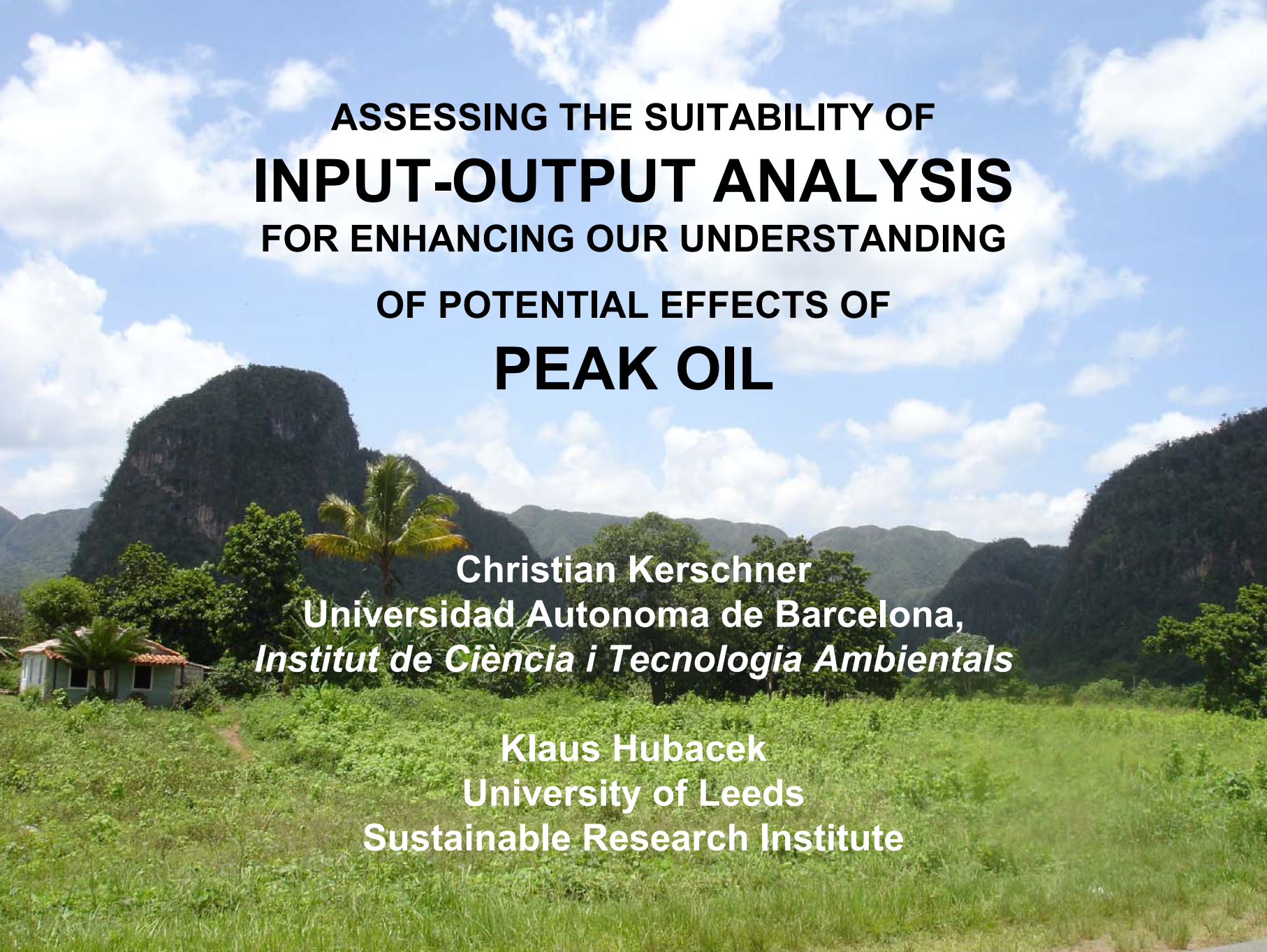

ASSESSING THE SUITABILITY OF
INPUT-OUTPUT ANALYSIS
FOR ENHANCING OUR UNDERSTANDING
OF POTENTIAL EFFECTS OF
PEAK OIL

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Objective

- Study of potential economic impacts of Peak Oil / resource supply constraints
  - precondition for development of policies to prepare ourselfs for such event
  - coinsiding with policies to combat climate change
- Determine if IO-analysis is a suitable tool
  - IO models - natural desasters (Katarina), accidents, risks
- Review existing variations of the traditional Leontief model
- Test potential candidates, covering both
  - quantity dimension
  - price dimension of PEAK OIL
- Extensive application of suitable models

