Lecture-1: Introduction to Freight Transportation Demand Modeling

In Today's Class

- Focus is on methods and techniques for freight modelling
- Short rehearsal of general introduction on modelling
- We follow the 4 step model architecture – modified for freight

1. Introduction to freight demand issues
2. Demand modelling principles
   - Production / attraction
   - Trade
   - Mode choice
   - Route choice

   } & integrative forms

What is Globalization?

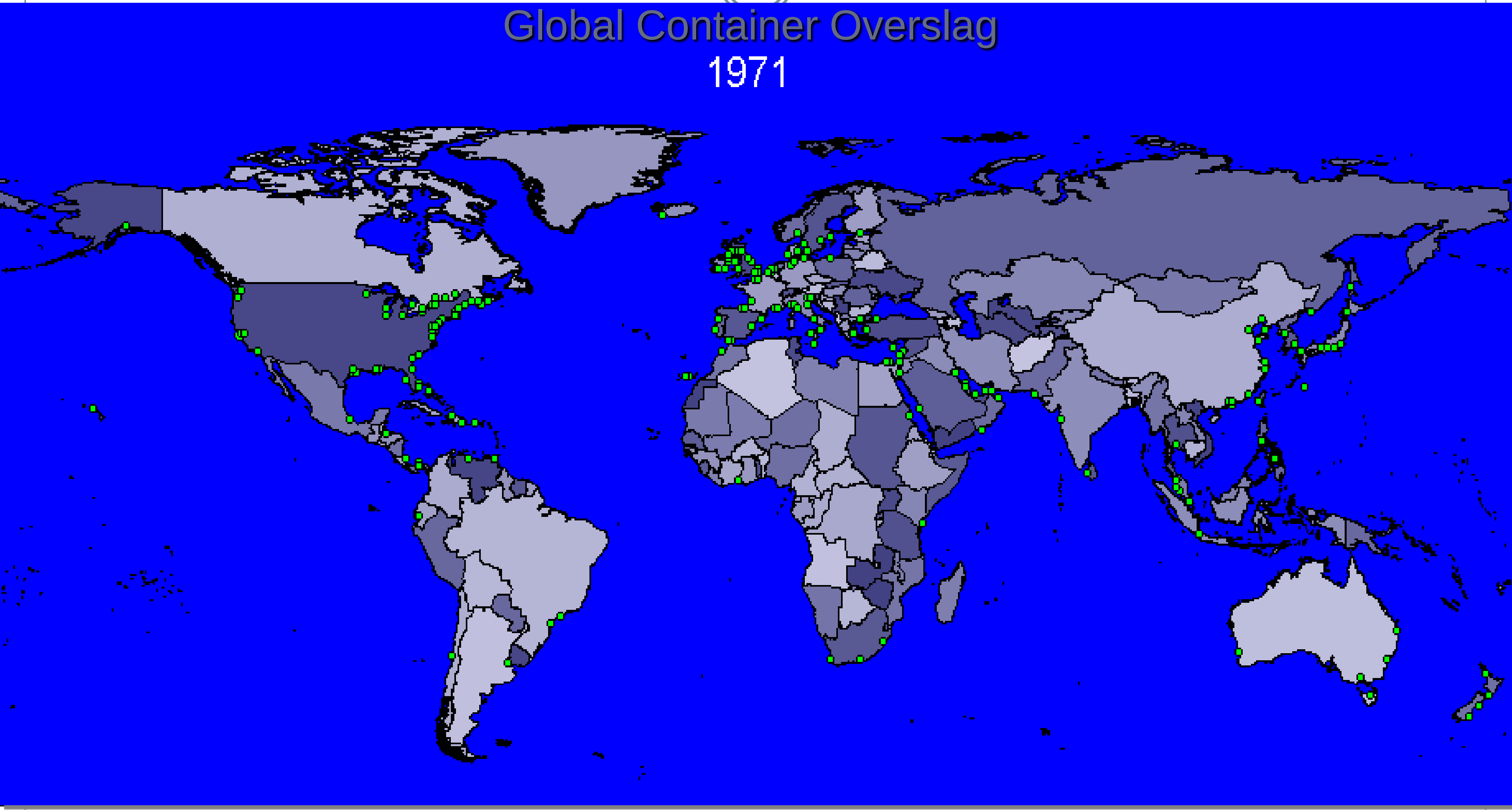
What does it take to have a cup of coffee in a café?

The combined efforts of
29 companies in 18 countries

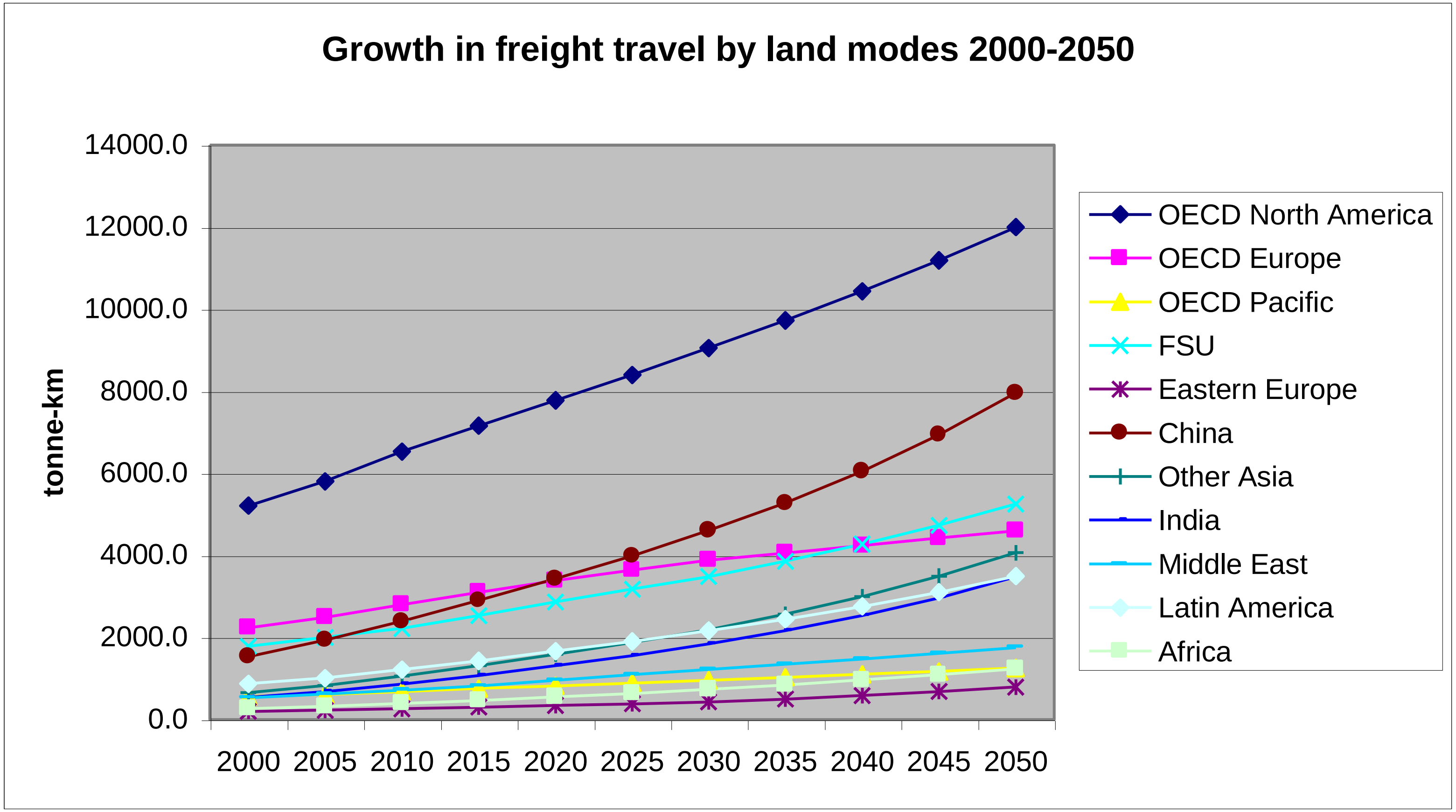
Road Transport has become a production tool!

Source: IRU

Q1: what's behind growth?



Q2: What's behind structural change?



