
<td>Households (Labor)</td>
</tr>
<tr>
<td>23</td>
<td>Local Government</td>
</tr>
<tr>
<td>24</td>
<td>Other Exogenous Payments</td>
</tr>
<tr>
<td>25</td>
<td>Imports</td>
</tr>
</tbody>
</table>

* Sector 5: Chemicals, Petroleum Refining and Rubber. Production is primarily for export to other regions (90%).
** In thousands of dollars.
TABLE IV—Impact Multipliers for Strategy 1 in Sector 5

<table>
<thead>
<tr>
<th>Sector</th>
<th>Relative Price Changes for Regional Production</th>
<th>Change in Regional Production</th>
<th>Change in Regional Employment*</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1.003</td>
<td>2290</td>
<td>507.</td>
</tr>
<tr>
<td>2</td>
<td>1.001</td>
<td>434</td>
<td>168.</td>
</tr>
<tr>
<td>3</td>
<td>1.0020</td>
<td>102</td>
<td>41.</td>
</tr>
<tr>
<td>4</td>
<td>1.0002</td>
<td>200</td>
<td>45.</td>
</tr>
<tr>
<td>5</td>
<td>1.0054</td>
<td>3223</td>
<td>8188.</td>
</tr>
<tr>
<td>6</td>
<td>1.0010</td>
<td>89</td>
<td>-11.</td>
</tr>
<tr>
<td>7</td>
<td>1.0001</td>
<td>-375</td>
<td>-174.</td>
</tr>
<tr>
<td>8</td>
<td>1.0001</td>
<td>956</td>
<td>506.</td>
</tr>
<tr>
<td>9</td>
<td>1.0001</td>
<td>1310</td>
<td>483.</td>
</tr>
<tr>
<td>10</td>
<td>1.0001</td>
<td>14148</td>
<td>6792.</td>
</tr>
<tr>
<td>11</td>
<td>1.0002</td>
<td>19</td>
<td>-17.</td>
</tr>
<tr>
<td>12</td>
<td>1.0001</td>
<td>478</td>
<td>39.</td>
</tr>
<tr>
<td>13</td>
<td>1.0001</td>
<td>138</td>
<td>36.</td>
</tr>
<tr>
<td>14</td>
<td>1.0000</td>
<td>108</td>
<td>49.</td>
</tr>
<tr>
<td>15</td>
<td>1.0001</td>
<td>513</td>
<td>290.</td>
</tr>
<tr>
<td>16</td>
<td>1.0001</td>
<td>17186</td>
<td>9383.</td>
</tr>
<tr>
<td>17</td>
<td>1.0000</td>
<td>7988</td>
<td>3500.</td>
</tr>
<tr>
<td>18</td>
<td>1.0006</td>
<td>729</td>
<td>133.</td>
</tr>
<tr>
<td>19</td>
<td>1.0002</td>
<td>6378</td>
<td>3506.</td>
</tr>
<tr>
<td>20</td>
<td>1.0000</td>
<td>5754</td>
<td>2057.</td>
</tr>
<tr>
<td>21</td>
<td>1.0001</td>
<td>4883</td>
<td>2997.</td>
</tr>
</tbody>
</table>

* Thousands of 1967 dollars.

in far greater expenditure within the region. Strategy 2, less expensive, depends primarily upon imported equipment.

Table IV shows the impact multipliers on prices, regional production, and regional employment or income for Strategy 1. The major price effects are within Sector 5* where the expenditures take place. Major changes in output occur in Sectors 10 and 16, the major suppliers for the given pollution control technology. A major part of the initial increase in regional incomes in Sector 5 is dissipated ($25,380 down to $8,158) because customers outside the region reduce somewhat their purchases of Sector 5 output. Impact multipliers are not shown for Strategy 2; however, they can be inferred to some extent from Table V, which presents summary measures of regional and national impacts of the two strategies. Here the difference in the distribution of the strategies' impacts is clearly shown.

First, the price increases fall largely outside the region in each case, as shown by the price indices for regional consumption and regional exports.

Second, suppose we make the tenuous assumption that a dollar increase in prices is offset by a dollar increase in incomes. Then a regional perspective would evaluate Strategy 1 at $35,471—$5,864—$32,407, ignoring the negative effects outside the region amounting to —$94,629. Again from a regional perspective, Strategy 2 has a value of $16,292, so that Strategy 1 is clearly preferable. From a national perspective, however, which would include both regional and extra-regional effects, both strategies have negative value, but Strategy 2 (at —$52,873) is preferable to Strategy 1 (at —$62,222).

The conclusions from this demonstration are twofold: first, that the characterization of proposed policy-guided technology changes in terms of impact multipliers can provide a useful basis for evaluating policy alternatives; and, second, that a regional model can be used to infer the distribution of impacts between the region studied and the rest of the nation. As a subsidiary observation, we also observe that an authority with only a regional constituency may have incentive to adopt a "beggar-my-neighbor" policy in circumstances similar to those presented here.

GENERALIZATION OF THE MODEL

The simulation procedure which we have described here derives from a simple case of technology change for a single industry in the interindustry model. The procedure can be—and in several instances has been—applied to a variety of circumstances. Several of these applications are outlined here.

**National basis**

Clearly the simulation procedure does not depend upon the regional nature of the input-output table. Technology change at a national level may be particularly interesting in connection with, for example, substitution of fuels to meet the "energy crisis" forecast for later in this century. At the national level, there is better information about consumption behavior and demand elasticities, so that the results of the macro-economic analysis can be brought into the model. In addition, national tax and other fiscal policies may be studied as adjuncts to the technology change under study.