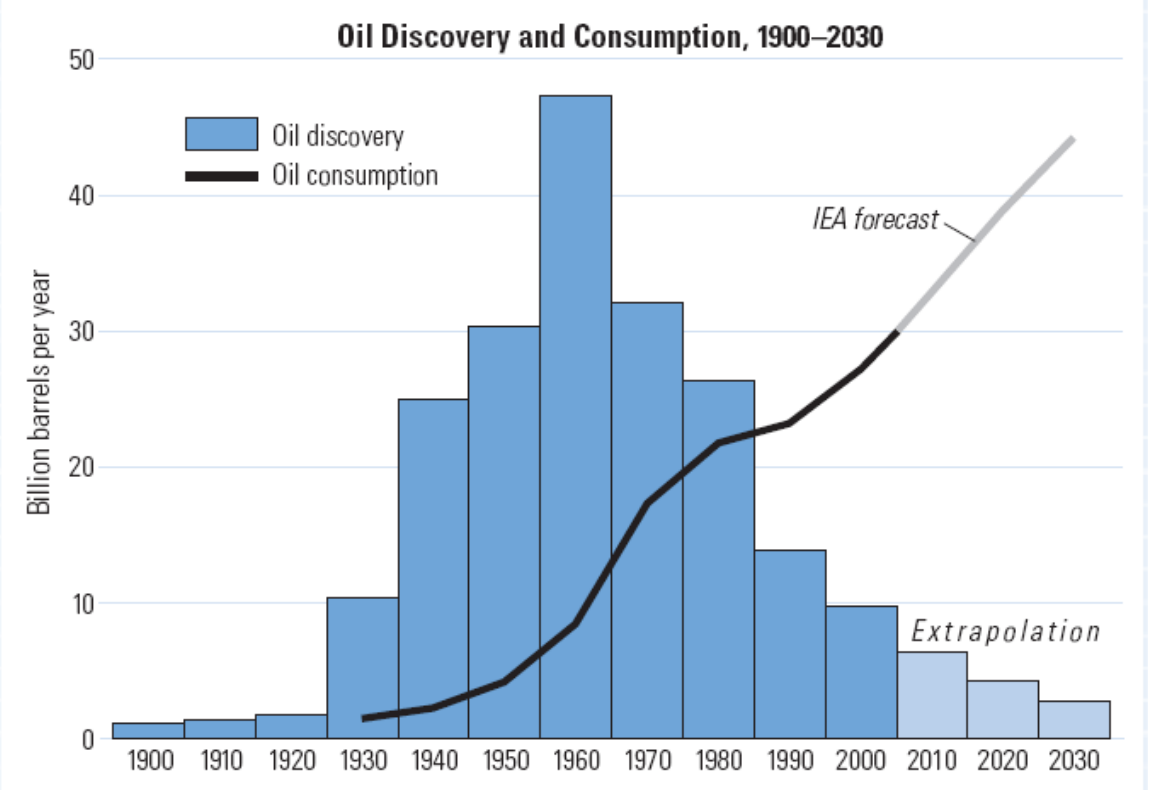
Introduction

- Peak Oil and Gas – imminent?
- Absolute and Relative scarcity
- low entropy matter/energy → absolutely scarce (e.g.: Daly 1992)
- Cuba's "periodo especial" (Soviet Union oil imports -50%)
- Need for study of potential effects → Precondition for developing policies

Adaptations in Cuba

Peak-Oil

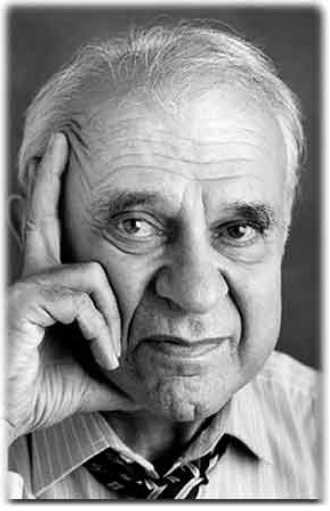
- The World-Oil-Production maximum



Source: (Aleklett 2006)

- **3 Factors:** maturing wells, discovery ↓, consumption ↑

Why IO-Analysis?



Wassily Leontief 1905 - 199
Nobel Laureate

- Fairly detailed description of economy
- Direct and indirect (ripple) effects
- Straightforward methodology/assumptions
- Availability of empirical data and ease of application
- Leontief (Science,1989): It can "*reduce the steadily widening gap between factual observation and deductive theoretical reasoning that threatens to compromise the integrity of economics as an empirical science*"
- Revival: tool for Ecological-Economic interactions as part of the LCA approach

The traditional Demand-Driven Leontief-type IO-Model

Row model →

		Processing sectors			Final Demand (Y) (*I* x *R*)				Total Output (x) (*J*)
		Agri-culture	Manu-factoring	Services	House-holds (H)	Invest-ment (I)	Govern-ment (G)	Exports (E)	
Processing Sectors (Z) (*I* x *J*)	Agriculture	z_{11}	z_{12}	z_{13}	y_{11}	y_{12}	y_{13}	y_{14}	x_1
	Manufacturing	z_{21}	z_{22}	z_{23}	y_{21}	y_{22}	y_{23}	y_{24}	x_2
	Services	z_{31}	z_{32}	z_{33}	y_{31}	y_{32}	y_{33}	y_{34}	x_3
Payments Sector (W) (*S* x *J*)	Labour (l)	w_{11}	w_{12}	w_{13}	l_H	l_I	l_G	l_E	l
	Other[1] (n)	w_{21}	w_{22}	w_{23}	n_H	n_I	n_G	n_E	n
	Imports (m)	w_{31}	w_{32}	w_{33}	m_H	m_I	m_G	m_E	m
Total Outlays (x') (*J*)		x_1	x_2	x_3	h	i	g	e	X

$$z_{11} + z_{12} + z_{13} + y_{11} + y_{12} + y_{13} + y_{14} = x_1$$

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

$$\mathbf{A} = \begin{bmatrix} \frac{z_{11}}{x_1} & \frac{z_{12}}{x_2} & \frac{z_{13}}{x_3} \\ \frac{z_{21}}{x_1} & \frac{z_{22}}{x_2} & \frac{z_{23}}{x_3} \\ \frac{z_{31}}{x_1} & \frac{z_{32}}{x_2} & \frac{z_{33}}{x_3} \end{bmatrix}$$

