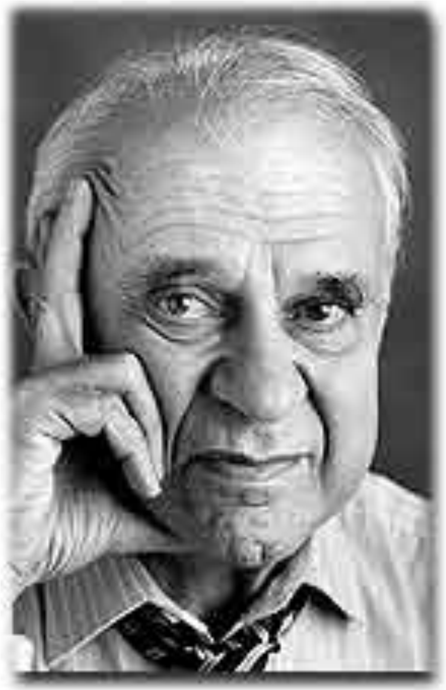
Multiregional Input-Output Disaster Risk Analysis for the Philippines

Dr. Krista Danielle Yu

Overview

- Brief introduction
  - Input-Output Modelling
  - Inoperability Input-Output Modelling
- Multiregional Input-Output Modelling
- Case Study
- Conclusion and Future Work

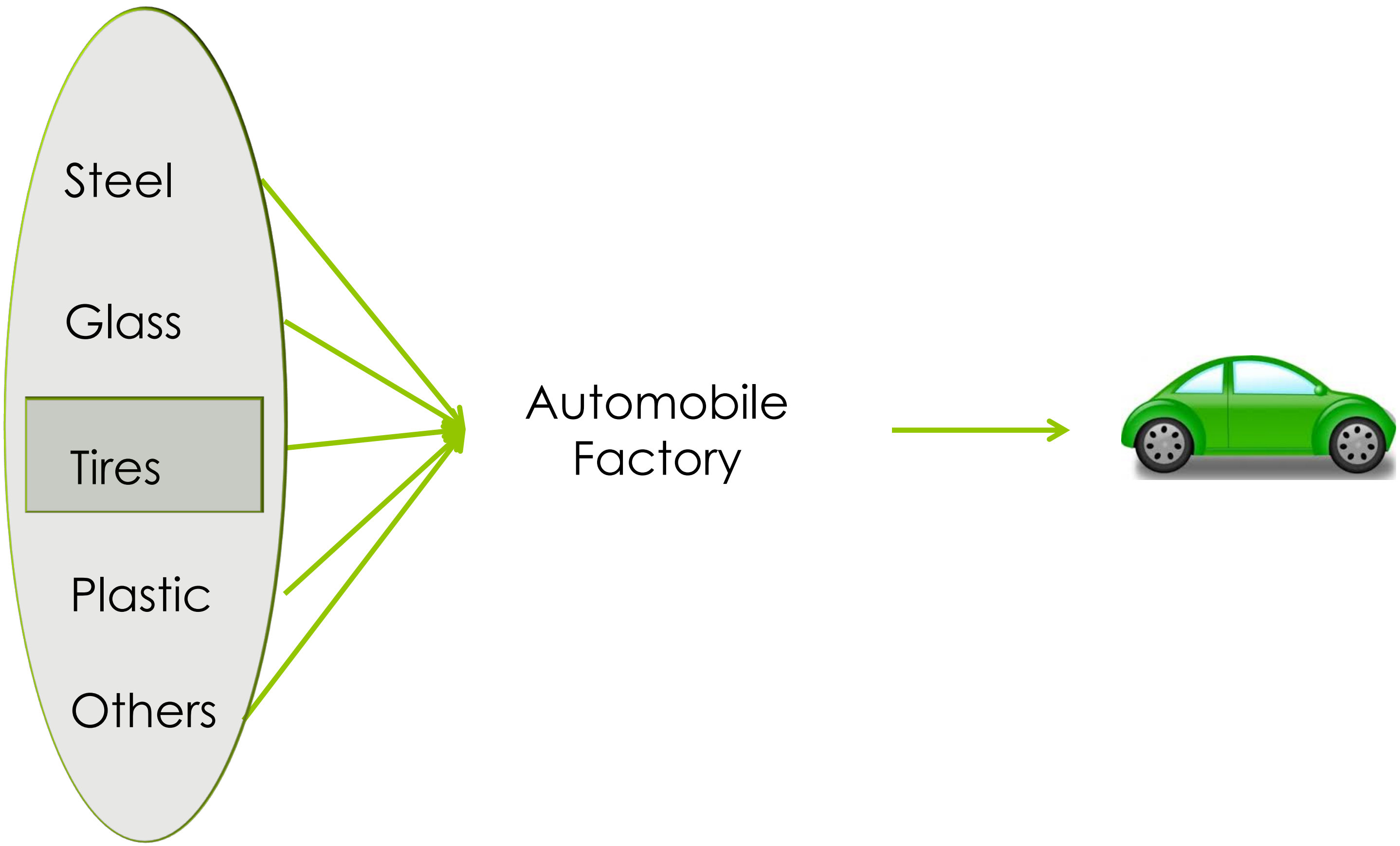
Input-Output Analysis: Historical Perspective



Wassily Leontief received the *Sveriges Riksbank Prize in Economic Sciences in Memory of Alfred Nobel 1973*

"for the development of the input-output method and for its application to important economic problems"