**Estimating the effects of final demand changes**

Certain national fiscal policy changes have widely differing regional effects. For example, the SST cutback had its
Estimating the effects of price changes

During the recent wage-price-rent freeze, there was considerable interest in the effects of price increases in individual industries on prices in other industries, and ultimately on the Consumer Price Index and the Wholesale Price Index. We used the simulation procedure described here to estimate the potential inflationary impacts, and the actual inflationary impacts of price changes in each of the industries in the 1963 OBE 478-sector interindustry model. The impacts were estimated only in terms of prices in other industries, and in terms of the GNP deflator, and deflators for GNP components: personal consumption expenditures, residential investment, equipment investment, exports, federal government purchases, etc.

In more general terms the impetus for price changes may be from wage, productivity and/or technology changes provided only that these can be expressed as changes to the inter-industry transactions table as demonstrated in Step 1 above.

Estimating time-phased effects

The effects of a time-phased sequence of changes to the transactions table can be estimated by applying the procedure successively. The new transactions table resulting from the set of changes for the first time period serves as the starting point for the changes corresponding to the second time period, and so on. The impact multipliers and other measures of interest are computed as a sequence of impact measures.

Estimating the effects of several simultaneous changes

The simulation procedure as demonstrated above deals with only a single change in technology; however, (1) a technology change may affect several entries in the industry's vector of inputs, and (2) one may wish to consider simultaneous technology changes in several industries at once. The simulation procedure as actually implemented accepts a set of changes to the transaction matrix and computes relative price and production change ratios for all sectors at each round of computations.

APPENDIX: TECHNOLOGY CHANGE IN INPUT-OUTPUT ANALYSIS

Traditional input-output analysis permits derivation of new (relative) prices for an input-output system based on changes in the prices of primary inputs. This paper demonstrates a simple process which permits inference of the new equilibrium input-output system, including price and technology changes, from stipulated initial changes to an input-output transaction matrix. The effects of these changes may be measured in terms of relative price changes by sector, and change to the technology and Leontief inverse matrices. The technique has been applied to demonstrate the regional economic impact of pollution control technology, and to estimate for the Price Commission the potential and actual effects of price changes on GNP component deflators in the 478-order 1963 OBE interindustry model.

The classic input-output model defines prices in terms of the direct and indirect labor requirements for production of the output of each activity. The analogue to labor requirements in applied interindustry analysis is value added, which is composed primarily of the payments to labor and capital and direct and indirect taxes levied by the various levels of government. These inputs are described in "primary" inputs. An additional primary input—which is not classified as value added in OBE interindustry models—is imports.

Prices in a Leontief input-output system are typically described as follows:

\[ P = (I - A')^{-1}A' \]

where

- \( P \) is a vector of (relative) prices
- \( I \) is the identity matrix
- \( A \) is the Leontief Coefficients Matrix (excluding the labor or value added row).
- \( A' \) is the (transposed) value added row of the matrix expressed in dollars per unit of output.

Consequently a given set of changes in the price of value added, \( dA_a \), will result in a set of price changes, \( dP \), in accordance with

\[ dP = (I - A')^{-1} \cdot dA_a \]  

(1)

To determine the impact of price increases for any set of industries (the proceeds are assumed to be distributed to value added only) on equilibrium prices in the system (measured in terms of the GNP and GNP component deflators), construct a diagonal matrix \( D \) whose components transform price changes into value-added changes.

\[ D = \text{diag} \left( \frac{1}{r_i} \right) \]

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Thus
\[ dP = (I - A')^{-1}D \cdot dP^* \]

where \( dP^* \) represents a vector of first round price changes.

Computationally, we may avoid direct inversion of \( (I - A') \) by using the identity
\[ (I - A')^{-1} = I + A' + A'^2(I + A') + \ldots \]

This series converges when the standard input-output assumptions hold, i.e., when the Hawkins-Simon conditions are satisfied.

We now express equation (1) in terms of the transactions matrix. The algorithm used to estimated \( dP \) is based on the power series expression in equation (2a) above. We rewrite equation (1) as
\[ dP = [I + A + A^2(I + A)] \cdot \ldots \cdot \Rightarrow D \cdot dP^* \]

We analyze equation (3) in the following form
\[ dP = (I - A')^{-1}D \cdot dP^* \]

and interpret the first term on the right hand side as the change in the price vector \( P \) induced by all activities (industries) "passing through" the first round of price changes; the second term as the change in \( P \) induced by passing through the second round of price change, etc.

Let \( T \) represent the matrix of interindustry transactions. Then \( T \) is related to \( A \) by
\[ A = D_1 \cdot T \cdot D_2 \]
or
\[ T = (D_1^{-1} \cdot A \cdot D_2^{-1}) \]

where
\[ D_1 = \text{diag } (1/P_i) \]
and
\[ D_2 = \text{diag } (1/V_i) \]

where \( V_i \) is total output for the \( i \)th industry.

Following the above formulation,
\[ dP = (I - A')^{-1}D \cdot dP^* \]

The new transactions matrix \( T^* \) (assuming that the quantities of output demanded are unchanged) is
\[ T^* = D_3 \cdot T \]

and the new matrix of technological coefficients is
\[ A^* = D_1 \cdot T^* \cdot D_2 \]

A more general procedure is used to accommodate changes in technology which may be expressed as changes to the transactions matrix.

Let \( dT \) represent expenditure changes in interindustry transactions and let \( dA_{O} \) represent changes in value-added expenditures.

Then
\[ dP = (I - A^*)^{-1}dA_{O} \]

A computation algorithm may be framed in terms of (4)-(7).

REFERENCES