$$\mathbf{X = Zi + y}$$

$$\mathbf{x = A\hat{x}i + y}$$

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

„Leontief Inverse“

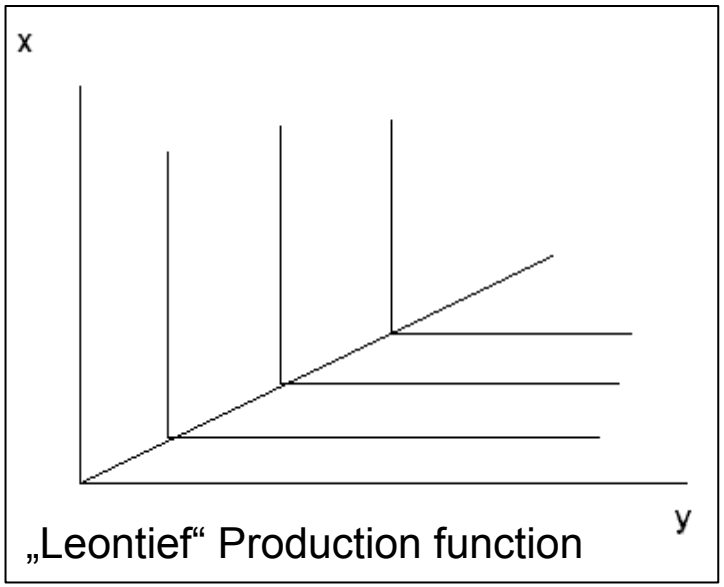
$\mathbf{a_{ij}}$ = inputs from sector *i* - necessary per one unit of total output from sector *j*

Assumptions of the demand-driven IO-Model

All IO Models: perfect competition, profit maximizing firms,

Demand-Driven - For the individual firm:

- a single homogeneous output (i.e. perfect substitution among all outputs)
- given demand for output
- multiple inputs x_j
- **fixed input ratios** (i.e. perfect complementarity of inputs *xj*)
- given prices for x_i
- cost minimization



„Leontief“ Production function

For the economy:

- derived demand for inputs x_i (i.e. backward linkages)
- exogenous final demand for *outputs* per sector
- endogenous intermediate demand for *outputs* per sector
- **perfectly elastic supply of every input x_i** (i.e. no jointness of production, no bottlenecks in capacity)

Adabted from Oosterhaven (1989)

The Ghosh or Supply-Driven IO model

(Ghosh 1958)

Column model ↓

			Processing sectors		Final Demand (Y) (I x R)				Total Output (x) (i)
			Agri-culture	Manu-factoring	Services	House-holds (H)	Invest-ment (I)	Govern-ment (G)	Exports (E)	
Processing Sectors (Z) (I x J)	Agriculture	$z_{11}+$	z_{12}	z_{13}	y_{11}	y_{12}	y_{13}	y_{14}	x_1
	Manufacturing	$z_{21}+$	z_{22}	z_{23}	y_{21}	y_{22}	y_{23}	y_{24}	x_2
	Services	$z_{31}+$	z_{32}	z_{33}	y_{31}	y_{32}	y_{33}	y_{34}	x_3
Payments Sector (W) (S x J)	Labour (l)	$w_{11}+$	w_{12}	w_{13}	l_H	l_I	l_G	l_E	l
	Other[1] (n)	$w_{21}+$	w_{22}	w_{23}	n_H	n_I	n_G	n_E	n
	Imports (m)	$w_{31}=$	w_{32}	w_{33}	m_H	m_I	m_G	m_E	m
Total Outlays (x') (i)		x_1	x_2	x_3	h	i	g	e	X

$$b_{ij} = \frac{z_{ij}}{x_i} \qquad \mathbf{B} = \begin{bmatrix} \frac{z_{11}}{x_1} & \frac{z_{12}}{x_1} & \frac{z_{13}}{x_1} \\ \frac{z_{21}}{x_2} & \frac{z_{22}}{x_2} & \frac{z_{23}}{x_2} \\ \frac{z_{31}}{x_3} & \frac{z_{32}}{x_3} & \frac{z_{33}}{x_3} \end{bmatrix}$$

$$\mathbf{x' = i'Z + w} \qquad \hat{\mathbf{x}}\mathbf{B} = \mathbf{Z}$$

$$\mathbf{x}' = \mathbf{i}'\hat{\mathbf{x}}\mathbf{B} + \mathbf{w}' \rightarrow \mathbf{x}' = \mathbf{w}'(\mathbf{I} - \mathbf{B})^{-1}$$

„Ghosh“ - inverse

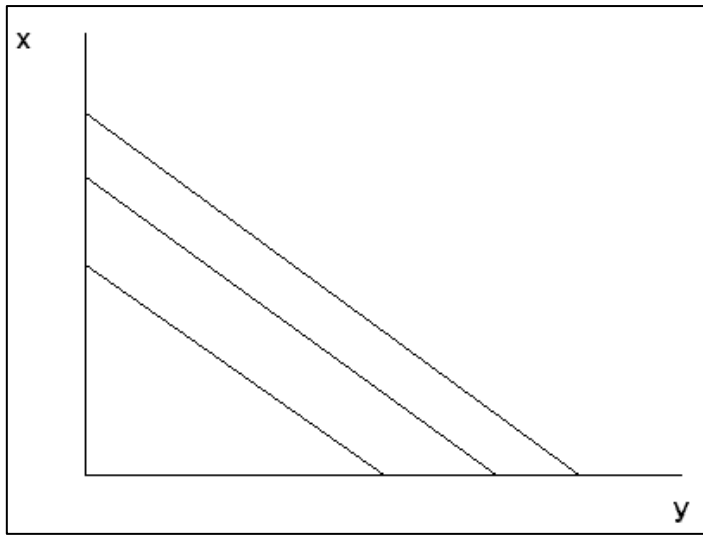
b_{ij} = output - generated in sector ***j*** if total outlays of sector ***i*** are increased by one unit.