Basic I-O Logic



Basic I-O Logic

From a tire producer's perspective

Final Demand
End-users

Tires

Automobile Factory

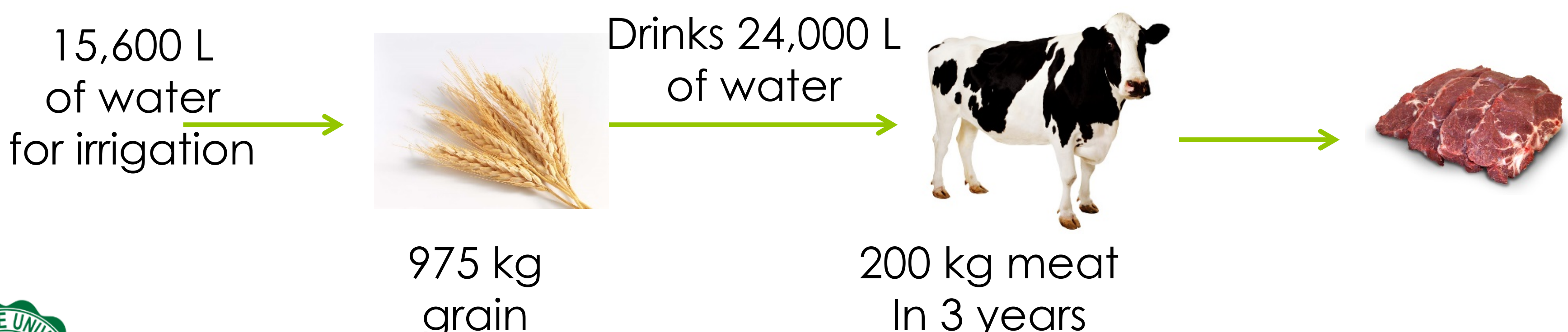
Truck Manufacturer

Intermediate Demand

Bus Operator

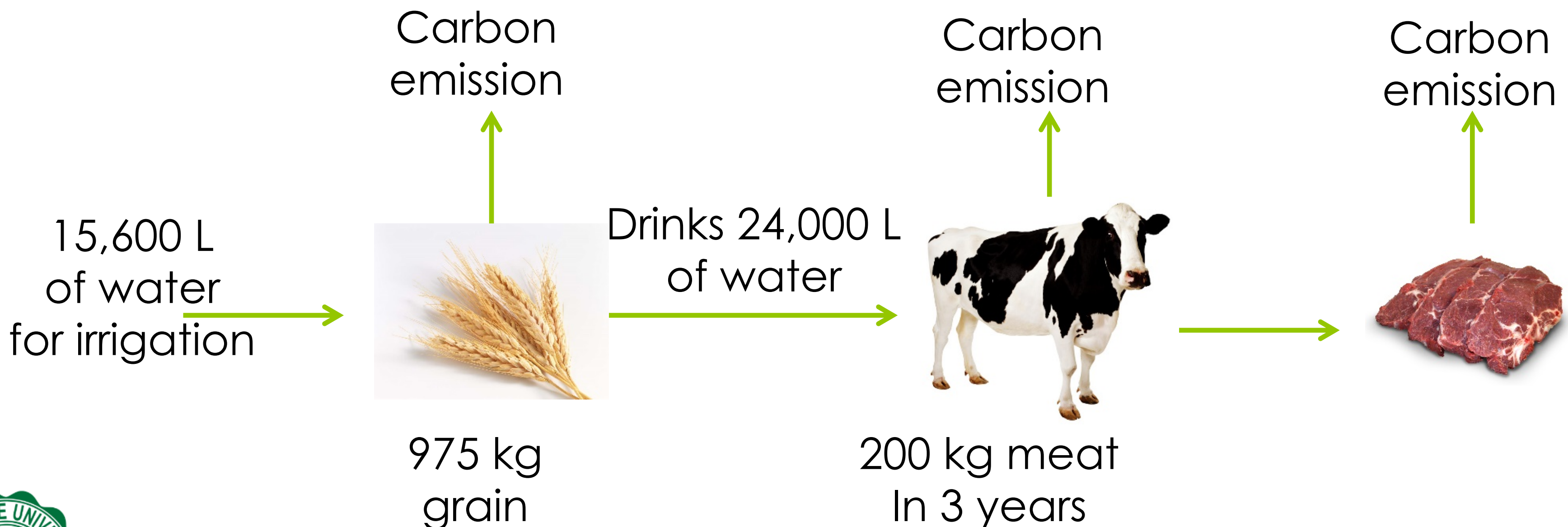
Uses of I-O

- Footprint calculation
- Water footprint:
  - 1 kg of beef = ? L of water



Uses of I-O

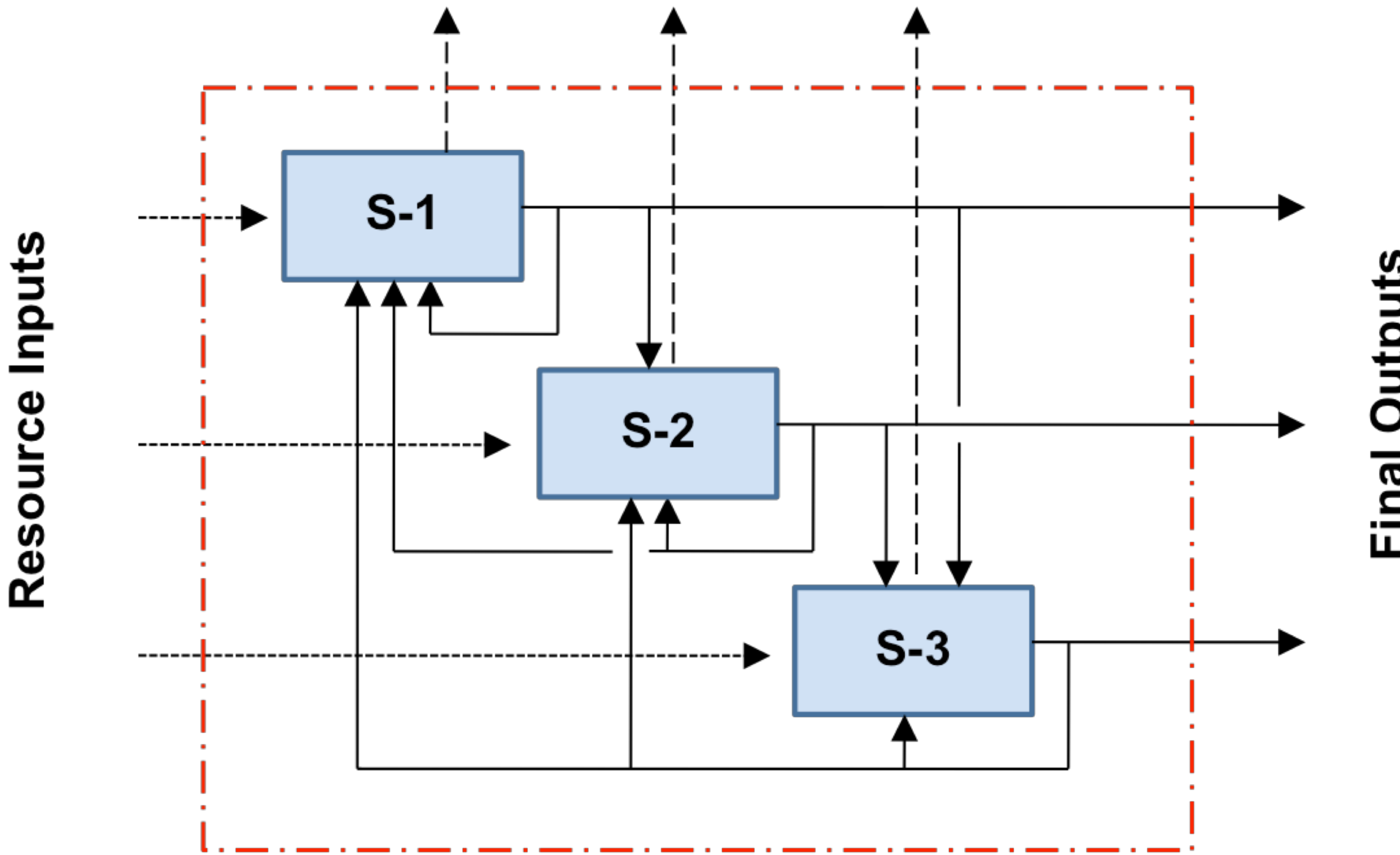
- Footprint calculation
- Carbon footprint:
  - 1 kg of beef = ? kg of carbon equivalent



Input-Output Analysis

- Illustrates macroeconomic activity as a system of interrelated goods and services
- various economic sectors as a series of inputs of source materials (or services) and outputs of finished or semi-finished goods (or services)
- Shows the inter-industry flow of goods and services in a given time period.

A Three-Sector Input-Output System



Input Output Modelling

- Using the technical coefficients $a_{ij} = \dfrac{z_{ij}}{x_j}$
  - We can construct the technical coefficients matrix **A** such that

$$\mathbf{A}=\begin{bmatrix} a_{11} & \cdots & a_{1n} \\ \vdots & \ddots & \vdots \\ a_{n1} & \cdots & a_{nn} \end{bmatrix} \quad \mathbf{x}=\begin{bmatrix} x_1 \\ \vdots \\ x_n \end{bmatrix} \quad \mathbf{f}=\begin{bmatrix} f_1 \\ \vdots \\ f_n \end{bmatrix}$$

$$\mathbf{x} = \mathbf{A}\mathbf{x} + \mathbf{f}$$

$$\mathbf{x} - \mathbf{A}\,\mathbf{x} = \mathbf{f}$$

$$\mathbf{I}\,\mathbf{x} - \mathbf{A}\,\mathbf{x} = \mathbf{f}$$

$$(\mathbf{I} - \mathbf{A})\;\mathbf{x} = \mathbf{f}$$

$$(\mathbf{I} - \mathbf{A})^{-1}(\mathbf{I} - \mathbf{A})\;\mathbf{x} = (\mathbf{I} - \mathbf{A})^{-1}\mathbf{f}$$

$$\mathbf{x} = (\mathbf{I} - \mathbf{A})^{-1}\mathbf{f}$$

A 2 – sector example

	Sector 1	Sector 2	Final Demand (f)	Total Output (x)
Sector 1	150	500	350	1000
Sector 2	200	100 **Z**	1700	2000
Primary Input	650	1400 **w'**		
Total Input	1000	2000 **x'**		

Adapted from Miller and Blair (2009)

A 2 – sector example

	Sector 1	Sector 2	Final Demand (f)	Total Output (x)
Sector 1	150	500	350	1000
Sector 2	200	100	1700	2000
Primary Input	650	1400		
Total Input	1000	2000		

150 pesos worth of inputs from Sector 1
and 200 pesos worth of inputs from Sector 2

A 2 – sector example

	Sector 1	Sector 2	Final Demand (f)	Total Output (x)
Sector 1	150	500	350	1000
Sector 2	200	100	1700	2000
Primary Input	650			
Total Input	1000			

Sector 1 produces 1,000 pesos worth of output
150 pesos of which is used by Sector 1
500 pesos by Sector 2
350 pesos is sold to consumers

A 2 – sector example

	Sector 1	Sector 2	Final Demand (f)	Total Output (x)
Sector 1	150/1000	500/2000	350	1000
Sector 2	200/1000	100/2000	1700	2000

$$a_{ij} = \frac{z_{ij}}{x_j}$$

Technical Coefficients Matrix **A**

	Sector 1	Sector 2
Sector 1	0.15	0.25
Sector 2	0.20	0.05

Impact Assessment

- What will happen if there is a one peso increase in final demand for the output of Sector 1?
- Will output also increase by 1 peso?

$$\mathbf{x} = \boxed{(\mathbf{I} - \mathbf{A})^{-1}}\mathbf{f}$$

Leontief Inverse

$$\mathbf{I} \begin{bmatrix} 1 & 0 \\ 0 & 1 \end{bmatrix} - \mathbf{A} \begin{bmatrix} 0.15 & 0.25 \\ 0.20 & 0.05 \end{bmatrix} = \mathbf{(I\text{-}A)} \begin{bmatrix} 0.85 & -0.25 \\ -0.20 & 0.95 \end{bmatrix}$$

$$(\mathbf{I} - \mathbf{A})^{-1} \begin{bmatrix} 1.25 & 0.33 \\ 0.26 & 1.12 \end{bmatrix} \quad \textbf{Change in f} \begin{bmatrix} 1 \\ 0 \end{bmatrix} = \begin{bmatrix} 1.25 \\ 0.26 \end{bmatrix}$$