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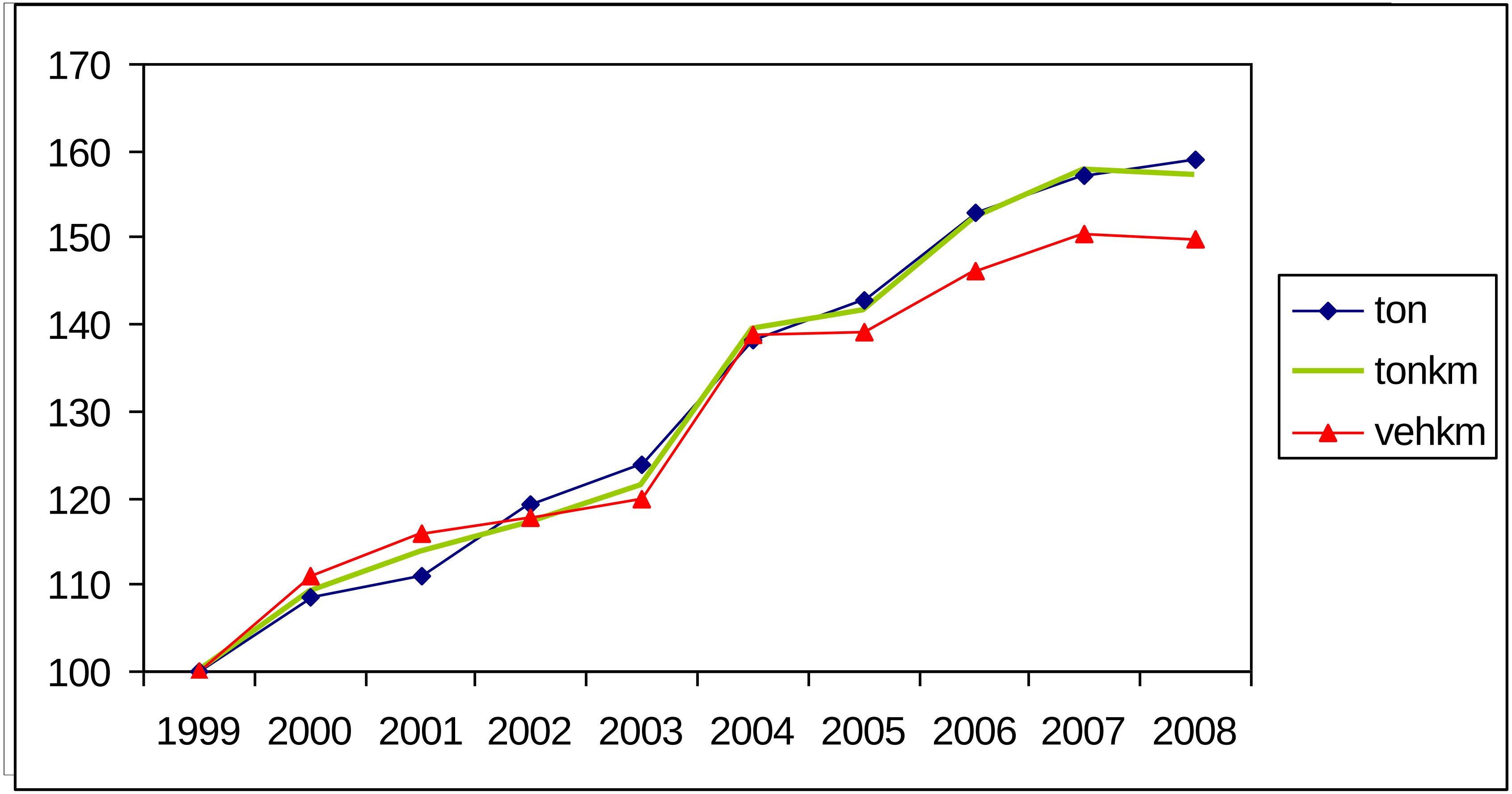
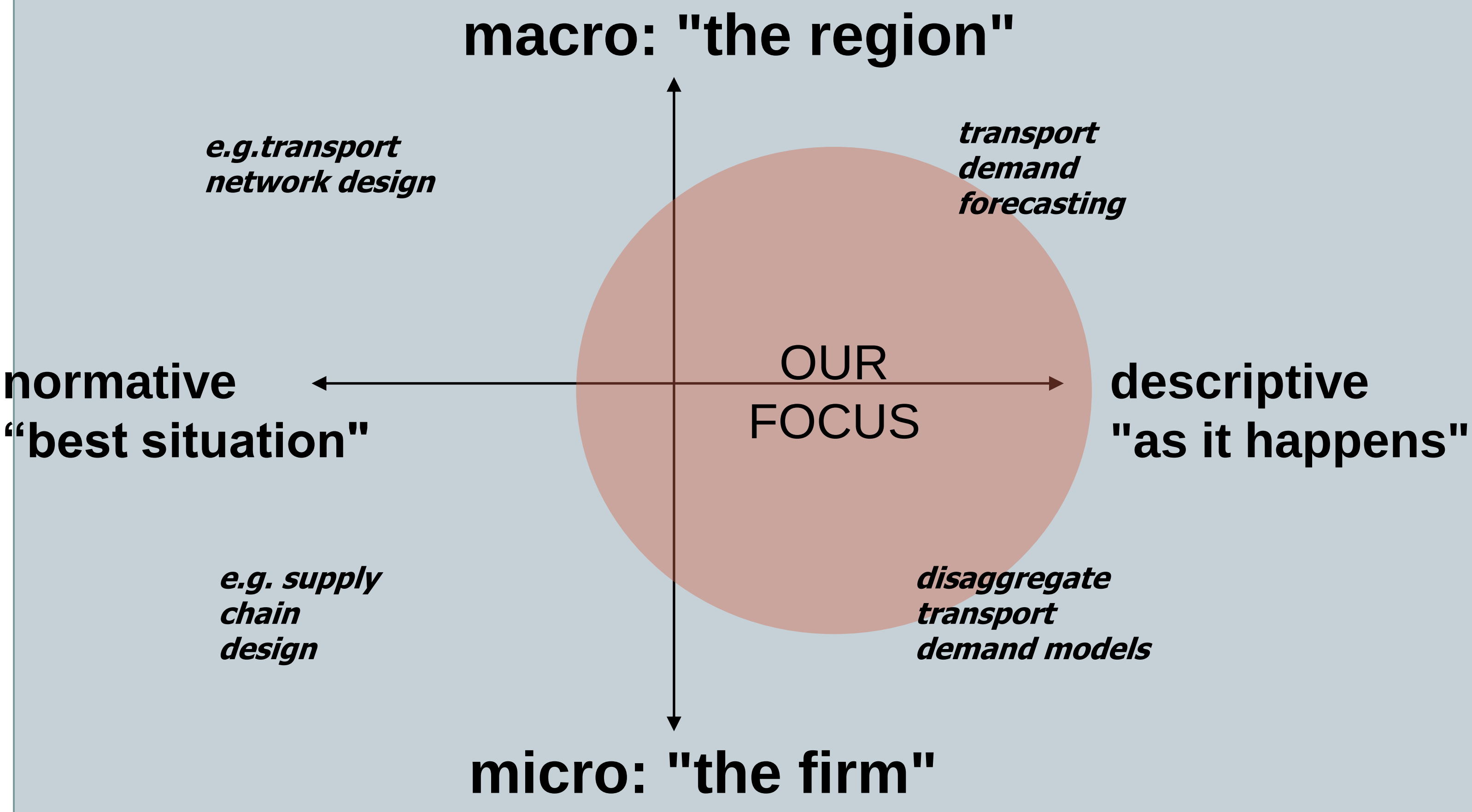