Assumptions of the Supply-Driven Model

All IO Models: perfect competition, profit maximizing firms

Supply-Driven IO Models- For the individual firm:

- **a single homogeneous *input* (i.e. perfect substitution among all *inputs*)**
- given supply of *inputs*
- multiple *outputs* x_i
- fixed *output* ratios (i.e. perfect jointness of *outputs* x_j)
- given prices for *outputs* x_j
- revenue maximization
- induced supply of *outputs* x_j (i.e. forward linkages)



„Ghosh"-Production function

For the economy:

- exogenous primary supply of *inputs* per sector
- endogenous intermediate supply of *inputs* per sector
- **perfectly elastic demand for every output x_j** (i.e. no complementarity in consumption no income constraints)

Adabted from Oosterhaven (1989)

Ghosh Model - Applications

- Augustinovics, M. A. (1970). “Methods of International and Intertemporal Comparison of Structure. Contributions to Input-Output Analysis.” (Descriptive Study)
- Giarratani, F. (1976). "Application of an Interindustry Supply Model to Energy Issues.“ (Forward linkage analysis)
  supply linkages associated with US energy production - highlighting the crucial position of the extractive energy sectors in the U.S. national economy
- Chen, C. and A. Rose (1985). "The joint stability of input-output production and allocation coefficients." Impact Analysis
  50% reduction of output in aluminium sector in Taiwan & Washington State (1989)

Oosterhaven (1988): Ghosh Model is implausible

Numerical Example

$$a_{ij} = \frac{z_{ij}}{x_j} \rightarrow a_{12} = \frac{400}{2000}$$

		Sectors			Final Demand		Total Output (x_i)
ctors		Agri-culture	Manu-facturing	Services	House-holds	Exports	
riculture		0	400	0	500	100	1000
nufacturing		350	0	150	800	700	2000
rvices		100	200	0	300	0	600
orts	W	250	600	50			
ages	W	200	↓ 250	300			
ner VA	W	100	300	100			
tal Input (x_j)		1000	2000	600			

A-Matrix		
0	0.2	0
0.35	0	0.25
0.1	0.1	0

Production coefficients

$$b_{ij} = \frac{z_{ij}}{x_i} \rightarrow b_{23} = \frac{150}{2000}$$

B (Ghosh) -Matrix		
0	0.4	0
0.175	0	0.075
0.166667	0.333333	0

Allocation coefficients

$(I-B)^{-1}$ - Ghosh inverse		
1.08	0.44	0.03
0.21	1.11	0.08
0.25	0.44	1.03

$$\mathbf{x' = w'(I - B)^{-1}}$$

x_1	x_2	x_3
947.9	**1,722.2**	**579.2**

$$a_{12} = \frac{400}{1722}$$

Matrix A^{new}		
0	0.23226	0
0.3692	0	0.259
0.1055	0.11613	0

Matrix A^{old}		
0	0.2	0
0.35	0	0.25
0.1	0.1	0

VARIATION		
0	0.0323	0
0.0192	0	0.009
0.0055	0.0161	0

The Ghosh model concluding

- Problematic Assumptions:
- Perfect elastic demand y – everything produced will be consumed (cars without petrol, etc.)
- Interindustry demand – rejection of production function
- E.g.: Steel factory -↑ man-hours → steel production ↑ (even if iron ore etc. ↔)

→ **Implausibility of Ghosh model** (Oosterhaven 1981)

→ **Not suitable for:**

•general description of economy,

•resource supply changes,

Supply-constrained or mixed IO models

			Processing sectors: non-constrained		Processing sectors: con-str'nd	Final Demand		Total Out-put (x) (j)
		to (j) / from (i)	Agri-culture	Manu-factoring	Services	House-holds etc.	Exports (e)	
Pro-cessing Sectors (Z) (I x J)	non-constrained	Agriculture	z_{11}	z_{12}	z_{13}	y_1	e_1	x_1
		Manufacturing	z_{21}	z_{22}	z_{23}	y_2	e_2	x_2
	constrained	Services	z_{31}	z_{32}	z_{33}	y_3	e_3	x_3
Payments Sector (w)		Value added	w_1	w_2	w_3			
		Imports (m)	m_1	m_2	m_3			
Total Outlays (x') (i)			x_1	x_2	x_3			

$$\mathbf{x} = \mathbf{A}\hat{\mathbf{x}}\mathbf{i} + \mathbf{y}$$

$$x_1 = a_{11}x_1 + a_{12}x_2 + a_{13}x_3 + y_1$$
$$x_2 = a_{21}x_1 + a_{22}x_2 + a_{23}x_3 + y_2$$
$$x_3 = a_{31}x_1 + a_{32}x_2 + a_{33}x_3 + y_3$$