Total =P 1.51

Sector 1's output will increase by 1.25 pesos

Sector 2's output will increase by 0.26 pesos

Impact Assessment

- What will happen if there is a one peso increase in final demand for the output of Sector 2?
- Will output also increase by 1 peso?

$$\mathbf{x} = \boxed{(\mathbf{I} - \mathbf{A})^{-1}}\mathbf{f}$$

Leontief Inverse

I

1	0
0	1

\-

A

0.15	0.25
0.20	0.05

=

(I-A)

0.85	-0.25
-0.20	0.95

$(\mathbf{I} - \mathbf{A})^{-1}$

1.25	0.33
0.26	1.12

Change in f

0
1

=

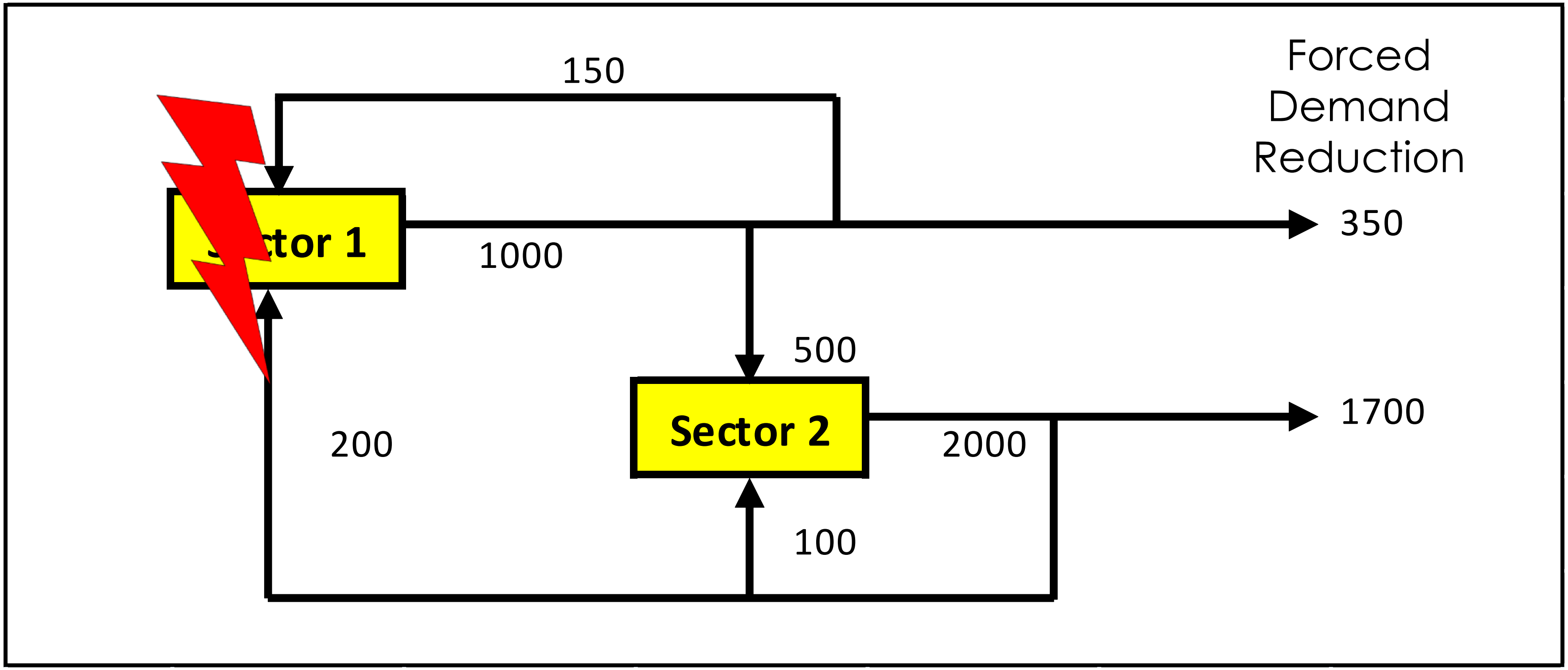
0.33
1.12

Total =P 1.45

Sector 1's output will increase by 0.33 pesos

Sector 2's output will increase by 1.12 pesos

Visual Presentation



What if a disaster strikes and Sector 1 will not be able to meet final demand requirements?

Inoperability Input-Output Model

- Haimes and Jiang (2001) defined inoperability as

  "the inability of the system to perform its intended function."

- Various interpretations of the concept have been proposed:
  - Probability-weighted degree of failure (Haimes and Jiang, 2001)
  - Loss of physical output or functionality (Haimes et al., 2005)
  - **Drop in economic output or demand (Santos and Haimes, 2004; Haimes et al., 2005)**

Important IIM Articles

Leontief-Based Model of Risk in Complex Interconnected Infrastructures

By Yacov Y. Haimes[1] and Pu Jiang[2]

ABSTRACT: Wassily Leontief received the 1973 Nobel Price in Econo
known as the Leontief input-output model of the economy. Leontief's m
connectedness among the various sectors of an economy and forecasting
in another. A Leontief-based infrastructure input-output model is develope
intraconnectedness within each critical infrastructure as well as the interc
input/output model is then generalized into a generic risk model with the f
A preliminary study of the dynamics of risk of inoperability is discussed, u
Several examples are presented to illustrate the theory and its application

BACKGROUND

The advancement in information technology has markedly increased the interconnectedness and interdependencies of our critical infrastructures, such as telecommunications, electrical power systems, gas and oil storage and transportation, banking and finance, transportation, water-supply systems, emergency services, and continuity of government. There is an urgent emerging need to better understand and advance the art and science of modeling complexity and of interconnected large-scale complex systems; this need stems from the increasing vulnerability of our critical infrastructures.

President Clinton's Executive Order 13010, issued on July 15, 1996, established the President's Commission on Critical Infrastructure Protection (PCCIP) in order to develop a national strategy for protecting these infrastructures from various

for generation
the quality and
systems intera
quantity of su
tity of surface
of point and n
ents. In additi
closely depen
of the watersh
hurricanes, cli
own critical i
and ground w
which enable
flow without
impacts on thi
and leaky inf

Risk Analysis, Vol. 24, No. 6, 2004

Modeling the Demand Reduction Input-Output (I-O) Inoperability Due to Terrorism of Interconnected Infrastructures[1]

Joost R. Santos[2]* and Yacov Y. Haimes[2]

Interdependency analysis in the context of this article is a process of assessing and managing risks inherent in a system of interconnected entities (e.g., infrastructures or industry sectors). Invoking the principles of input-output (I-O) and decomposition analysis, the article offers a framework for describing how terrorism-induced perturbations can propagate due to interconnectedness. Data published by the Bureau of Economic Analysis Division of the U.S. Department of Commerce is utilized to present applications to serve as test beds for the proposed framework. Specifically, a case study estimating the economic impact of airline demand perturbations to national-level U.S. sectors is made possible using I-O matrices. A ranking of the affected sectors according to their vulnerability to perturbations originating from a primary sector (e.g., air transportation) can serve as important input to risk management. For example,

Multiregional input output disaster risk analysis for the Philippines

Inoperability Input-Output Model

Santos and Haimes

$$q = A^{*} q + c^{*} \longrightarrow x = Ax + f$$

$$q = (I - A^{*})^{-1} \; c^{*} \longrightarrow x = (I - A)^{-1} f$$

where:

A*	= interdependency matrix
c*	= initial inoperability matrix
I	= identity matrix
q	= inoperability vector

Inoperability Input-Output Model

- Can be computed based on I-O tables published by national statistics offices
- National Statistical Coordination Board under the Philippine Statistics Authority

Santos and Haimes (2004)

$$q_i = \frac{x_i - \widetilde{x}_i}{x_i}$$

where:

q_i = inoperability level of sector *i*
x_i = ideal level of production of sector *i*
$\widetilde{x}_i$ = degraded level of production of sector *i*

Inoperability Input-Output Model

Santos and Haimes (2004)

$$\mathbf{A}^* = \hat{\mathbf{x}}^{-1}\mathbf{A}\hat{\mathbf{x}}$$

where:

$\mathbf{A}^*$ = interdependency matrix

$\hat{\mathbf{x}}$ = diagonalized output vector

$\mathbf{A}$ = technical coefficients matrix

a_{ij}^* = Additional inoperability contributed by sector j to sector i

Inoperability Input-Output Model

Santos and Haimes (2004)

$$\mathbf{c}^* = \hat{\mathbf{x}}^{-1}(\mathbf{c} - \tilde{\mathbf{c}})$$

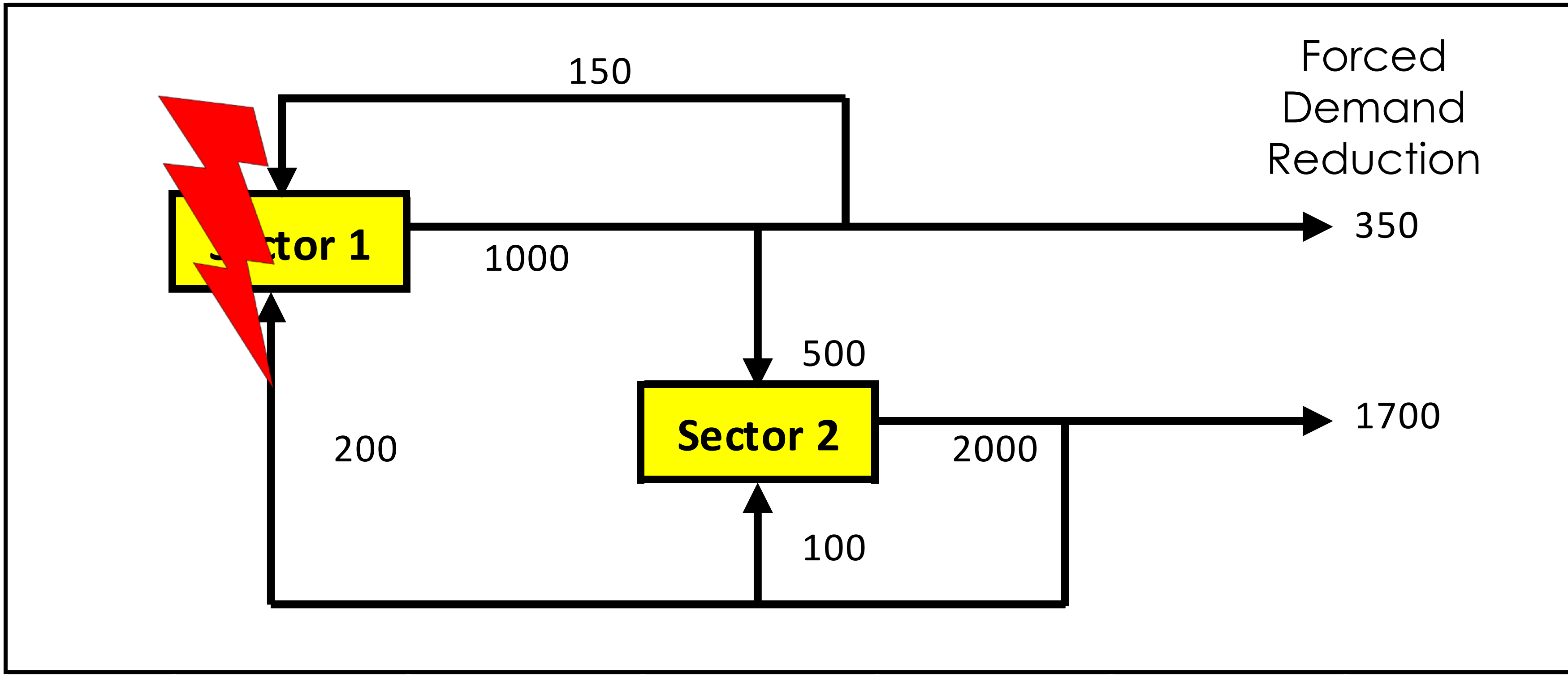
where:

$\mathbf{c}^*$ = normalized degraded demand vector

$\mathbf{c}$ = ideal final demand vector

$\tilde{\mathbf{c}}$ = degraded final demand vector

Visual Presentation



What happens if the final demand for Sector 1 decreases by an amount equivalent to 10% of the baseline total output of sector 1?

Multiregional input output disaster risk analysis for the Philippines

A 2 – sector example

	Sector 1	Sector 2	Final Demand (c)	Total Output (x)
Sector 1	0.15	0.25	**250**	**?**
Sector 2	0.20	0.05	1700	**?**

$$\mathbf{c}^* = \hat{\mathbf{x}}^{-1}(\mathbf{c} - \tilde{\mathbf{c}})$$

$$\mathbf{c}^* = \begin{bmatrix} 1/1000 & 0 \\ 0 & 1/2000 \end{bmatrix} \begin{bmatrix} 350 - 250 \\ 1700 - 1700 \end{bmatrix} = \begin{bmatrix} 0.10 \\ 0 \end{bmatrix}$$

Demand perturbation

A 2 – sector example

	Sector 1	Sector 2	Final Demand (c)	Total Output (x)
Sector 1	0.15	0.25	**250**	**?**
Sector 2	0.20	0.05	1700	**?**

$$\mathbf{A}^* = \hat{\mathbf{x}}^{-1}\mathbf{A}\hat{\mathbf{x}}$$

$$= \begin{bmatrix} 1/1000 & 0 \\ 0 & 1/2000 \end{bmatrix} \begin{bmatrix} 0.15 & 0.25 \\ 0.20 & 0.05 \end{bmatrix} \begin{bmatrix} 1000 & 0 \\ 0 & 2000 \end{bmatrix}$$

$$\mathbf{A}^* = \begin{bmatrix} 0.15 & 0.50 \\ 0.10 & 0.05 \end{bmatrix}$$

A 2 – sector example

	Sector 1	Sector 2	Final Demand (c)	Total Output (x)
Sector 1	0.15	0.25	**250**	**?**
Sector 2	0.20	0.05	1700	**?**

$$\mathbf{q} = (\mathbf{I} - \mathbf{A}^*)^{-1}\mathbf{c}^*$$

$$= \left(\begin{bmatrix} 1 & 0 \\ 0 & 1 \end{bmatrix} - \begin{bmatrix} 0.15 & 0.50 \\ 0.10 & 0.05 \end{bmatrix}\right)^{-1} \begin{bmatrix} 0.10 \\ 0 \end{bmatrix}$$

$$\mathbf{q} = \begin{bmatrix} 1.25 & 0.66 \\ 0.13 & 1.12 \end{bmatrix} \begin{bmatrix} 0.10 \\ 0 \end{bmatrix} = \begin{bmatrix} 0.125 \\ 0.013 \end{bmatrix}$$

Sector 1's final inoperability is 12.5%

Sector 2's final inoperability is 1.3%

A 2 – sector example

	Sector 1	Sector 2	Final Demand (c)	Total Output (x)
Sector 1	0.15	0.25	**250**	**?**
Sector 2	0.20	0.05	1700	**?**

$$\mathbf{q} = (\mathbf{I} - \mathbf{A}^*)^{-1}\mathbf{c}^*$$

$$= \left(\begin{bmatrix} 1 & 0 \\ 0 & 1 \end{bmatrix} - \begin{bmatrix} 0.15 & 0.50 \\ 0.10 & 0.05 \end{bmatrix}\right)^{-1} \begin{bmatrix} 0.10 \\ 0 \end{bmatrix}$$

$$\mathbf{q} = \begin{bmatrix} 1.25 & 0.66 \\ 0.13 & 1.12 \end{bmatrix} \begin{bmatrix} 0.10 \\ 0 \end{bmatrix} = \begin{bmatrix} 0.125 \\ 0.013 \end{bmatrix}$$

Sector 1's final inoperability is 12.5%

Sector 2's final inoperability is 1.3%

A 2 – sector example

	Sector 1	Sector 2	Final Demand (c)	Total Output (x)
Sector 1	0.15	0.25	**250**	**?**
Sector 2	0.20	0.05	1700	**?**

$$\mathbf{q} = \begin{bmatrix} 0.125 \\ 0.013 \end{bmatrix} \quad \mathbf{x} = \begin{bmatrix} 1000 \\ 2000 \end{bmatrix}$$

New level of output as a result of the perturbation

$$\mathbf{x} = \begin{bmatrix} 1000 - (1000 * 0.125) \\ 2000 - (2000 * 0.013) \end{bmatrix} = \begin{bmatrix} 874.59 \\ 1973.60 \end{bmatrix}$$

A 2 – sector example

	Sector 1	Sector 2	Final Demand (c)	Total Output (x)
Sector 1	0.15	0.25	**250**	**874.59**
Sector 2	0.20	0.05	1700	**1973.60**

$$\mathbf{q} = \begin{bmatrix} 0.125 \\ 0.013 \end{bmatrix} \quad \mathbf{x} = \begin{bmatrix} 1000 \\ 2000 \end{bmatrix}$$

New level of output as a result of the perturbation

$$\mathbf{x} = \begin{bmatrix} 1000 - (1000 * 0.125) \\ 2000 - (2000 * 0.013) \end{bmatrix} = \begin{bmatrix} 874.59 \\ 1973.60 \end{bmatrix}$$

A 2 – sector example

	Sector 1	Sector 2	Final Demand (c)	Total Output (x)
Sector 1	0.15	0.25	**250**	**874.59**
Sector 2	0.20	0.05	1700	**1973.60**

$$\mathbf{q} = \begin{bmatrix} 0.125 \\ 0.013 \end{bmatrix} \quad \mathbf{x} = \begin{bmatrix} 1000 \\ 2000 \end{bmatrix}$$

New level of output as a result of the perturbation

$$\mathbf{x} = \begin{bmatrix} 1000 - (1000 * 0.125) \\ 2000 - (2000 * 0.013) \end{bmatrix} = \begin{bmatrix} 874.59 \\ 1973.60 \end{bmatrix}$$