Autos/freight: fundamental differences

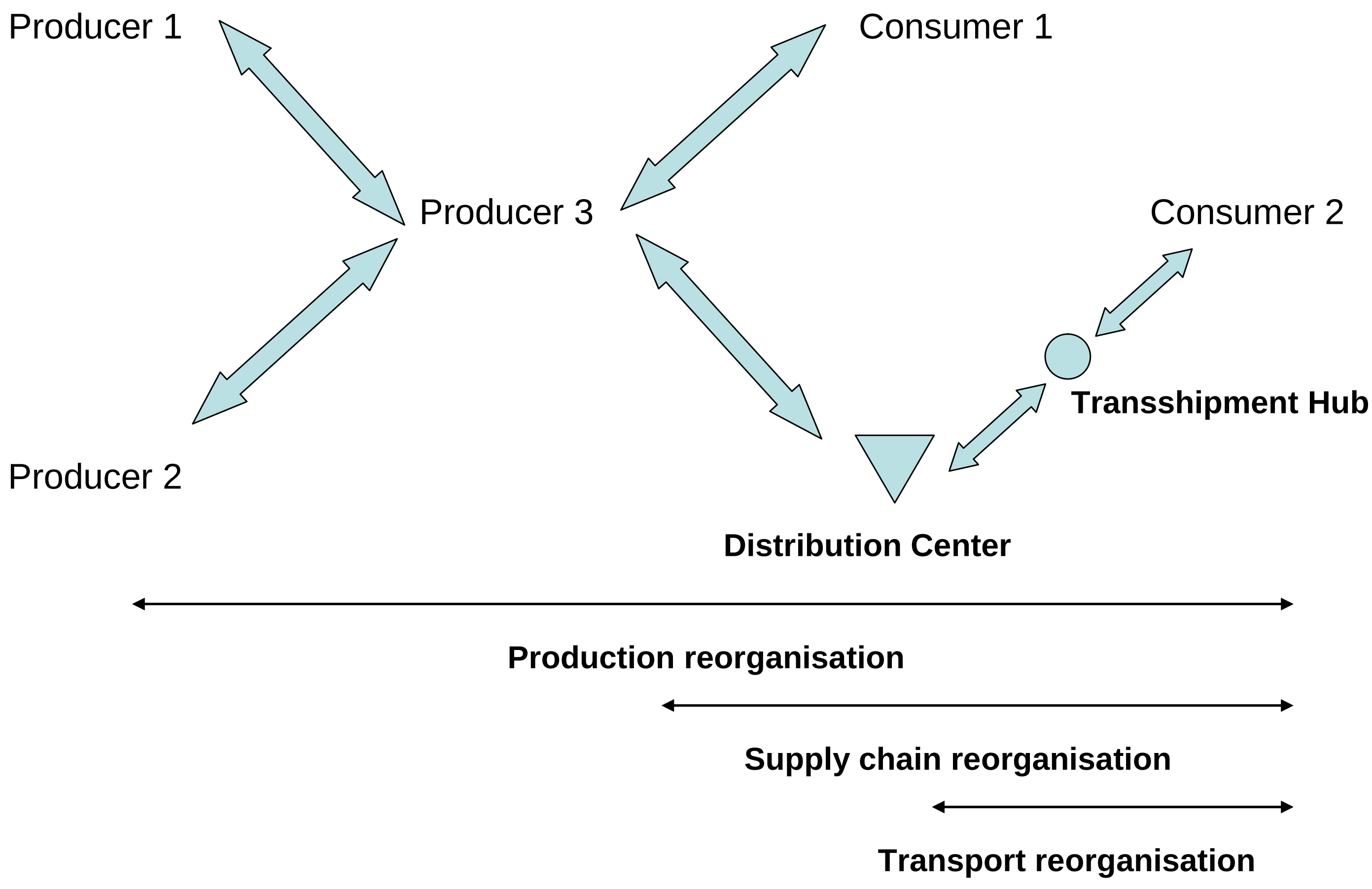
- One decision maker or many?
- Unit of transport = decision maker?
- Many interactions between decision makers, or few?
- Correspondence between demand and trips: simple or complex?
- Heterogeneity in trip purposes: low or high?

NCFRP 25. Holguin Veras et al, 2010

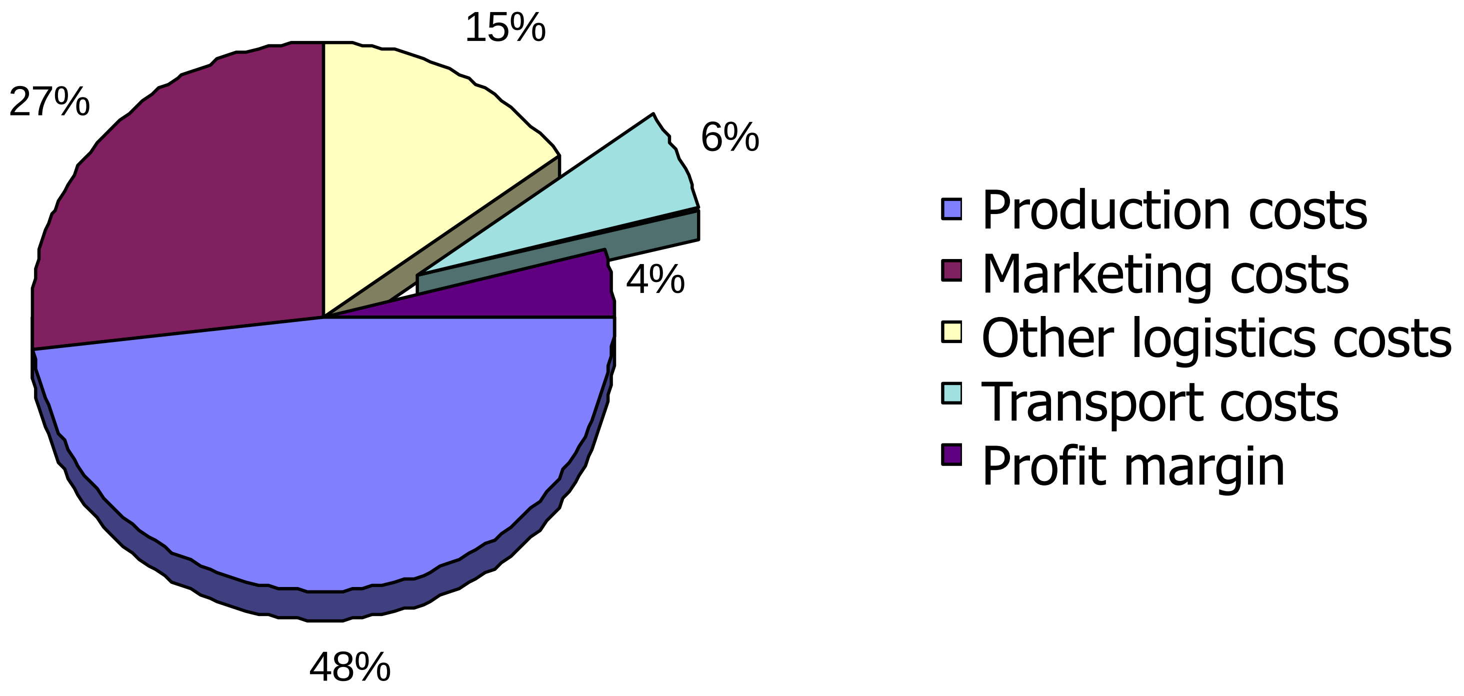
Modelling freight transport demand in the context of public policy