$$(1 - a_{11})\,x_1 - a_{12}x_2 - a_{13}\mathbf{x_3}^* = \mathbf{y_1}^*$$
$$-a_{21}x_1 + (1 - a_{22})\,x_2 - a_{23}\mathbf{x_3}^* = \mathbf{y_2}^*$$
$$-a_{31}x_1 - a_{32}x_2 + (1 - a_{33})\mathbf{x_3}^* = y_3$$

$$(1-a_{11})\,x_1 - a_{12}\,x_2 + 0y_3 = \mathbf{y_1}^* + 0y_2^* + a_{13}\mathbf{x_3}^*$$
$$-a_{21}x_1 + (1 - a_{22})\,x_2 + 0y_3 = 0y_1^* + \mathbf{y_2}^* + a_{23}\mathbf{x_3}^*$$
$$-a_{31}x_1 - a_{32}x_2 - y_3 = 0y_1^* + 0y_2^* - (1 - a_{33})\mathbf{x_3}^*$$

$$\underbrace{\begin{bmatrix} (1-a_{11}) & -a_{12} & 0 \\ -a_{21} & (1-a_{22}) & 0 \\ -a_{31} & -a_{32} & -1 \end{bmatrix}}_{\mathbf{M}} \times \begin{bmatrix} x_1 \\ x_2 \\ y_3 \end{bmatrix} = \begin{bmatrix} \bar{y}_1 + a_{13}\bar{x}_3 \\ \bar{y}_2 + a_{23}\bar{x}_3 \\ -(1-a_{33})\bar{x}_3 \end{bmatrix}$$

$$\underbrace{\begin{bmatrix} (1-a_{11}) & -a_{12} & 0 \\ -a_{21} & (1-a_{22}) & 0 \\ -a_{31} & -a_{32} & -1 \end{bmatrix}}_{\mathbf{M}} \times \begin{bmatrix} x_1 \\ x_2 \\ y_3 \end{bmatrix} = \underbrace{\begin{bmatrix} 1 & 0 & a_{13} \\ 0 & 1 & a_{23} \\ 0 & 0 & -(1-a_{33}) \end{bmatrix}}_{\mathbf{N}} \times \begin{bmatrix} \bar{y}_1 \\ \bar{y}_2 \\ \bar{x}_3 \end{bmatrix}$$

$$\begin{bmatrix} x_1 \\ x_2 \\ y_3 \end{bmatrix} = \underbrace{\begin{bmatrix} \alpha_{11} & \alpha_{12} & 0 \\ \alpha_{21} & \alpha_{22} & 0 \\ \beta_1 & \beta_2 & -1 \end{bmatrix}}_{\mathbf{M}^{-1}} \times \underbrace{\begin{bmatrix} 1 & 0 & a_{13} \\ 0 & 1 & a_{23} \\ 0 & 0 & -(1-a_{33}) \end{bmatrix}}_{\mathbf{N}} \times \begin{bmatrix} \bar{y}_1 \\ \bar{y}_2 \\ \bar{x}_3 \end{bmatrix}$$

$$\begin{bmatrix} \mathbf{x}_{no} \\ \mathbf{y}_{co} \end{bmatrix} = \begin{bmatrix} \mathbf{P} & \mathbf{0} \\ \mathbf{R} & -\mathbf{I} \end{bmatrix}^{-1} \times \begin{bmatrix} \mathbf{I} & \mathbf{Q} \\ \mathbf{O} & \mathbf{S} \end{bmatrix} \times \begin{bmatrix} \bar{\mathbf{y}}_{no} \\ \bar{\mathbf{x}}_{co} \end{bmatrix}$$