Economic loss of sector *i* = $x_i q_i$

Multiregional input output disaster risk analysis for the Philippines

A 2 – sector example

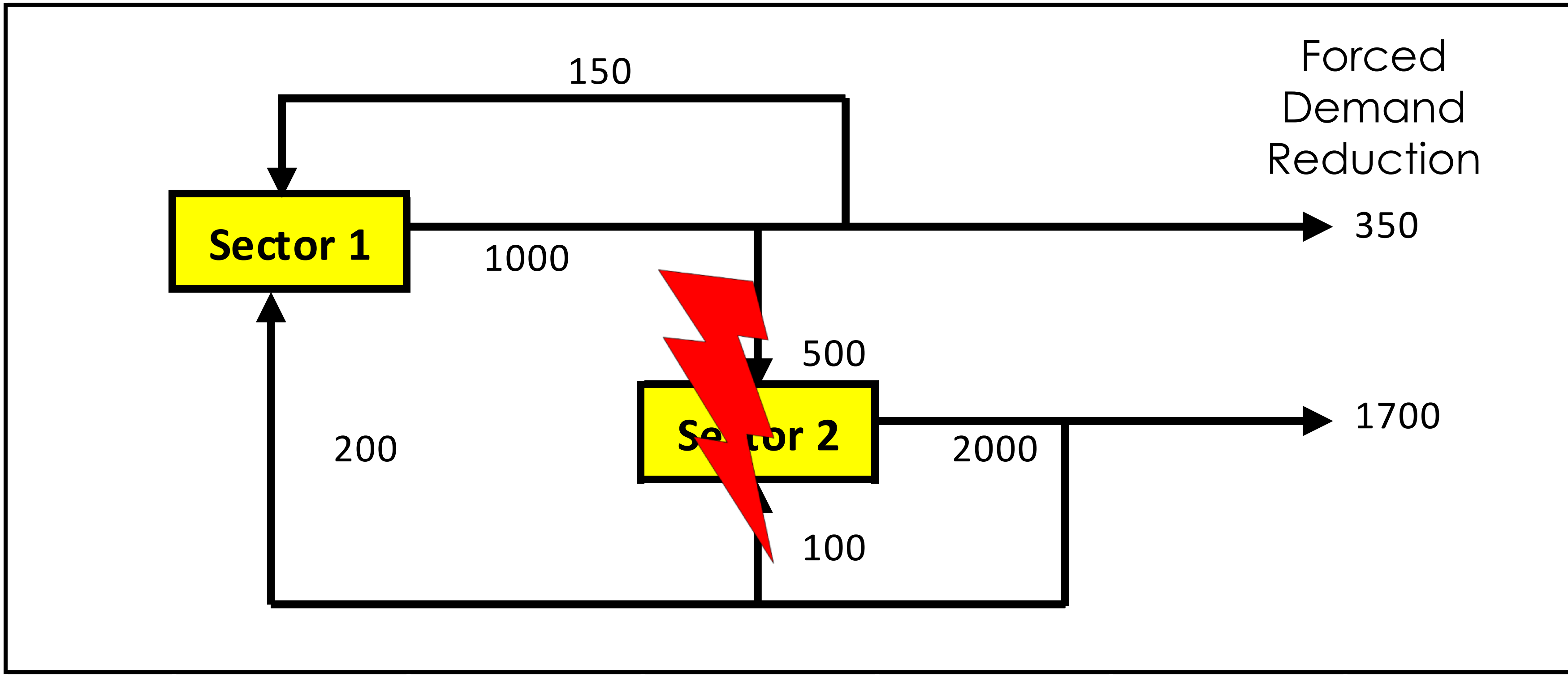
	Sector 1	Sector 2	Final Demand (c)	Total Output (x)
Sector 1	0.15	0.25	**250**	**874.59**
Sector 2	0.20	0.05	1700	**1973.60**

$$\mathbf{q} = \begin{bmatrix} 0.125 \\ 0.013 \end{bmatrix} \quad \mathbf{x} = \begin{bmatrix} 1000 \\ 2000 \end{bmatrix}$$

$$\mathbf{EL} = \begin{bmatrix} (1000 * 0.125) \\ (2000 * 0.013) \end{bmatrix} = \begin{bmatrix} 125.41 \\ 26.40 \end{bmatrix}$$

Economic loss of sector *i* = $x_i q_i$ **PhP 151.81**

Visual Presentation



What happens if the final demand for Sector 1 decreases by an amount equivalent to 10% of the baseline total output of sector 1?

A 2 – sector example

	Sector 1	Sector 2	Final Demand (c)	Total Output (x)
Sector 1	0.15	0.25	350	?
Sector 2	0.20	0.05	**1500**	?

$$\mathbf{c}^* = \hat{\mathbf{x}}^{-1}(\mathbf{c} - \tilde{\mathbf{c}})$$

$$\mathbf{c}^* = \begin{bmatrix} 1/1000 & 0 \\ 0 & 1/2000 \end{bmatrix} \begin{bmatrix} 350 - 350 \\ 1700 - 1500 \end{bmatrix} = \begin{bmatrix} 0 \\ 0.10 \end{bmatrix}$$

Demand perturbation

A 2 – sector example

	Sector 1	Sector 2	Final Demand (c)	Total Output (x)
Sector 1	0.15	0.25	350	**?**
Sector 2	0.20	0.05	**1500**	**?**

$$\mathbf{q} = (\mathbf{I} - \mathbf{A}^*)^{-1}\mathbf{c}^*$$

$$= \left(\begin{bmatrix} 1 & 0 \\ 0 & 1 \end{bmatrix} - \begin{bmatrix} 0.15 & 0.50 \\ 0.10 & 0.05 \end{bmatrix}\right)^{-1} \begin{bmatrix} 0 \\ 0.10 \end{bmatrix}$$

$$\mathbf{q} = \begin{bmatrix} 1.25 & 0.66 \\ 0.13 & 1.12 \end{bmatrix} \begin{bmatrix} 0 \\ 0.10 \end{bmatrix} = \begin{bmatrix} 0.066 \\ 0.112 \end{bmatrix}$$

Sector 1's final inoperability is 6.6%

Sector 2's final inoperability is 11.2%

Multiregional input output disaster risk analysis for the Philippines

A 2 – sector example

	Sector 1	Sector 2	Final Demand (c)	Total Output (x)
Sector 1	0.15	0.25	350	**933.99**
Sector 2	0.20	0.05	**1500**	**1775.58**

$$\mathbf{q} = \begin{bmatrix} 0.066 \\ 0.112 \end{bmatrix} \quad \mathbf{x} = \begin{bmatrix} 1000 \\ 2000 \end{bmatrix}$$

New level of output as a result of the perturbation

$$\mathbf{x} = \begin{bmatrix} 1000 - (1000 * 0.066) \\ 2000 - (2000 * 0.112) \end{bmatrix} = \begin{bmatrix} 933.99 \\ 1775.58 \end{bmatrix}$$

A 2 – sector example

	Sector 1	Sector 2	Final Demand (c)	Total Output (x)
Sector 1	0.15	0.25	350	**933.99**
Sector 2	0.20	0.05	**1500**	**1775.58**

$$\mathbf{q} = \begin{bmatrix} 0.066 \\ 0.112 \end{bmatrix} \quad \mathbf{x} = \begin{bmatrix} 1000 \\ 2000 \end{bmatrix}$$

New level of output as a result of the perturbation

$$\mathbf{x} = \begin{bmatrix} 1000 - (1000 * 0.066) \\ 2000 - (2000 * 0.112) \end{bmatrix} = \begin{bmatrix} 933.99 \\ 1775.58 \end{bmatrix}$$

Economic loss of sector *i* = $x_i q_i$

Multiregional input output disaster risk analysis for the Philippines

A 2 – sector example

	Sector 1	Sector 2	Final Demand (c)	Total Output (x)
Sector 1	0.15	0.25	350	**933.99**
Sector 2	0.20	0.05	**1500**	**1775.58**

$$\mathbf{q} = \begin{bmatrix} 0.125 \\ 0.013 \end{bmatrix} \quad \mathbf{x} = \begin{bmatrix} 1000 \\ 2000 \end{bmatrix}$$

$$\mathbf{EL} = \begin{bmatrix} (1000 * 0.66) \\ (2000 * 0.112) \end{bmatrix} = \begin{bmatrix} 66.01 \\ 224.42 \end{bmatrix}$$

Economic loss of sector *i* = $x_i q_i$ **PhP 290.43**

Multiregional input output disaster risk analysis for the Philippines

Comparing the outcomes

Scenario 1 (10% demand reduction in S1)	Sector 1	Sector 2	Total
Inoperability	0.125	0.013	
Economic Loss	125.41	26.40	151.82

Scenario 2 (10% demand reduction in S2)	Sector 1	Sector 2	Total
Inoperability	0.066	0.112	
Economic Loss	66.01	224.42	290.43