Freight reorganization responses & their determinants

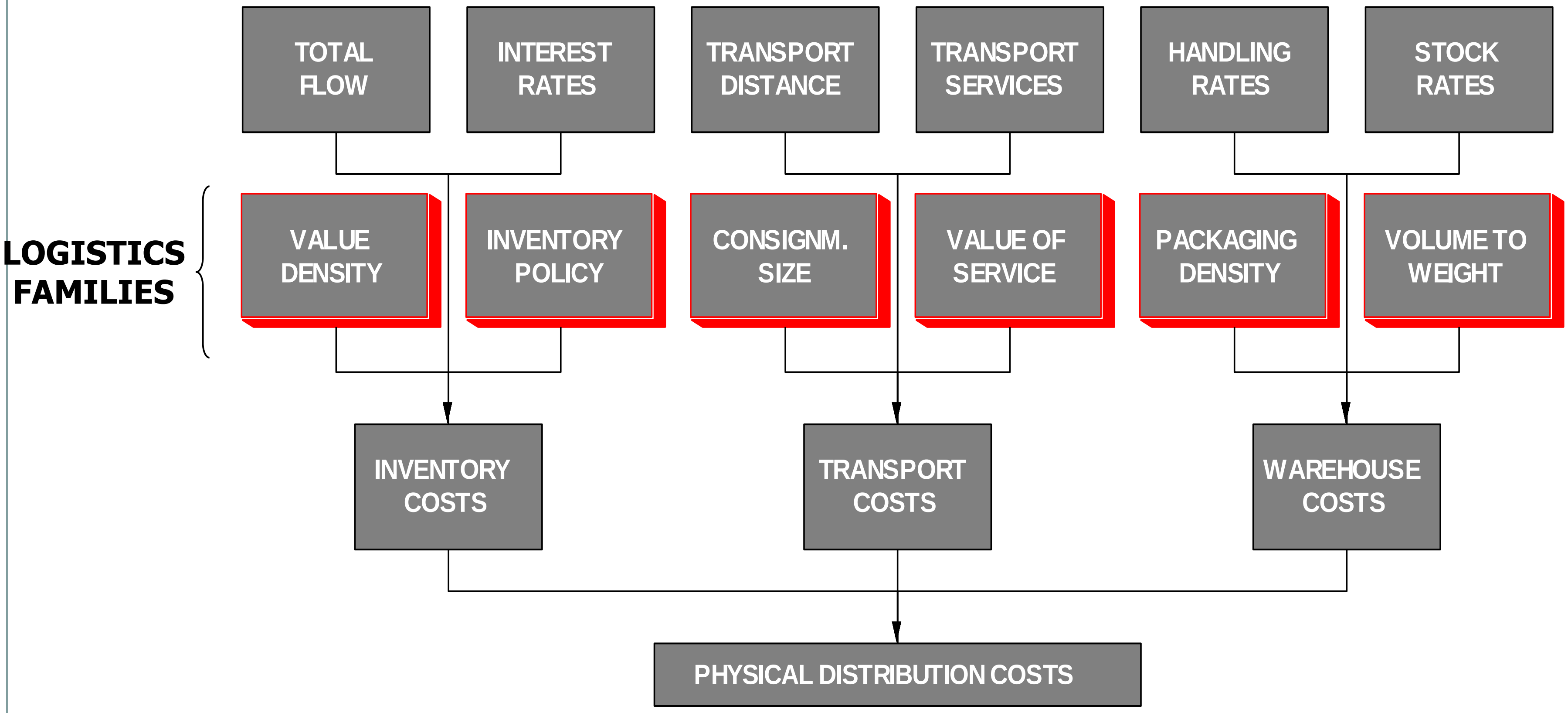


There is more than transport costs…

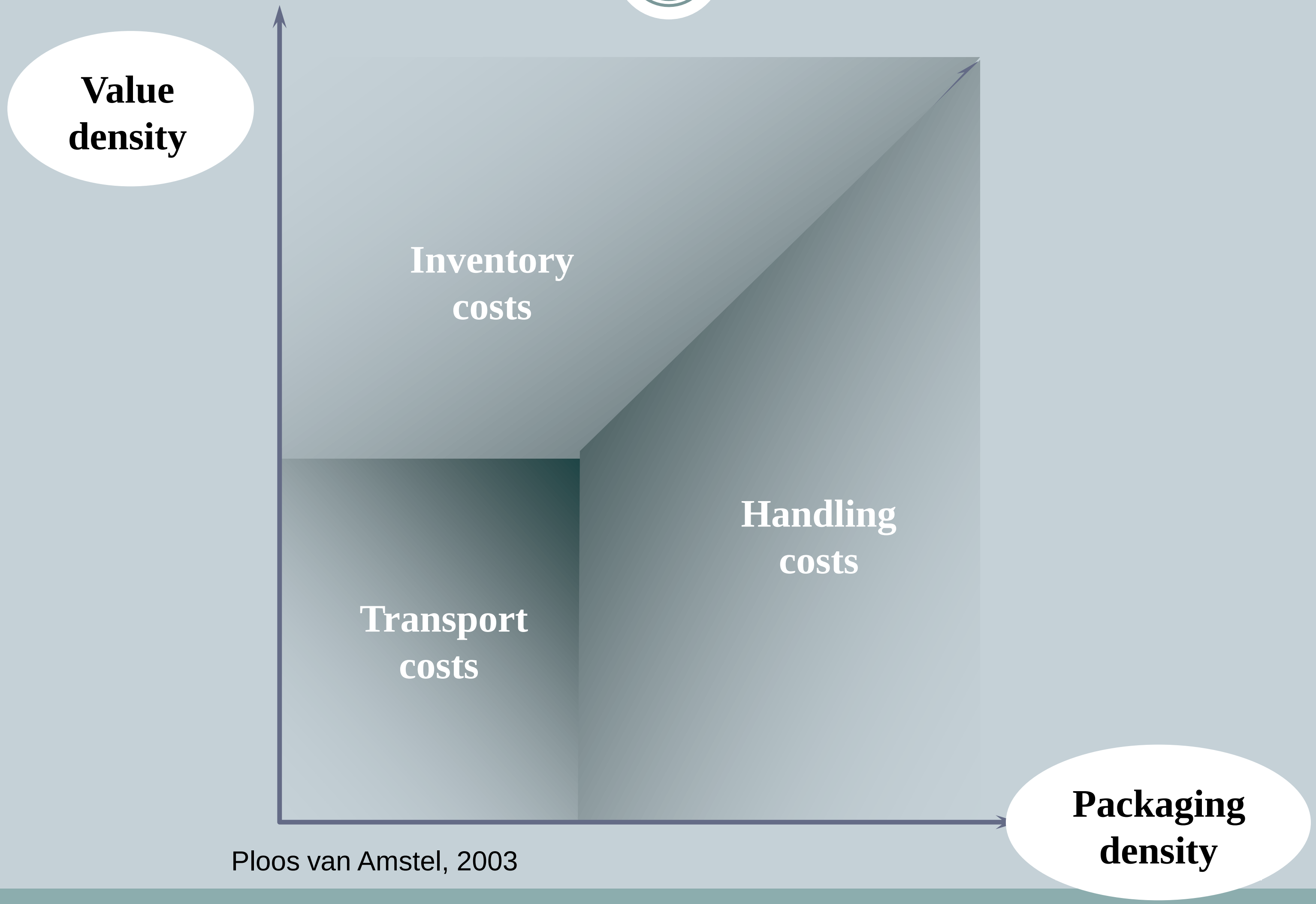


Groothedde, 2004

Total logistics costs: determinants

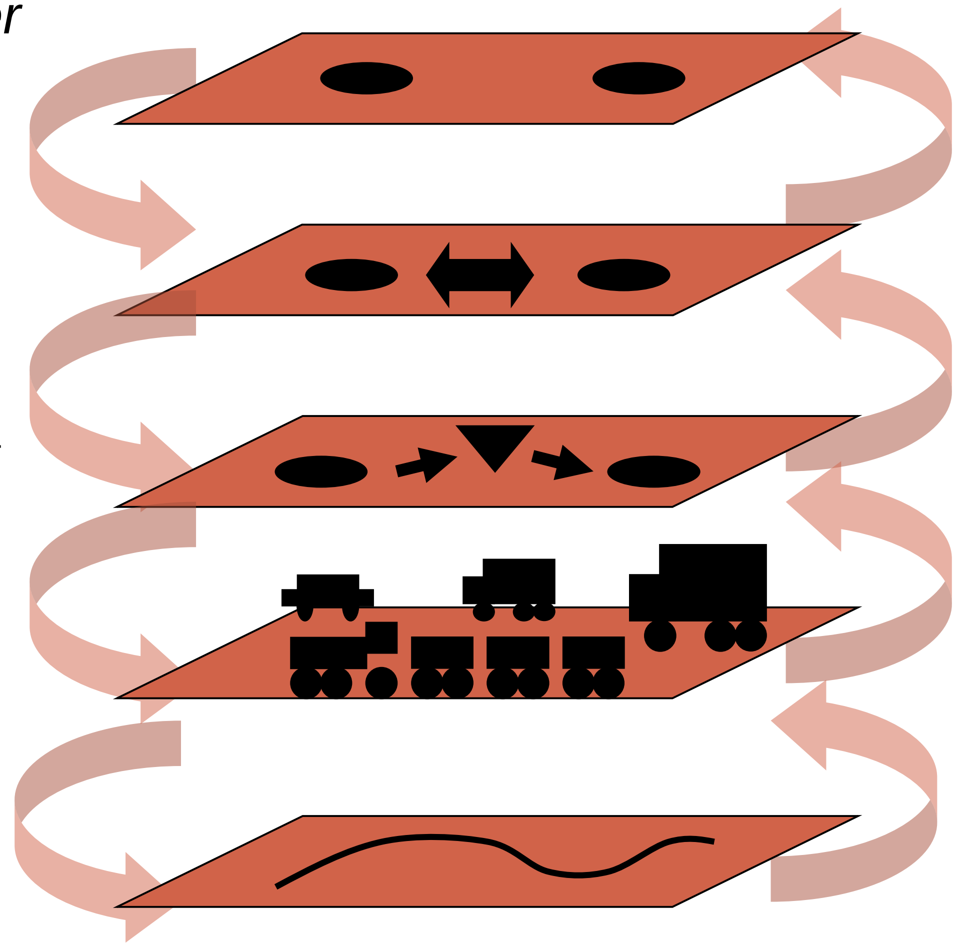


Goods types & critical cost fields



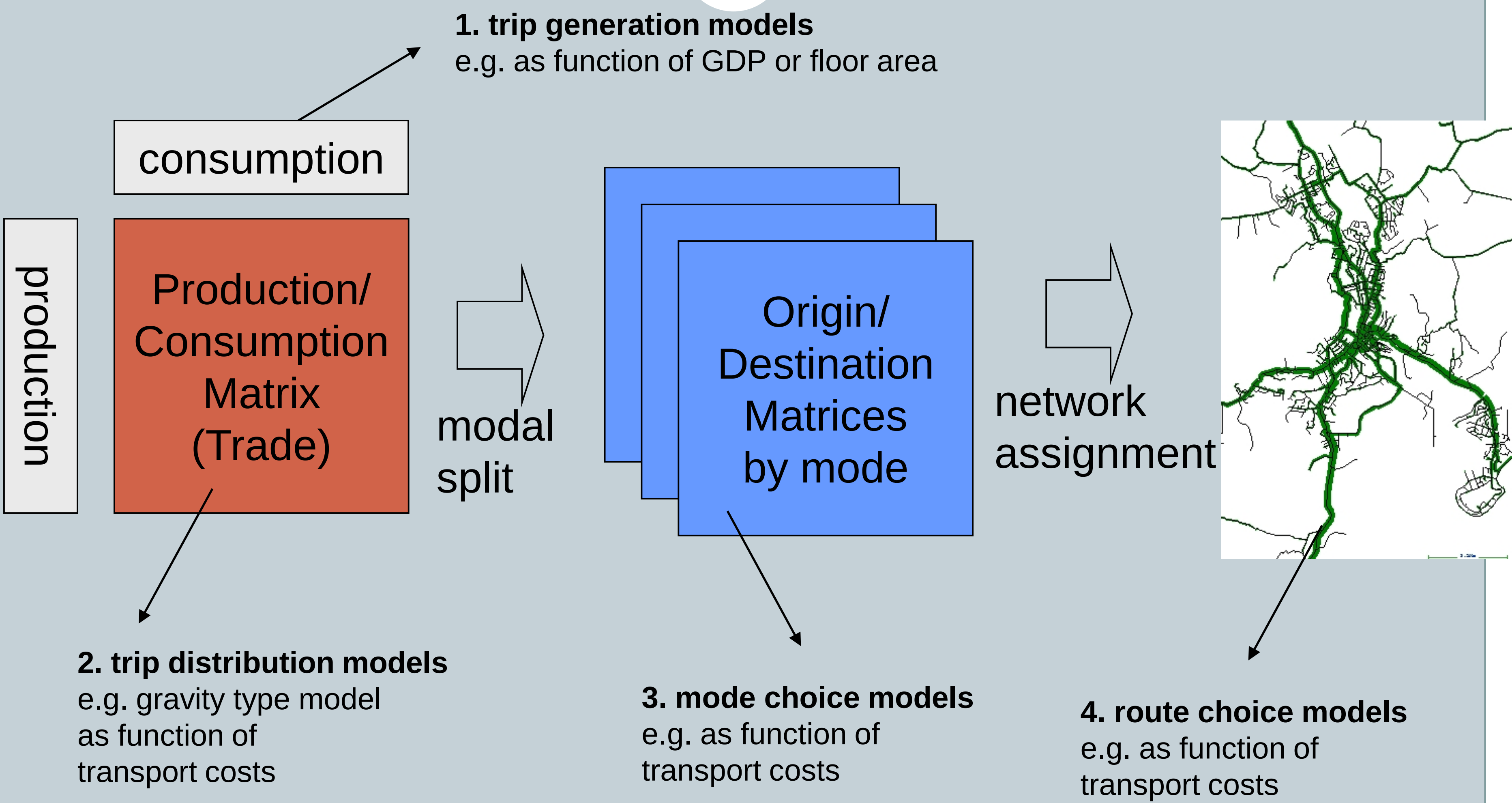
Ploos van Amstel, 2003

A layered model of logistics decisions

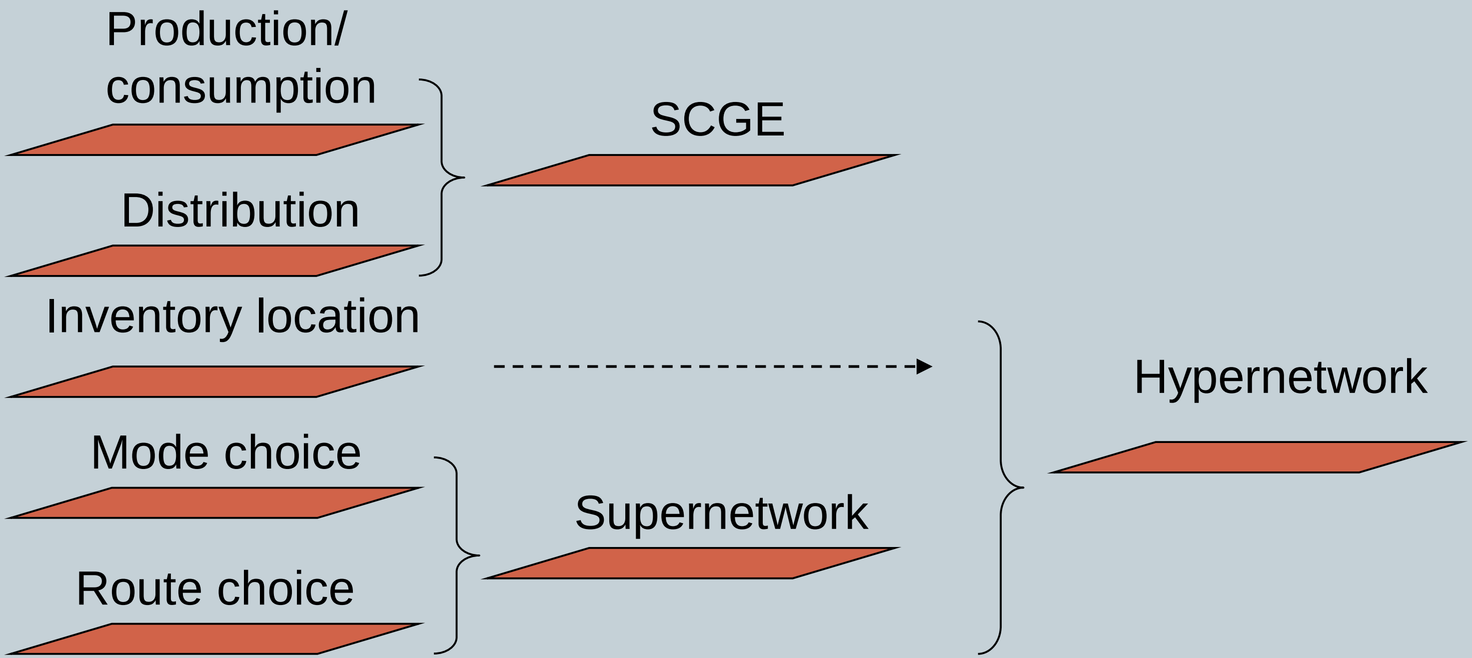


	Decision maker	Decision
"shipper"	Producent / plant mgr. Consumers	Production Location choice Type of product Production volume Consumer choices
"shipper"	Sales managers Sourcing managers	Trading contracts
"shipper"	Logistics service provider Logistics manager	Shipment sizes, frequencies Location en volume of inventory Distribution channels
"carrier"	Logistics manager Transport manager Forwarder	Mode(s) of transport DIY or Hire & Reward? Long term or spot contract? Means of transport
"carrier"	Transport planner Driver	Routing and scheduling Time of departure Capacity planning