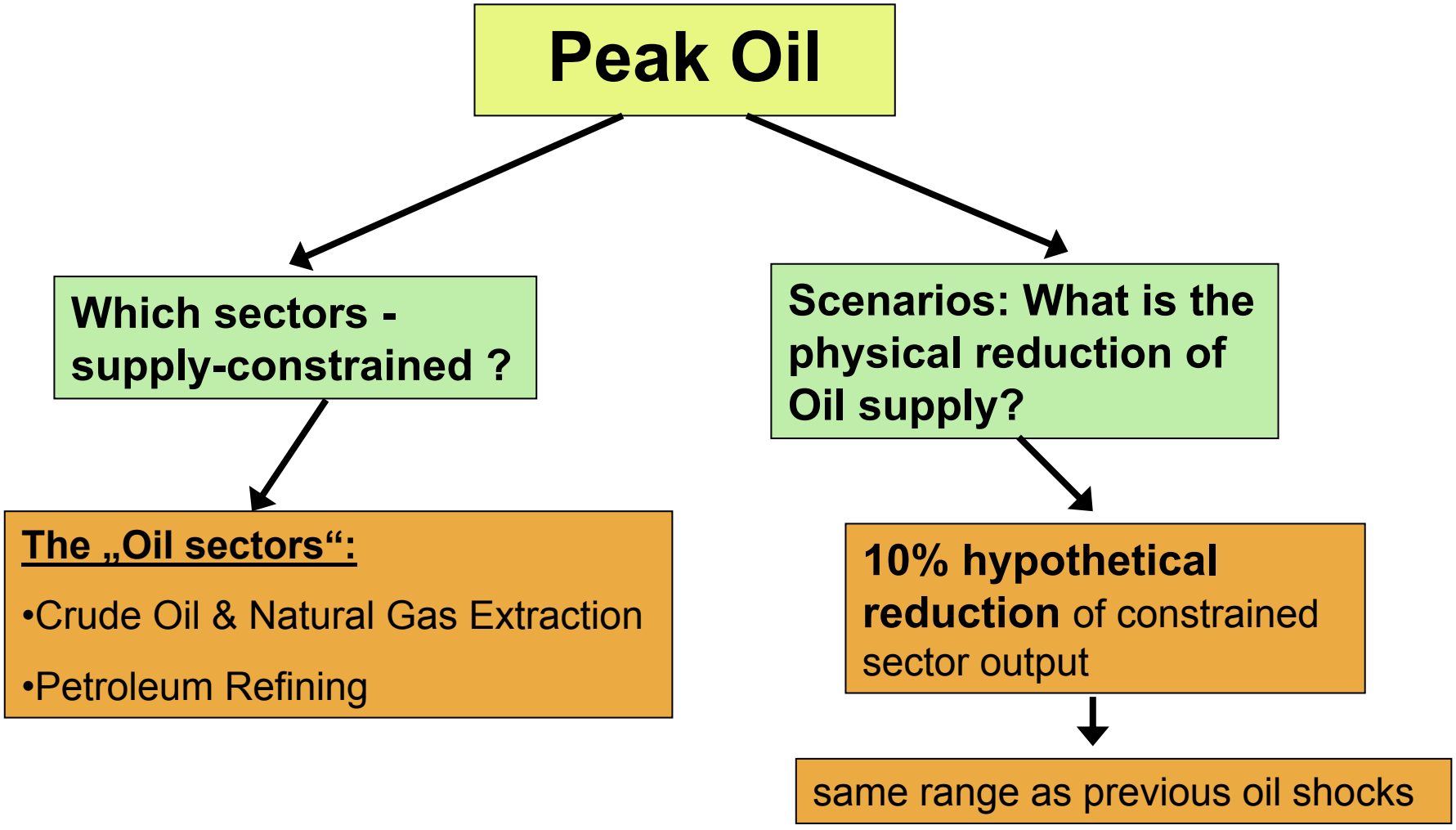
Mixed Models – Previous Applications

- Tiebout (1969). "An Empirical Regional Input-Output Projection Model: The State of Washington 1980.“
- Davis & Salkin (1984). "Alternative approaches to the estimation of economic impacts resulting from supply constraints.“
- Subramanian & Sadoulet (1990). "The transmission of production fluctuations and technical change in a village economy: A social accounting matrix approach."
- Lewis & Thorbecke (1992). "District-level economic linkages in Kenya: Evidence based on a small regional social accounting matrix.“
- Parikh & Thorbecke (1996). "Impact of rural industrialization on village life and economy: A social accounting matrix approach."
- Hubacek & Sun (2001). "A scenario analysis of China's land use and land cover change: incorporating biophysical information into input-output modeling.“

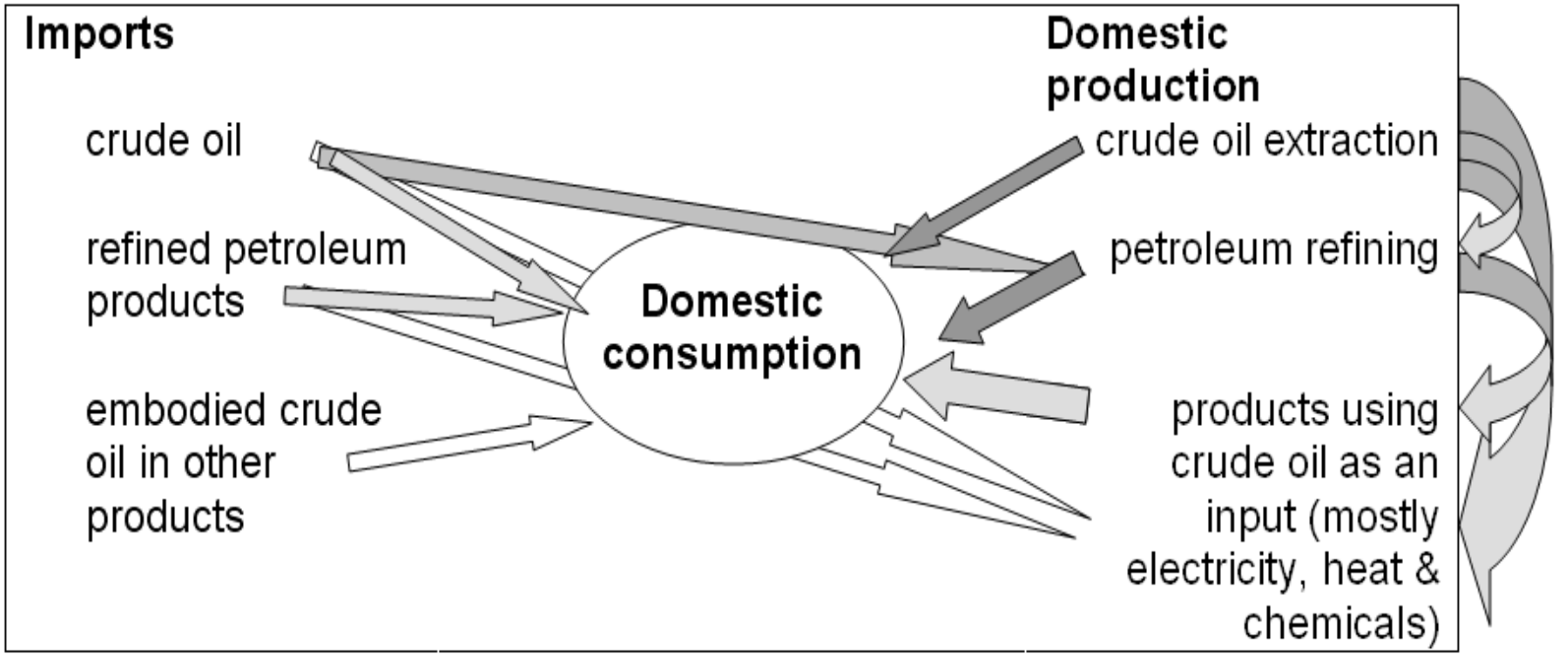
Recognition of **absolute scarcity of land** on planet earth → Placing supply constraints on the sector of **Agriculture**

