Lecture #42

ERDM

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EIO-LCA

- EIO-LCA (Economic Input/Output - Life Cycle Assessment)
- Input / Output Analysis??

```
Matl A
1000 kg
```

```
System
```

```
Waste
2 kg
```

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Environmentally Responsible Design & Manufacturing (MEEM 4685/5685)
Dept. of Mechanical Engineering - Engineering Mechanics
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Simple Input - Output Analysis

Data for a snapshot in time

\[ W = 0.002 \times A \]
What are I-O models?

- Used to capture inter-industry/system transactions.
- Industries use the products of other industries to produce their own products
  e.g. - Automobile manufacturers rely on products from chemical, metal, electronics, tire, etc. industries
- Outputs from one industry become inputs to another industry
- When you buy a car, the demand for steel, glass, plastic, etc. is affected.
More on EIO Basic Idea

A $1000 purchase results in way more than $1000 in total activity. Where to invest to get best total impact?
Basic Input-Output Logic

- Steel
- Glass
- Tires
- Plastic
- Other Components

Automobile Factory

Cars
Assumptions

- The economy/system is divided into $n$ sectors [sectors - individuals, companies, nations, etc.]
- Each sector produces exactly one output
- One non-product - Labor
- Constant returns to scale [To increase output by ‘A’, scale input by ‘A’]
- No choice of production techniques [No substitution possible between inputs]
Temporal Distinctions of I-O models

- **Static** - Snap-shot of a system in motion. Represents phenomena at a single interval of time.

- **Comparative Static** - Succession of snap-shots. Compares phenomena at several instances of time.

- **Dynamic** - relation of a frame to the succeeding frame. Shows how phenomena within an interval are related to activities outside the interval.

- **Comparative Dynamic** - comparison of two segments of motion picture.
Economic I-O Analysis

Method to systematically quantify the interrelationships among various sectors of an economic system.
Model Formulation

\( X_i : \) Entire output of industry sector \( i \) -- in $$$$  

\[ X_i = Z_{i1} + Z_{i2} + Z_{i3} + \ldots + Y_i \]

\[ X_i = \sum Z_{ij} + Y_i \]

\( Z_{ij} : \) Output of industry sector \( i \) sold to industry sector \( j \)

\( Y_i : \) Final demand for sector \( i \)'s products (other than inter-industry exchanges) -- Govt., export, etc.
Inter-industry Demand

\[ Z_{ij} = a_{ij} \cdot X_j \]

- **\( Z_{ij} \)**: Output of sector i sold to sector j
- **\( X_j \)**: Output of sector j
- **\( a_{ij} \)**: Input-output coefficient \((0 < a_{ij} < 1)\)

\[ X_i = a_{i1} \cdot X_1 + a_{i2} \cdot X_2 + a_{i3} \cdot X_3 + \ldots + Y_i \]

\[ X_i = \sum a_{ij} \cdot X_j + Y_i \quad \text{or} \quad X_i - \sum a_{ij} \cdot X_j = Y_i \]
Matrix Form

In matrix form the complete n x n system is:

\[(I - A)X = Y, \text{ where, } A - \text{ matrix of input output coefficients}\]

If \(|I - A|\) is not equal to zero, \((I - A)^{-1}\) can be determined.

Therefore, \(X = (I - A)^{-1} Y\)

Here \((I - A)^{-1}\) is known as the LEONTIEF INVERSE.
Example

Consider two hypothetical sectors

<table>
<thead>
<tr>
<th>From Processing Sectors</th>
<th>To Processing Sectors</th>
<th>Final Demand</th>
<th>Total Output</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1</td>
<td>(Y_i)</td>
<td>(X_i)</td>
</tr>
<tr>
<td>2</td>
<td>2</td>
<td>150</td>
<td>500</td>
</tr>
<tr>
<td>Payments (value added)</td>
<td>650</td>
<td>1400</td>
<td></td>
</tr>
<tr>
<td>Total Outlays</td>
<td>(X_i)</td>
<td>1000</td>
<td>2000</td>
</tr>
</tbody>
</table>

Since $X = (I-A)^{-1}Y$, we can describe how sector outputs, X’s, will change when Y changes.
Example (cont.)

Input output coefficients:
\( a_{11} = \frac{150}{1000} = 0.15 \)

\( a_{12} = \frac{500}{2000} = 0.25 \)

Therefore, 
\[
A = \begin{bmatrix}
0.15 & 0.25 \\
0.20 & 0.05
\end{bmatrix}
\]

\[ Y = \begin{bmatrix}
350 \\
1700
\end{bmatrix}, \quad X = \begin{bmatrix}
1000 \\
2000
\end{bmatrix}
\]

Analyze how sector 1 & 2 outputs are affected if final demand for sector 1 is increased from $350 to $400 and that of sector 2 is reduced from $1700 to $1600.
Example (cont.)