The conventional 4-stage model



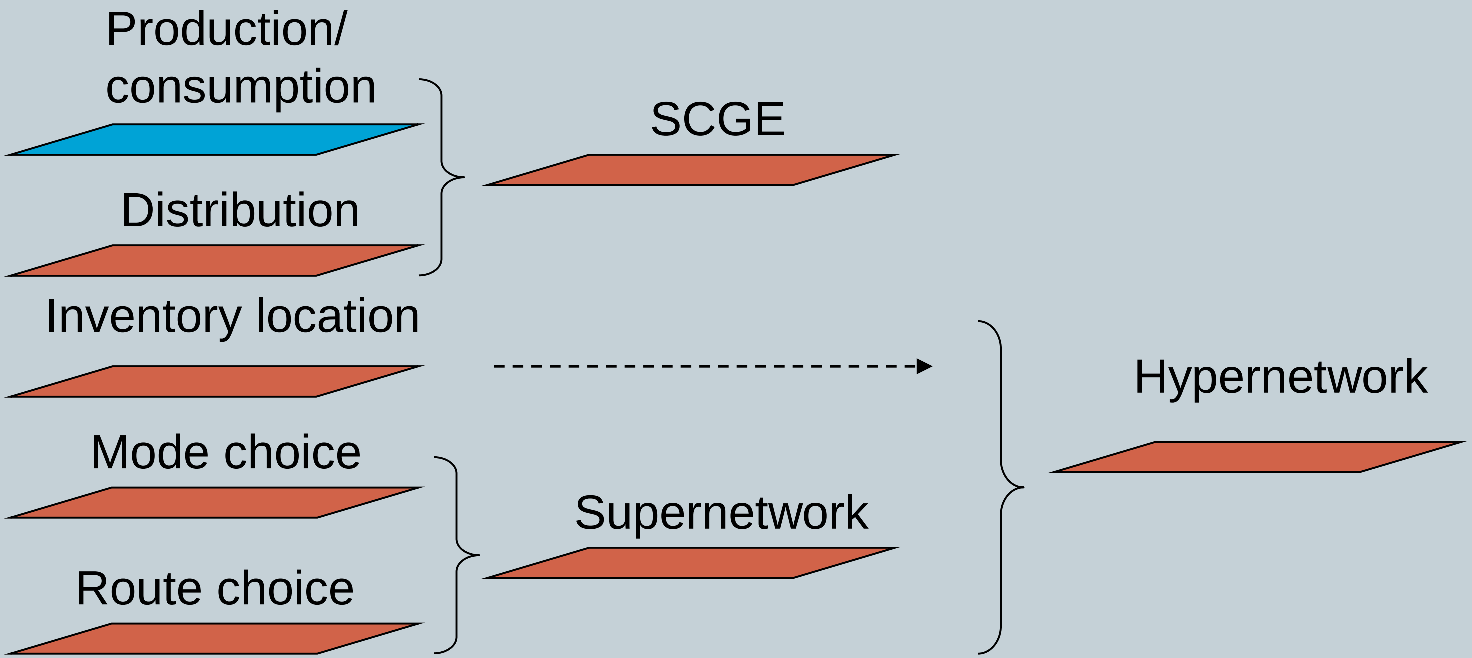
Model taxonomy: 4 stage and beyond



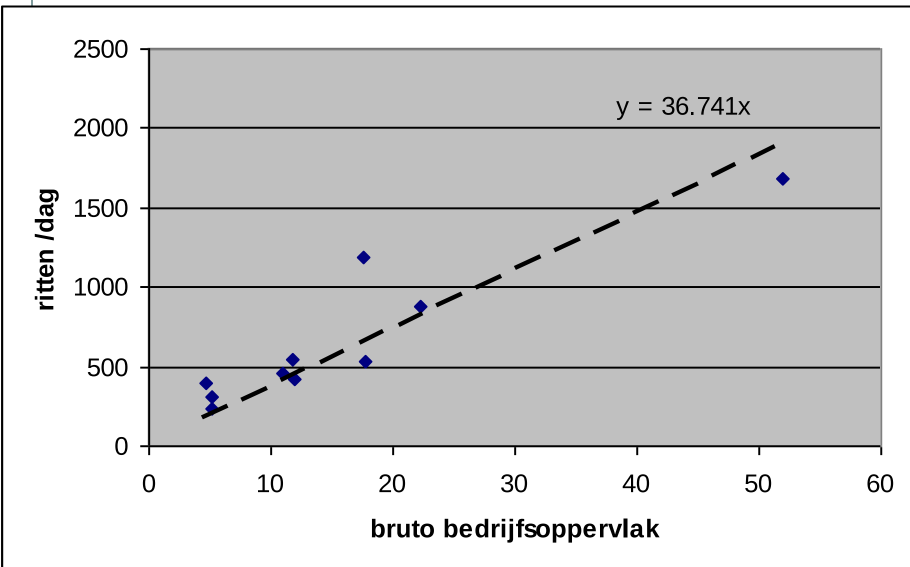
Intermediate conclusion

- Freight changes caused by:
  - Changes in the economy
  - Changes in number of tons lifted
  - Changes in the transport performance
  - Changes in traffic performance
- Supply chain considerations: logistics service & total logistics costs
  - Transport
  - Inventory
  - Handling
- 4 step transport demand model needs to be extended to accommodate freight specific issues

Freight generation

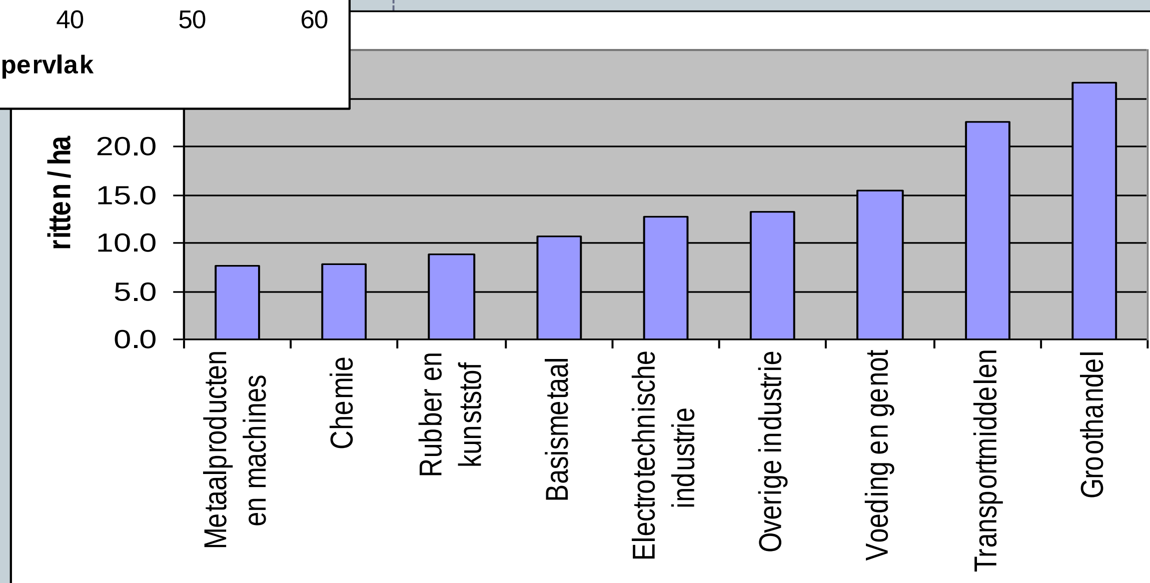


Simple freight trip generation models



Zonnenberg, 1989

- Freight generation vs. freight *trip* generation
- Increases with economic activity (business size, # of consumers)
- Depends on sector/ goods type
- Mostly simplified into *linear* model



Klaver, 2001

Problem: Just Regression

(why a problem?)