Peak Oil → **Suitable tool for Analysis for quantity dimension !**

Empirical Application of the supply-constrained model



Domestic Oil Flows



- Not captured: white arrows (empodied oil in imported products!)
- Partly captured: light grey arrows
- Fully captured: dark grey arrows

Assumptions/Limitations

- Static model
  - final demand in non-supply constrained sectors remains constant after shock
  - constant technology during initial shock period
- Net-Exports (i.e. imports) allowed
  - focus on national economy
  - if not – necessity of rationing

Case Studies - Data

- UK–1995: 138 sectors
- Japan-2000: 104 sectors
- Chile-1996: 73 sectors

RESULTS
Non-Supply-constrained Sectors

- Reductions in allmost all sectors
- Rather minor in both relative & absolute terms - UK 0.17%, Japan 0.028% and Chile 0.056% of total value added in all non-constrained sectors
- Not-surprising: monetary output value of oil sectors relative to the whole economy - very small and decreasing in the past

	UK 1995	Japan 2000	Chile 1996
	Absolute	Absolute	Abs'lt Δ
	Δ mill. £	Δ mill. ¥	mill. Pts
Total Value ADDED:	661,770	519,481,892	29,255,529
Oil & Gas Extraction VA	11,541	55,376	50,808
Petroleum Refining VA	3,128	5,023,381	425,046
Oil sector - share of total VA	**2.22**	**0.98**	**1.63**

10 most affected sectors absolute & relative

UK

	relative sector change	%	absolute sector change	Mill £
1	Inorganic chemicals	-0,99	Financial intermediation	425,93
2	Manufacture - Fabricated Metal Prod.	-0,39	Construction	147,21
3	Coal extraction	-0,23	Manufacture - Fabricated Metal Prod.	89,29
4	Railway transport	-0,20	Wholesale and Retail Trade	71,42
5	Construction	-0,17	Manufactoring (other)	67,50
6	Financial intermediation	-0,15	Ancilliary Transprt, Postal Services, Telecom	54,43
7	Electricity production & Distribution	-0,14	Electricity production & Distribution	35,38
8	Manufacture -Iron and Steel	-0,14	Manufacture - Machinery & Applicances	25,48
9	Air Transport	-0,13	Other land transport	22,05
10	Ancilliary Transprt, Postal Services, Telecom	-0,10	Other services	17,82

Japan

	relative sector change	%	absolute sector change	Mill ¥
1	Water transport	-0,328	Other Services, Office Supplies etc.	23594,84
2	Transportation services	-0,140	Financial and Insurance	19813,29
3	Electricity	-0,073	Water transport	17518,26
4	Coal mining	-0,055	Commerce	12610,22
5	Financial and Insurance	-0,051	Transportation services	12279,94
6	Reuse and redycling	-0,038	Electricity	12275,62
7	Road transport (except by private cars)	-0,025	Education, health and social work	6565,02
8	Gas, heat and water supply	-0,023	Communication and broadcasting	4319,07
9	Organic chemicals	-0,023	Misc. manufactured products (1/3)	4161,23
10	Communication and broadcasting	-0,019	Road transport (except by private cars)	4078,59

Chile

	relative sector change	%	absolute sector change	Mill. Ptas
1	Road freigth transport services	-0,2513	Real Estate, Business Services & Housing	4.047,63
2	Metal products	-0,0937	Road freigth transport services	2.926,93
3	Electric& Non-electric machinery& equmnt	-0,0843	Trade services	1.688,74
4	Basic chemical products	-0,0831	Misc. Manufactured Prod. (1/2)	1.033,60
5	Rubber products	-0,0771	Electricity	693,44
6	Railway transport services	-0,0763	Metal products	627,74
7	Real Estate, Business Services & Housing	-0,0601	Financial & Insurance services	429,51
8	Glass and non metallic mineral products	-0,0559	Electric& Non-eclectric machinery& equmnt	374,13
9	Air transport services	-0,0554	Hotel & Restaurant Services	355,30
10	Electricity	-0,0501	Glass and non metallic mineral products	353,15

Observations

Electricity Production: top 10 - absolute and relative in all three countries (least affected – Chile – position 10 – Hydropower)

Transportation:

- **Relative:** Water Transport, Transportation Services (1&2 Japan), Road freight Transport (1 Chile), Rail Transport (4 UK, 6 Chile);
- **Absolute:** Ancilliary Transport Services (...), Other land Transport (6&9 UK), Water Transport, Transportation Services (3&5 Japan), Road Freight (2 Chile);

Financial & Insurance Services:

- **UK:** 6 relative & 1 absolute
- **Japan:** 2 absolute
- **Chile:** 7 absolute

Wholesale & Retail Trade and Commerce (absolute only):