From problem statement,

\[ Y = \begin{bmatrix} 400 \\ 1600 \end{bmatrix} \sim Y = \begin{bmatrix} 50 \\ -100 \end{bmatrix} \]

Also,

\[ (I - A) = \begin{bmatrix} 0.85 & -0.25 \\ -0.20 & 0.95 \end{bmatrix} \quad \text{and} \quad (I - A)^{-1} = \begin{bmatrix} 1.254 & 0.33 \\ 0.264 & 1.122 \end{bmatrix} \]

\[
dX = (I - A)^{-1} \cdot dY = \begin{bmatrix} 1.254 & 0.33 \\ 0.264 & 1.122 \end{bmatrix} \cdot \begin{bmatrix} 50 \\ -100 \end{bmatrix} = \begin{bmatrix} 29.7 \\ -99 \end{bmatrix}
\]

The change in demand produces an increase in sector 1 output of $29.7 and a decrease in sector 2 output of $99.0.
EIO-LCA
(http://www.eiolca.net/)

- The model divides the U.S. economy into roughly 500 sectors.

- The model can be visualized as a large table (or matrix) with 500 rows and 500 columns, with one row and one column for each sector.

- Economic matrix is augmented with environmental impact indices, used to analyze economy-wide environmental impacts of changes in the output of selected industrial sectors.
EIO-LCA

- The environmental effects estimated include:
  - Electricity consumption,
  - Fuel use, Ore consumption,
  - Fertilizer use, Water consumption

- Environmental outputs:
  - Toxic emissions from the Toxics Release Inventory (TRI),
  - Toxicity-weighted chemical emissions (CMU-ET),
  - RCRA hazardous waste generation/management,
  - Ozone depletion & Global warming potentials,
  - Conventional pollutant emissions
Example of an eiolca.net Application

- $1,000,000 spent to purchase vehicles.

<table>
<thead>
<tr>
<th>Effects</th>
<th>Total all sectors</th>
</tr>
</thead>
<tbody>
<tr>
<td>Economic Purchases [$ million]</td>
<td>2.805601</td>
</tr>
<tr>
<td>Electricity Used [MkW-hr]</td>
<td>0.619805</td>
</tr>
<tr>
<td>Energy Used [TJ]</td>
<td>14.247421</td>
</tr>
<tr>
<td>Conventional Pollutants Released [metric tons]</td>
<td>12.123697</td>
</tr>
<tr>
<td>OSHA Safety [fatalities]</td>
<td>0.000611</td>
</tr>
<tr>
<td>Greenhouse Gases Released [metric tons CO2 equiv.]</td>
<td>1015.733333</td>
</tr>
<tr>
<td>Fertilizers Used [$ million]</td>
<td>0.000313</td>
</tr>
<tr>
<td>Fuels Used [metric tons]</td>
<td>387.640473</td>
</tr>
<tr>
<td>Ores Used - at least [metric tons]</td>
<td>326.117099</td>
</tr>
<tr>
<td>Hazardous Waste Generated [RCRA, metric tons]</td>
<td>47.438562</td>
</tr>
<tr>
<td>External Costs Incurred [median, $ million]</td>
<td>0.027846</td>
</tr>
<tr>
<td>Toxic Releases and Transfers [metric tons]</td>
<td>2.023702</td>
</tr>
<tr>
<td>Weighted Toxic Releases and Transfers [metric tons]</td>
<td>11.583339</td>
</tr>
<tr>
<td>Water Used [billion gallons]</td>
<td>0.006308</td>
</tr>
</tbody>
</table>
- $1,000,000 to a University

<table>
<thead>
<tr>
<th>Effects</th>
<th>Total all sectors</th>
</tr>
</thead>
<tbody>
<tr>
<td>Economic Purchases [$ million]</td>
<td>1.765978</td>
</tr>
<tr>
<td>Electricity Used [MkW-hr]</td>
<td>0.182479</td>
</tr>
<tr>
<td>Energy Used [TJ]</td>
<td>4.376041</td>
</tr>
<tr>
<td>Conventional Pollutants Released [metric tons]</td>
<td>5.138401</td>
</tr>
<tr>
<td>OSHA Safety [fatalities]</td>
<td>0.000634</td>
</tr>
<tr>
<td>Greenhouse Gases Released [metric tons CO2 equiv.]</td>
<td>298.175632</td>
</tr>
<tr>
<td>Fertilizers Used [$ million]</td>
<td>0.000184</td>
</tr>
<tr>
<td>Fuels Used [metric tons]</td>
<td>110.132634</td>
</tr>
<tr>
<td>Ores Used - at least [metric tons]</td>
<td>34.658559</td>
</tr>
<tr>
<td>Hazardous Waste Generated [RCRA, metric tons]</td>
<td>13.064121</td>
</tr>
<tr>
<td>External Costs Incurred [median, $ million]</td>
<td>0.011248</td>
</tr>
<tr>
<td>Toxic Releases and Transfers [metric tons]</td>
<td>0.193479</td>
</tr>
<tr>
<td>Weighted Toxic Releases and Transfers [metric tons]</td>
<td>1.017710</td>
</tr>
<tr>
<td>Water Used [billion gallons]</td>
<td>0.001088</td>
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</tbody>
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