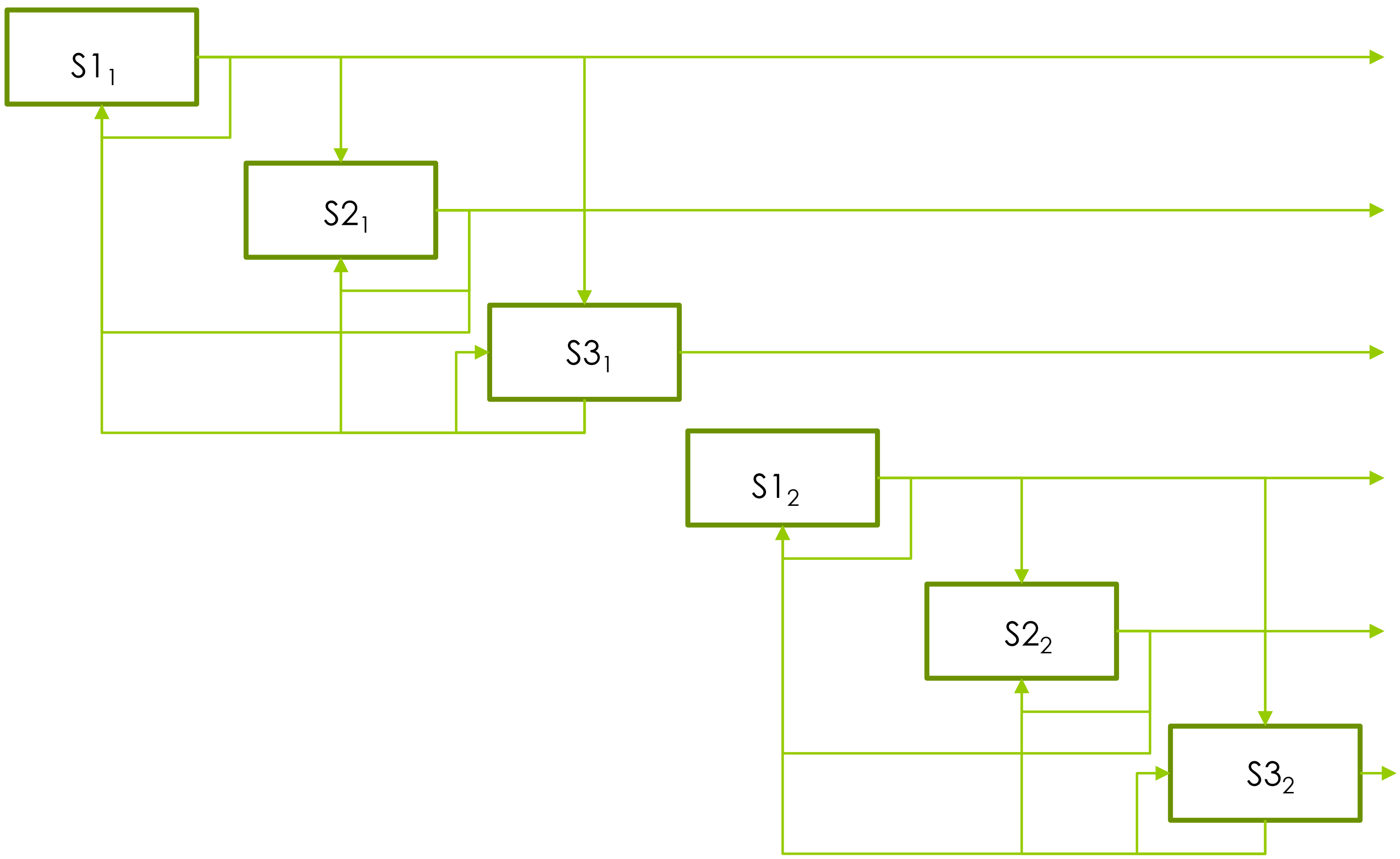
National IO Models vs. Regional IO Models

- National IO Model: Macro view of the entire economy, showing inter-industry transactions on a national scale
- Regional IO Model:
  - Single Region Model: shows the intra-regional flow of transactions, treats all other regions as part of the rest of the world.
  - Inter Regional Input-Output Model (IRIO): Single Region Model with intra-regional transaction flows; Data gathered through survey
  - Multi Regional Input-Output Model (MRIO): Single Region Model with intra-regional transaction flows; Data gathered through non-survey methods or hybrid methods; an estimation of IRIO.

Why Regionalize?

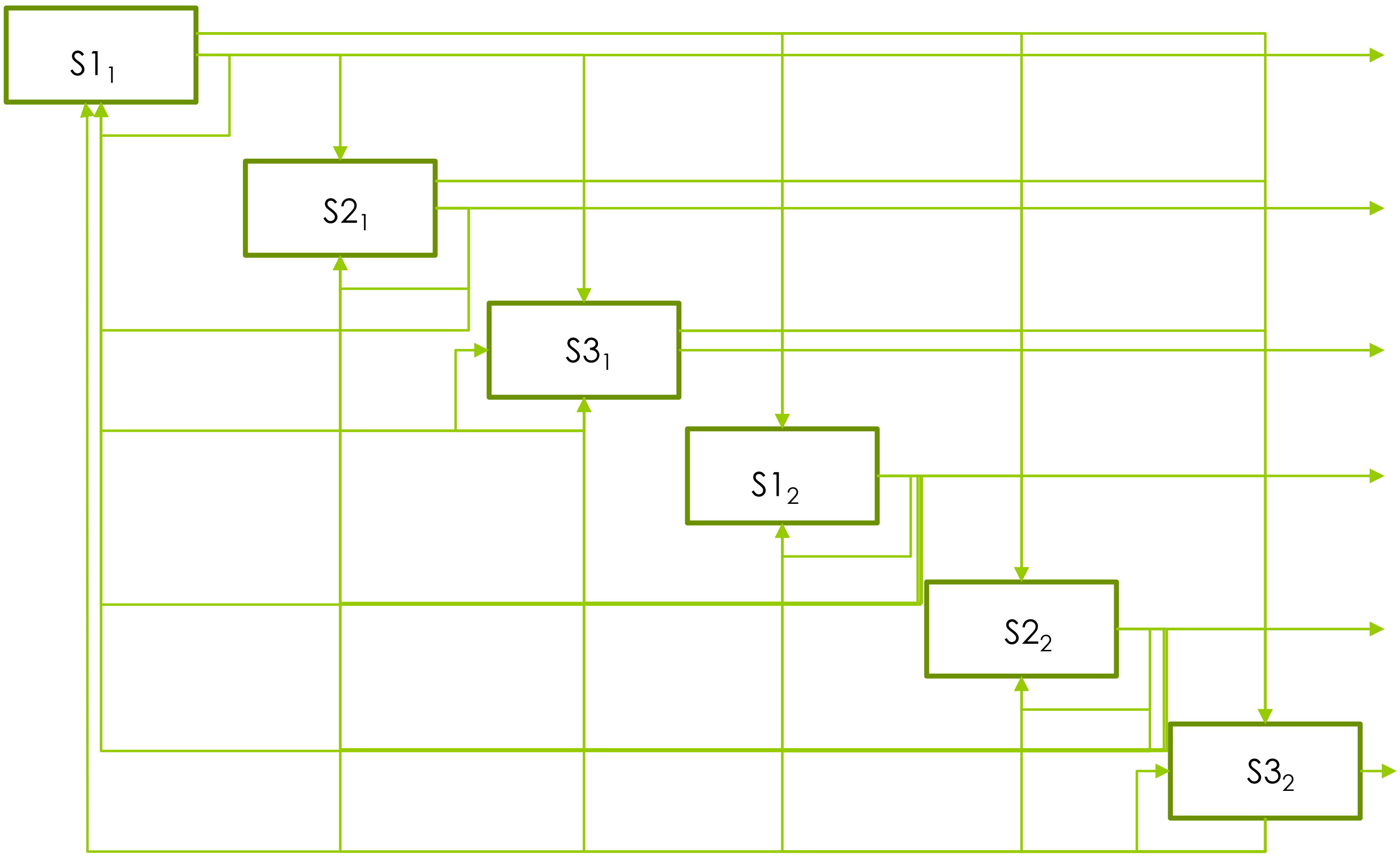
- Technology of production of each region is specific
  - It may be very close or very different from the national table.
- To account for cross-regional interdependencies.
  - Demand footprint – purchasing goods and services from other regions
  - Supply footprint – supplier of goods and services for other regions
- Policymakers can mitigate risks against:
  - Disaster scenarios that produce supply perturbations in their demand footprint
  - Disaster scenarios that produce demand perturbations in their supply footprint

Single Regional IO Model Schematic



Multiregional input output disaster risk analysis for the Philippines

Multiregional IO Schematic



Multiregional input output disaster risk analysis for the Philippines

Constructing the MRIO

From \ To		Luzon			Visayas			Mindanao			Final Demand	Total Output
		AGR	IND	SRV	AGR	IND	SRV	AGR	IND	SRV		
Luzon	S1											
	S2	Z_{11}			Z_{12}			Z_{13}			f_1	x_1
	S3											
Visayas	S1											
	S2	Z_{21}			Z_{22}			Z_{23}			f_2	x_2
	S3											
Mindanao	S1											
	S2	Z_{31}			Z_{32}			Z_{33}			f_3	x_3
	S3											
Value Added		v_1			v_2			v_3				
Total Input		x_1^T			x_2^T			x_3^T				