- **UK- Wholesale & Retail Trade: 4**
- **Japan - Commerce: 4**
- **Chile – Trade Services: 3**

Peak Oil – effects on „backbone of economy“

✓Secondary Energy (Electricity)

x Agriculture - despite dependence on fossil fuel inputs

✓Transport

Construction – absolute & relative in UK top ten, but Japan & Chile – very low ranking

Supply-constrained Sectors

		Total Final Demand (Y)				Net Exports (E^{net})	
		Y^{old}	$Y_{new}^{-10\%}$	$Y_{new} - Y_{old}$	%	before	after
UK 95	crued oil & gas ex.	7,630	6,470	1,160	-15	6,200	5,040
Mill. €	petroleum refining	6,640	5,480	1,170	-18	1,700	530
Japan 00	crued oil & gas ex.	-23,500	-197,000	173,500	-738	-7,122,000	-7,295,500
Mill. ¥	petroleum refining	4,399,500	3,086,000	1,313,400	-30	-1,563,200	-2,876,600
Chile 96	crued oil & gas ex.	500	-1,300	1,800	-377	-536,700	-538,500
Mill. Pts	petroleum refining	201,400	119,400	82,000	-41	-294,500	-376,500

Recall: Final consumption of Households and Government = constant

→ **all changes - reflected as reductions in EXPORTS (increase in IMPORTS)**

Conclusion

- IO-analysis – promising tool for researching potential effects of Peak-Oil / resource supply constraints, risks (disasters), etc.
- Supply-driven: inspiring / but implausible assumptions
- Supply-constrained (mixed model): highly promising for quantity dimension of peak oil

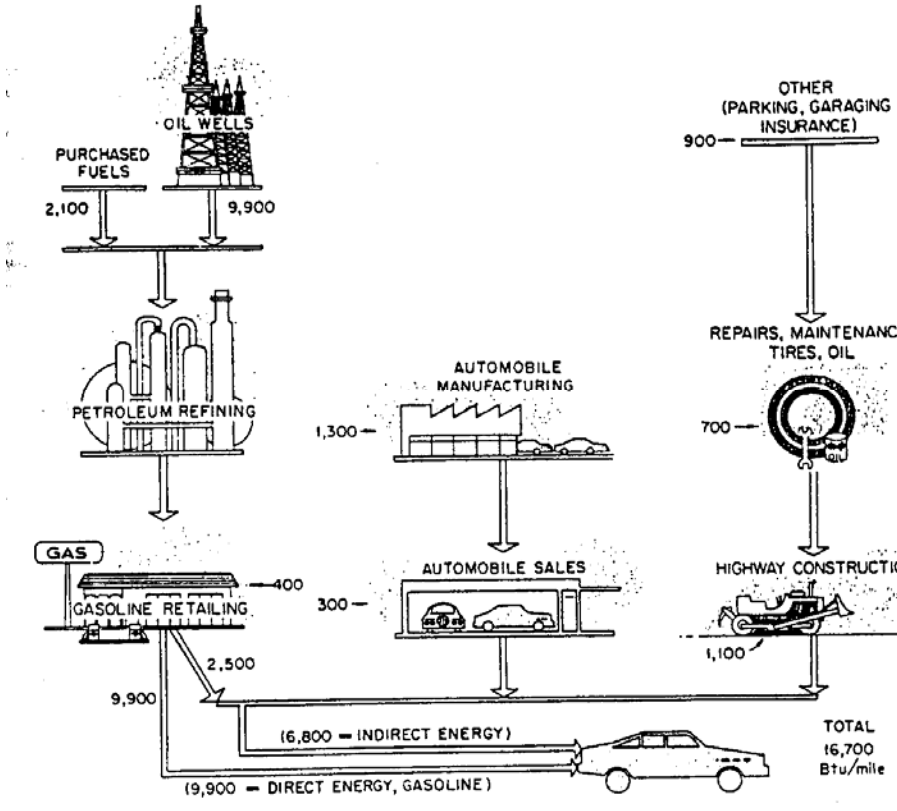
Further Steps

- More Country Case Studies (China, India, USA)
- Leontief Price Model – for price dimension
- World Trade Model (Duchin 2005)
  - international perspective
  - leontief price model
  - dynamic
  - linear programming to min. factor use
  - scenario analysis (Peak-Oil scenarios)
- MRIO (Multiregional-IO): includes all major trading partners of an economy.

Grazie

Indirect Effects: Example Car Fuels

- How much energy is required to allow your car to travel 1 mile?
  - The fuel burned
  - Plus the energy to extract, refine, and transport the fuel
  - Plus the energy to manufacture the car
  - Plus the energy to produce tires, replacement parts, etc.
  - Plus the energy to build and maintain roads
  - Plus the energy to maintain auto repair shops, government regulation services, etc.
  - Plus the energy to produce and maintain that portion of the health system used to care for the consequences of auto accidents and auto-related health problems



Backward & Forward linkages of the „oil sectors“

Country	Year	Linkages of oil & gas extraction with petroleum refining	
		Direct Backward	Direct Forward
UK	1995	0.4	0.28
Japan	2000	0.4	0.76
China	1997	0.48	0.78

BWD = corresponding entry in the **A** matrix

€’s worth of inputs from oil and gas extraction - necessary per one € worth of total output from the petroleum refining sector

FWD = corresponding entry in the **B** matrix

€’s worth of output - generated in the petroleum refining sector, if total outlays of the crude oil and gas extraction sector are increased by one €.