Trip generation & shipment size

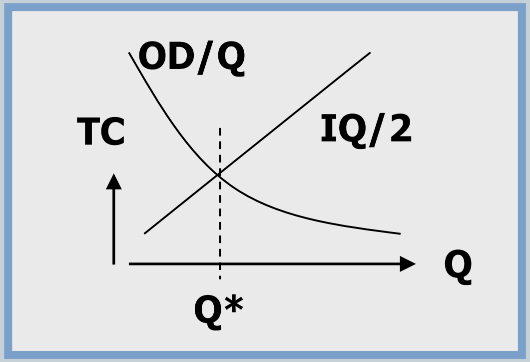
Problem Ordering goods from manufacturer: what order size?
EOQ - economic order quantity

Total costs = product costs + ordering costs + inventory costs

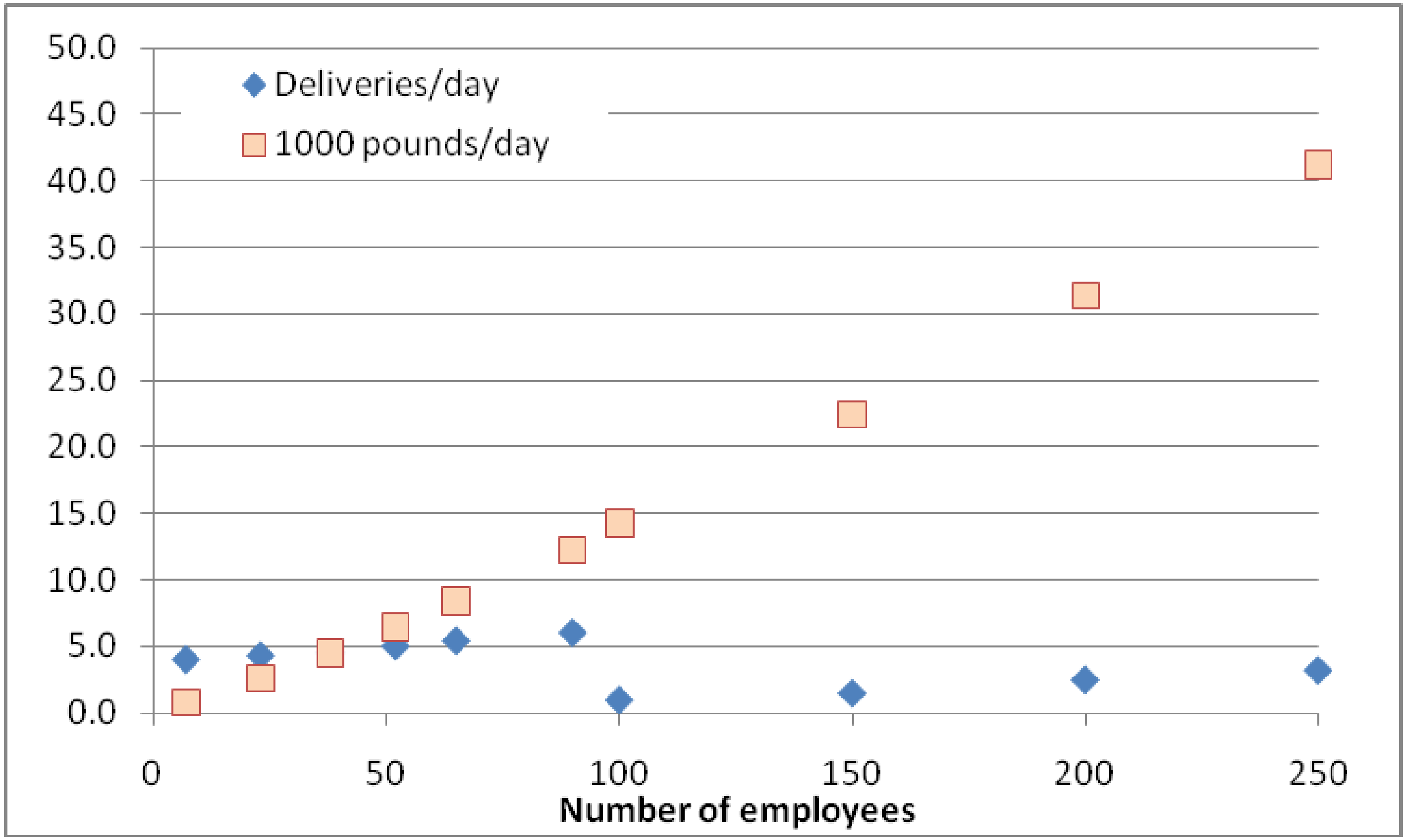
- Price (P) * demand (D)
- Ordering costs /unit (O) * # units (D/Q)
- Inventory cost / unit (I) * average inventory (Q/2)

TC = P*D + O*D/Q + I*Q/2; minimize for shipment size Q

Solution at OD/Q = IQ/2; $Q^* = \sqrt{(2OD/I)}$



Effect of logistics on freight trip generation – or…?



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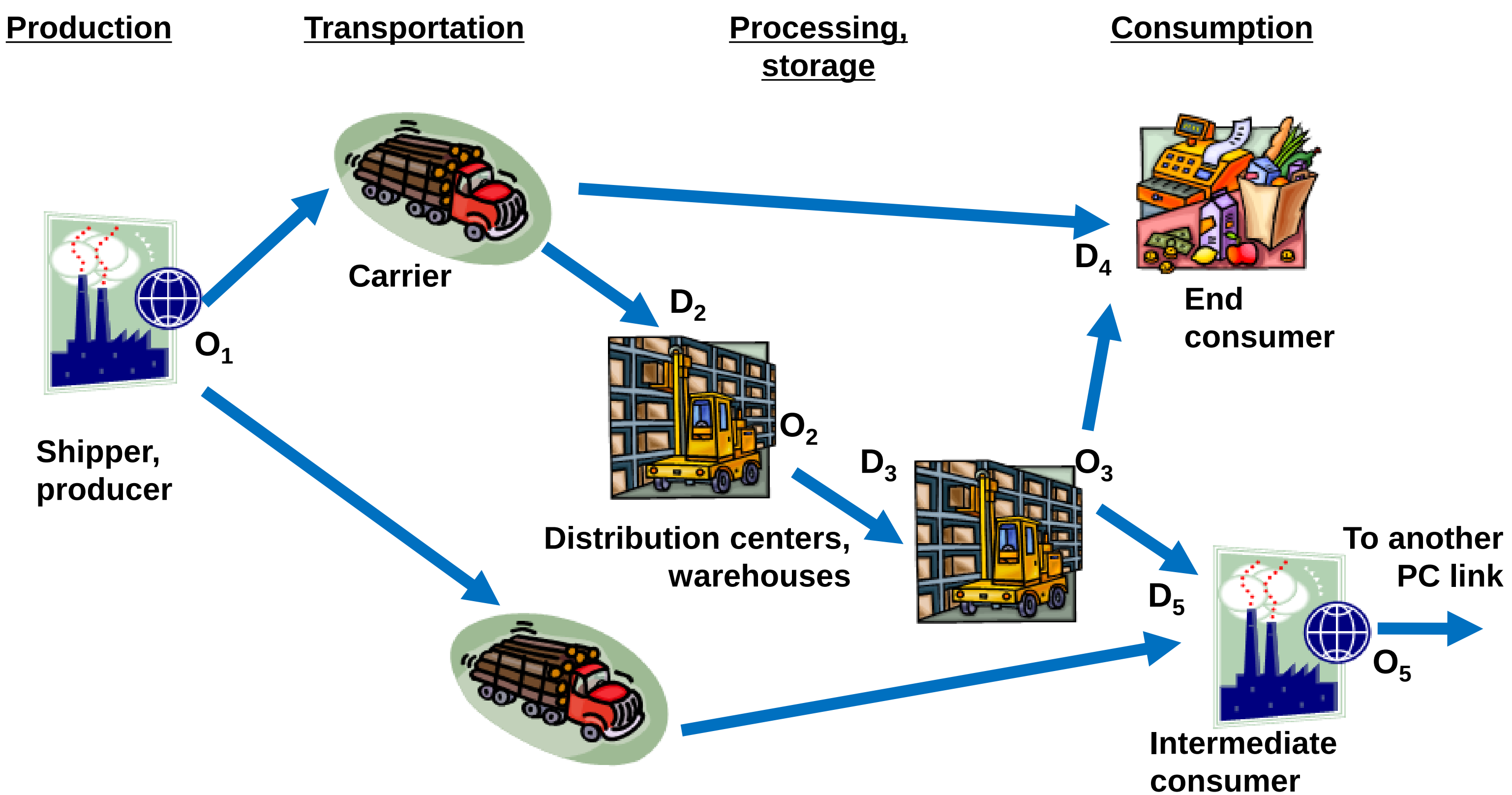
Trip generation vs. production and consumption