Multiregional input output disaster risk analysis for the Philippines

Examples of MRIOs

- Global Models
  - World Input-Output Database (WIOD) –environment and socio-economic indicators
  - Global Trade Analysis Project (GTAP) – focuses on trade
  - OECD – focuses on TiVA more specifically on manufacturing sectors
  - Asian International IO Table (IDE-JETRO) – concentrates on Asian economies with 70 sectors
  - EORA – extensive environmental indicators including 187 countries
  - ADB MRIO- includes 45 economies and 35 sector breakdown
- Country Level
  - Japan
  - China
  - Australia
  - US

Philippines

- 1994 Metro-Manila Inter-Regional Input Output Table (Secretario, Kim and Dakila 2002)
- 1994 Philippine Multiregion Inter-regional Input Output Table (Kim, Secretario and Kaneko, 2010)
- 2012 10-region 7-sector Philippine IO Table
  - Sectors: Agriculture, Mining and Quarrying, Manufacturing, Construction, Electricity Gas and Water, Transportation Communication and Storage, Other Services
  - Regions: NCR, CAR, I, II, III, IVA, IVB, V, Visayas and Mindanao

Constructing the MRIO

- Simple Location Quotients (SLQ): a measure of a region's industrial specialization relative to a nation

$$SLQ_i^r = \frac{x_i^r \Big/ \sum_{i=1}^{n} x_i^r}{x_i^N \Big/ \sum_{i=1}^{n} x_i^N}$$

where x_i^r is the regional total output for sector *i*,
x_i^N is the national total output for sector *i*

	Luzon	Visayas	Mindanao
AGR	0.8128	1.1877	1.7624
IND	0.9996	1.0078	0.9954
SRV	1.0455	0.9474	0.8208

The value of SLQ_i^r reflects region *r*'s sector *i*'s self-sufficiency such that it assumes a value greater than or equal to 1 indicates that it does not require imports from other regions, while a value less than 1 indicates the region *r*'s output for sector *i* is not sufficient to address its intermediate demand.

Constructing the MRIO

- $a_{ij}^{rr} = \begin{cases} SLQ_i^r \; a_{ij}^N & \text{if } SLQ_i^r < 1 \\ a_{ij}^N & \text{if } SLQ_i^r \geq 1 \end{cases}$

- $a_{ij}^{sr} = \begin{cases} (1 - SLQ_i^r) \; a_{ij}^N & \text{if } SLQ_i^r < 1 \\ 0 & \text{if } SLQ_i^r \geq 1 \end{cases}$

$\mathbf{A}^{sr}$, where region s is the source region and region r is the destination region. In a two-region case, we can assume that given a location quotient $SLQ_i^r = 0.85$, the remaining 15 percent of the input requirement of region *r* will be imported from region *s*.

Assumptions of MRIO

- Output of sector i in region r is equal to the sum of intermediate consumption across all regions plus the sum of final consumption across all regions.
- Intermediate consumption of any sector in any region is proportional to its production output
  - Proportion of output of sector j in region s that equates to the amount of intermediate consumption by sector j in region s of sector I production in region r
  - $a_{ij}^{rs} = t_i^{rs} a_{ij}^{\cdot s}$
- Demand by all sectors in region s for commodity i in region r is pooled to modify the distribution of intermediate and final consumption
  - t_i^{rs} is the proportion of commodity I consumed by region s that originated in region r

Multi-regional Input-Output Model

- **Pre-disaster**

$$\mathbf{x} = \mathbf{TAx} + \mathbf{Tf} \text{ or } \left\{ \mathrm{x}_{\mathrm{i}}^{\mathrm{r}} = \sum_j t_i^{rs} a_{ij}^{\cdot s} x_j^s + \sum_s t_i^{rs} f_i^s \right\}, \forall i, r$$

where $\mathbf{T} = \begin{bmatrix} \mathbf{T}^{11} & \cdots & \mathbf{T}^{p1} \\ \vdots & \ddots & \vdots \\ \mathbf{T}^{1p} & \cdots & \mathbf{T}^{pp} \end{bmatrix}$, $\mathbf{x} = \begin{bmatrix} \mathbf{x}^1 \\ \vdots \\ \mathbf{x}^p \end{bmatrix}$, $\mathbf{f} = \begin{bmatrix} \mathbf{f}^1 \\ \vdots \\ \mathbf{f}^p \end{bmatrix}$

- **Post-disaster**

$$\tilde{\mathbf{x}} = \mathbf{TA}\tilde{\mathbf{x}} + \mathbf{T}\tilde{\mathbf{f}} \text{or} \left\{ \tilde{x}_{\boldsymbol{i}}^{\boldsymbol{r}} = \sum_j t_i^{rs} a_{ij}^{\cdot s} \tilde{x}_{\boldsymbol{j}}^{\boldsymbol{s}} + \sum_s t_i^{rs} \tilde{f}_{\boldsymbol{i}}^{\boldsymbol{s}} \right\}, \forall i, r$$

where $\tilde{\mathbf{x}} = \begin{bmatrix} \tilde{\mathbf{x}}^1 \\ \vdots \\ \tilde{\mathbf{x}}^p \end{bmatrix}$, $\tilde{\mathbf{f}} = \begin{bmatrix} \tilde{\mathbf{f}}^1 \\ \vdots \\ \tilde{\mathbf{f}}^p \end{bmatrix}$

Multiregional input output disaster risk analysis for the Philippines

Multiregional Inoperability Input-Output Model

- Crowther and Haimes (2009)

Pre-disaster scenario: $\mathbf{x} = \mathbf{TAx} + \mathbf{Tf}$

Post-disaster scenario: $\tilde{\mathbf{x}} = \mathbf{TA}\tilde{\mathbf{x}} + \mathbf{T}\tilde{\mathbf{f}}$

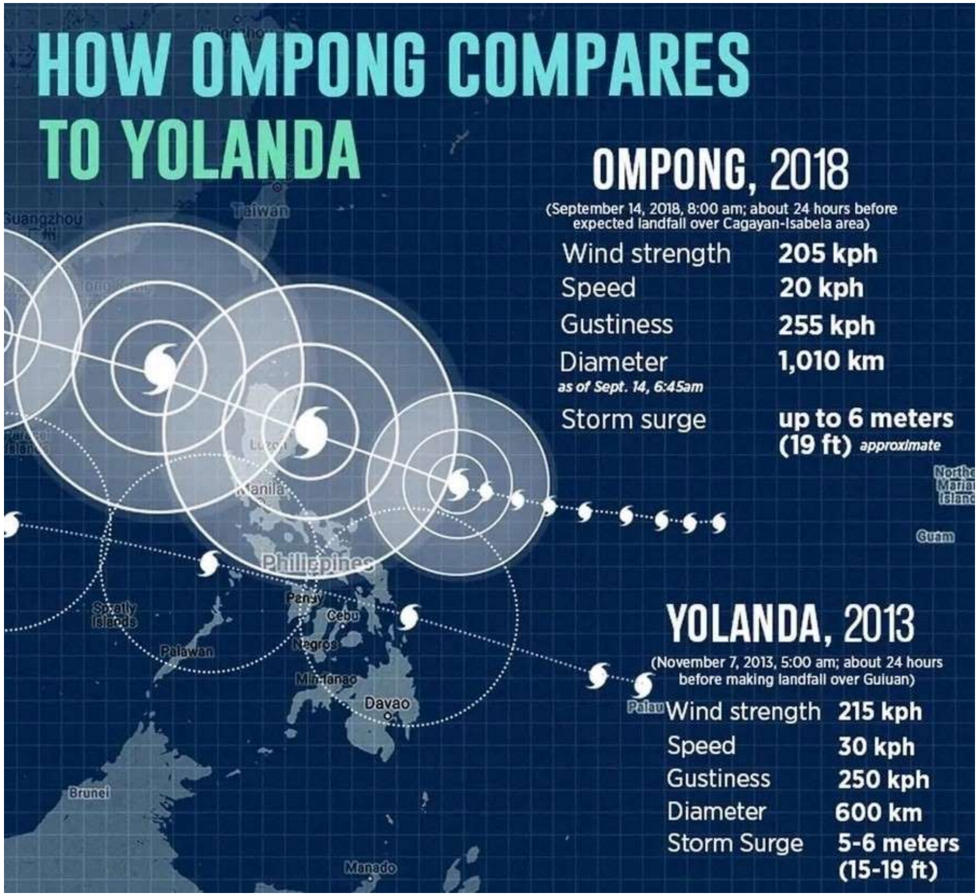
$$(\mathbf{x} - \tilde{\mathbf{x}}) = \mathbf{TA}(\mathbf{x} - \tilde{\mathbf{x}}) + \mathbf{T}\left(\mathbf{f} - \tilde{\mathbf{f}}\right)$$
$$\hat{\mathbf{x}}^{-1}(\mathbf{x} - \tilde{\mathbf{x}}) = (\hat{\mathbf{x}}^{-1}\mathbf{T}\hat{\mathbf{x}})(\hat{\mathbf{x}}^{-1}\mathbf{A}\hat{\mathbf{x}})\hat{\mathbf{x}}^{-1}(\mathbf{x} - \tilde{\mathbf{x}}) + (\hat{\mathbf{x}}^{-1}\mathbf{T}\hat{\mathbf{x}})\hat{\mathbf{x}}^{-1}(\mathbf{f} - \tilde{\mathbf{f}})$$

Let $\mathbf{q} = \hat{\mathbf{x}}^{-1}(\mathbf{x} - \tilde{\mathbf{x}})$, $\mathbf{f}^* = \hat{\mathbf{x}}^{-1}(\mathbf{f} - \tilde{\mathbf{f}})$, $\mathbf{A}^* = (\hat{\mathbf{x}}^{-1}\mathbf{A}\hat{\mathbf{x}})$, $\mathbf{T}^* = (\hat{\mathbf{x}}^{-1}\mathbf{T}\hat{\mathbf{x}})$

$$\mathbf{q} = \mathbf{T}^*\mathbf{A}^*\mathbf{q} + \mathbf{T}^*\mathbf{f}^*$$
$$\mathbf{q} = (\mathbf{I} - \mathbf{T}^*\mathbf{A}^*)^{-1}\mathbf{T}^*\mathbf{f}^*$$

Typhoon Ompong

- September 13, 2018
- Northern Luzon was severely affected
- Crops were damaged close to harvest season.
- Power was shutdown in several areas



Multiregional input output disaster risk analysis for the Philippines

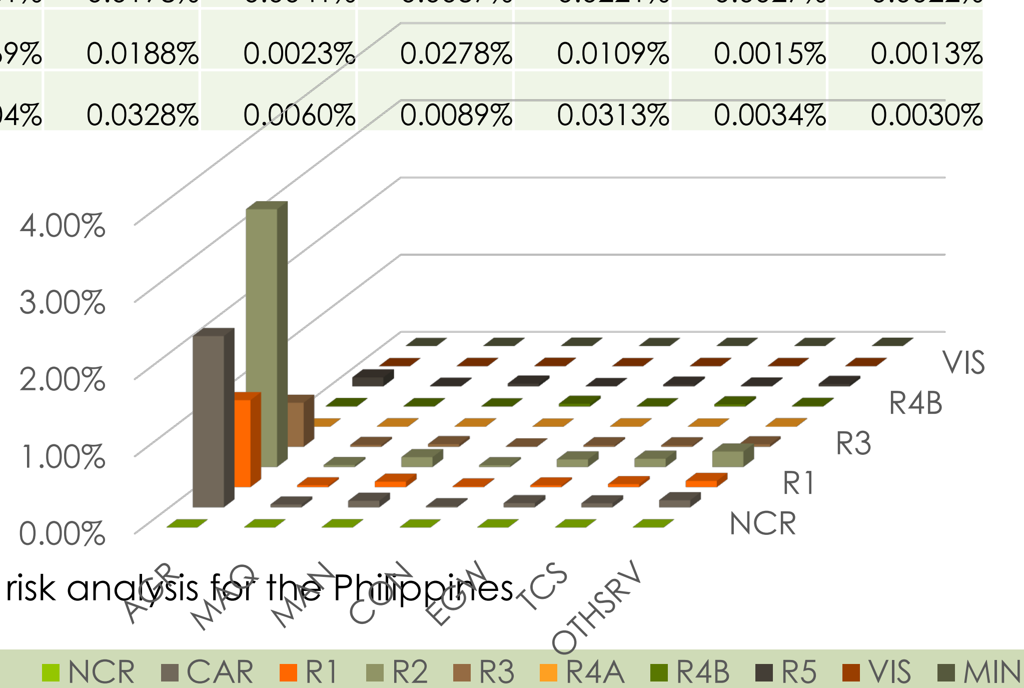
Case Study

- Multi-regional IIM shocks

Region	f* in Agri
NCR	0
CAR	0.02
R1	0.01
R2	0.03
R3	0.005
R4A	0
R4B	0
R5	0.001
VIS	0
MIN	0

Case Study Results: Inoperability

Sector	NCR	CAR	R1	R2	R3	R4A	R4B	R5	VIS	MIN
AGR	0.0012%	2.2176%	1.1262%	3.3378%	0.5705%	0.0026%	0.0060%	0.1156%	0.0014%	0.0008%
MAQ	0.0021%	0.0362%	0.0241%	0.0251%	0.0244%	0.0046%	0.0047%	0.0077%	0.0031%	0.0024%
MAN	0.0035%	0.0843%	0.0707%	0.1272%	0.0347%	0.0045%	0.0026%	0.0356%	0.0048%	0.0040%
CON	0.0004%	0.0141%	0.0093%	0.0229%	0.0055%	0.0010%	0.0351%	0.0033%	0.0005%	0.0005%
EGW	0.0020%	0.0537%	0.0223%	0.0981%	0.0198%	0.0041%	0.0037%	0.0221%	0.0027%	0.0022%
TCS	0.0011%	0.0516%	0.0385%	0.1069%	0.0188%	0.0023%	0.0278%	0.0109%	0.0015%	0.0013%
OTHSRV	0.0019%	0.0919%	0.0808%	0.2004%	0.0328%	0.0060%	0.0089%	0.0313%	0.0034%	0.0030%

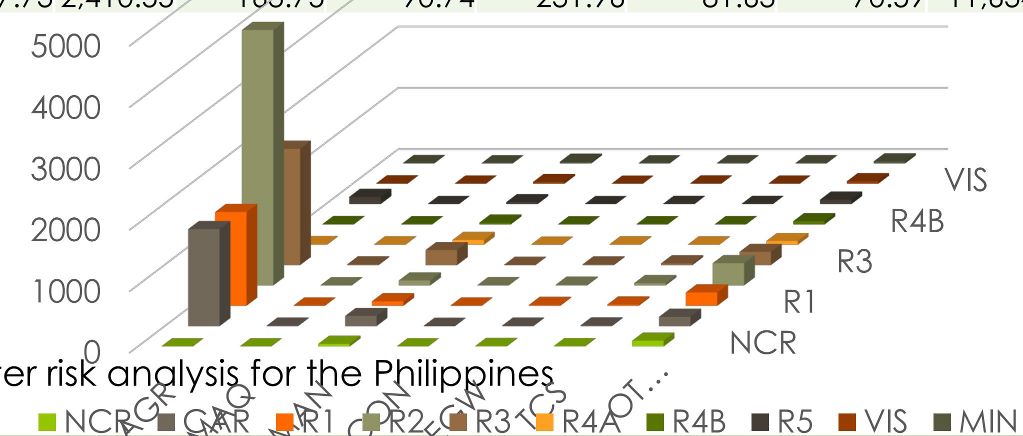


Multiregional input output disaster risk analysis for the Philippines.

Case Study Results: Economic Loss

Sector	NCR	CAR	R1	R2	R3	R4A	R4B	R5	VIS	MIN	Total
AGR	1.52	1,580.76	1,526.71	4,162.28	1,895.19	9.46	4.42	117.77	5.37	5.02	9,308.48
MAQ	1.07	7.37	3.59	2.15	11.73	4.54	1.38	1.69	1.76	1.66	36.93
MAN	41.88	165.47	72.61	79.96	245.25	76.68	28.51	31.15	28.54	26.26	796.31
CON	0.75	2.73	2.79	3.52	4.70	1.26	0.60	0.84	0.71	0.64	18.54
EGW	6.24	6.52	13.18	10.81	10.55	6.33	1.65	4.56	2.90	2.16	64.91
TCS	4.21	10.60	19.29	36.83	27.68	4.23	2.50	3.91	2.56	2.36	114.17
OTHSRV	92.71	150.93	216.76	362.18	215.45	61.26	51.68	72.04	39.79	32.50	1,295.29
Total	148.38	1,924.37	1,854.93	4,657.73	2,410.55	163.75	90.74	231.96	81.63	70.59	11,634.63

Unit: In million pesos



Multiregional input output disaster risk analysis for the Philippines

Case Study

- National level equivalent of the perturbation introduced = 0.004

	Inoperability
AGR	0.4656%
MAQ	0.0158%
MAN	0.0246%
CON	0.0043%
EGW	0.0137%
TCS	0.0157%
OTHSRV	0.0216%

	Economic Loss	Regional Total
AGR	11,148.03	9,308.48
MAQ	70.17	36.93
MAN	1,321.26	796.31
CON	34.41	18.54
EGW	114.53	64.91
TCS	192.37	114.17
OTHSRV	2,105.35	1,295.29
Total	14,986.12	11,634.63

Unit: In million pesos

Multiregional input output disaster risk analysis for the Philippines

Conclusion and Future Work

- Constructed a 10-region 7-sector multiregional input-output model
- This study is able to show that while national level input-output analysis can provide good estimates, it is better to have regional level tables in order to see the interactions between sectors within regions and across regions
- Policymakers at the regional level can use MRIIM model for disaster risk planning.
- Future work on exploring the use of analytic hierarchy process as a non-survey estimation method for regional tables.

Thank you for your attention.

Questions?

krista.yu@dlsu.edu.ph