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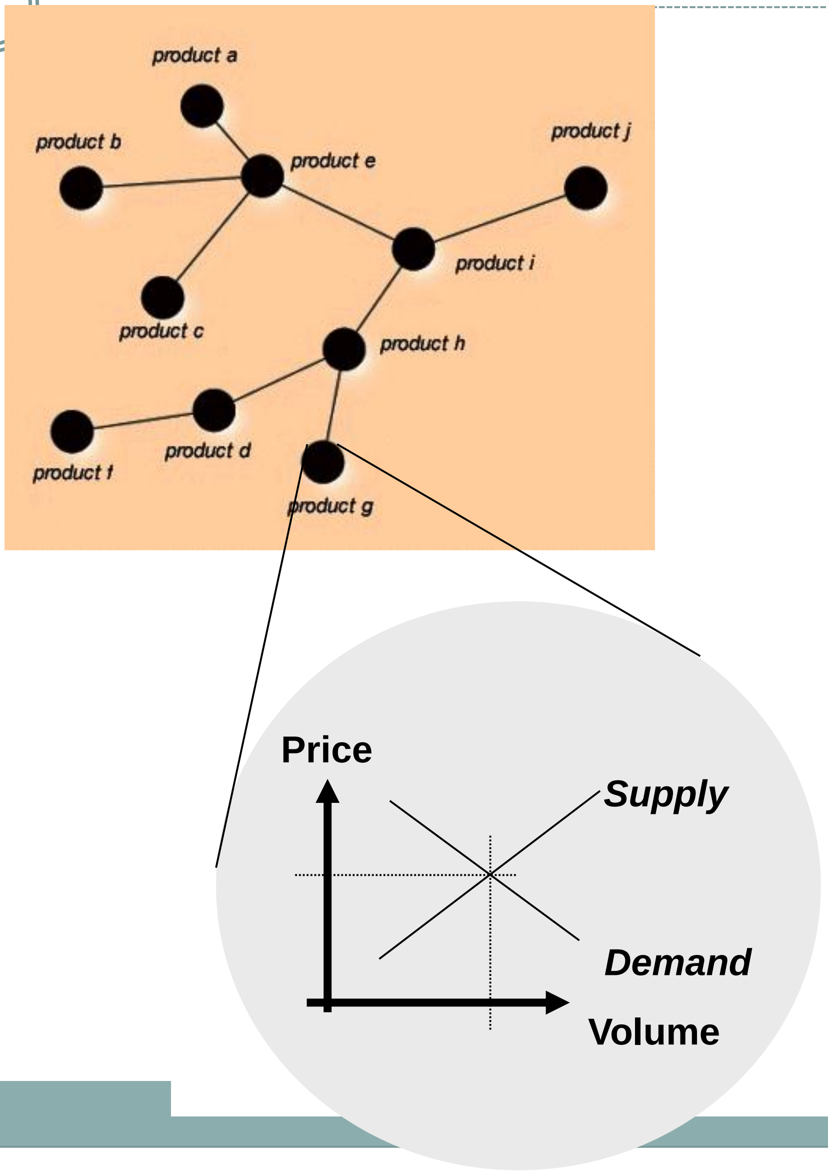
Production and consumption networks

- Input/Output analysis allows us to trace demand effects through sectors as pulled by consumer demand (“final demand”)

  => I/O model with fixed relations

- More realistic approach through flexible production functions

  => computable general equilibrium models



Input-Output analysis: basic framework

I/O origin = estimation of GDP for national accounts

(1) Total production **t** = Final demand **y** + Intermediate demand f**(t)**

(2) Intermediate demand = technical coefficient **A** * total production **t**

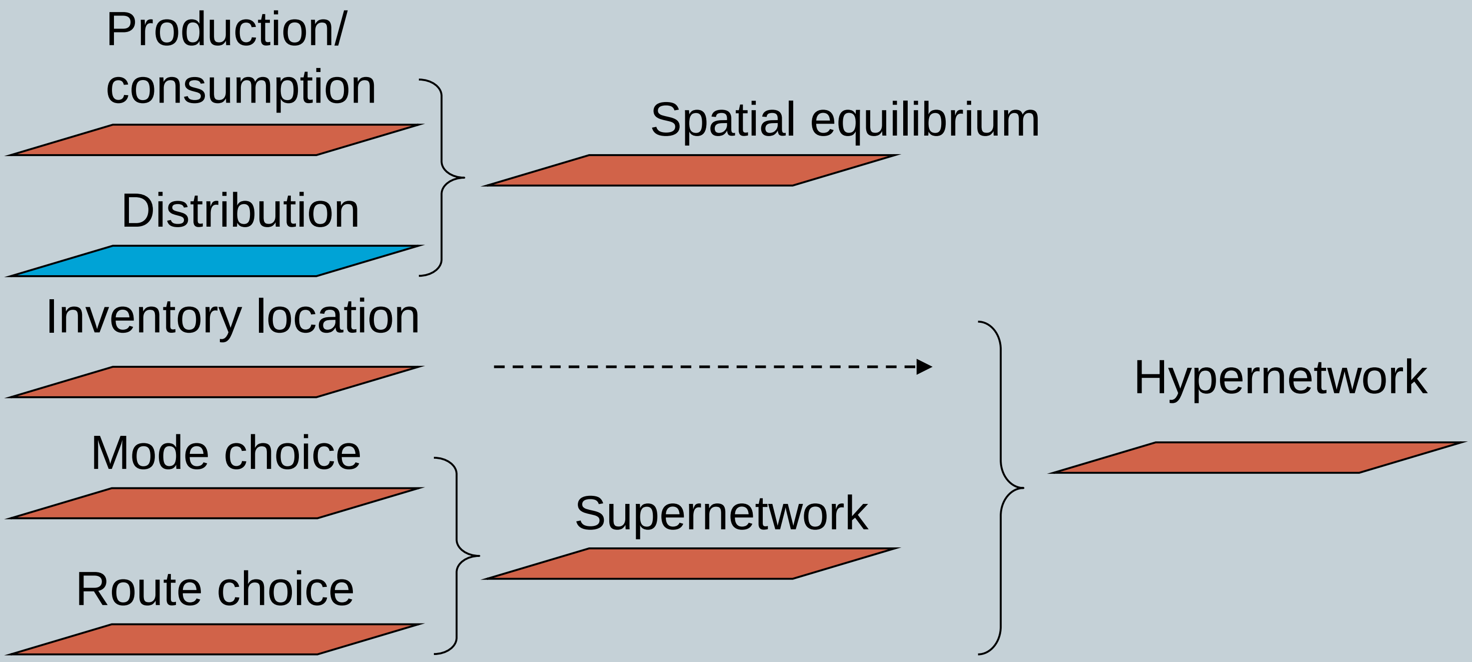
Assumed fixed!

$\mathbf{t} = \mathbf{y} + \mathbf{At} \Rightarrow \mathbf{t} = \mathbf{y}(\mathbf{I}-\mathbf{A})^{-1}$

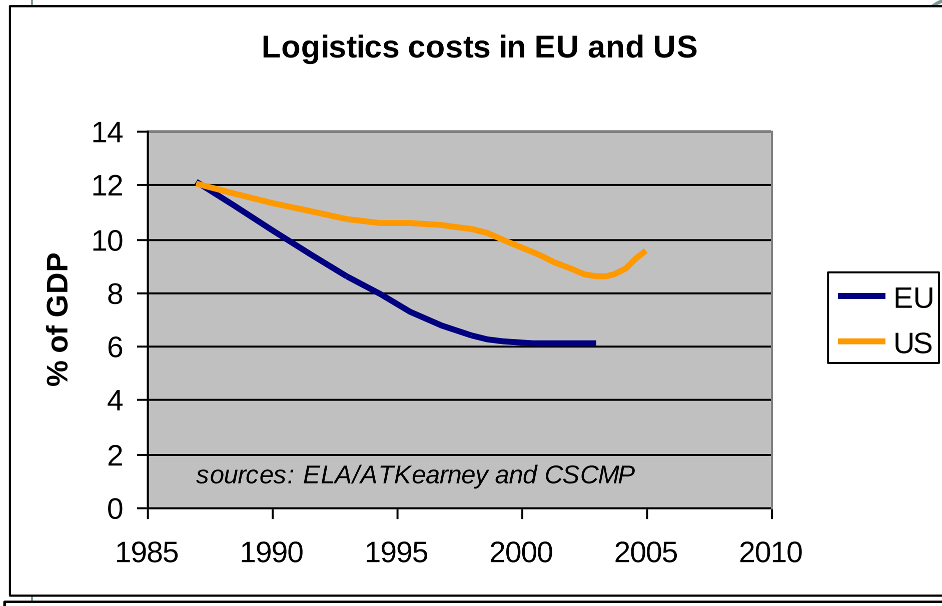
t = vector of total production
y = vector of final demand
A = matrix of technical coefficients

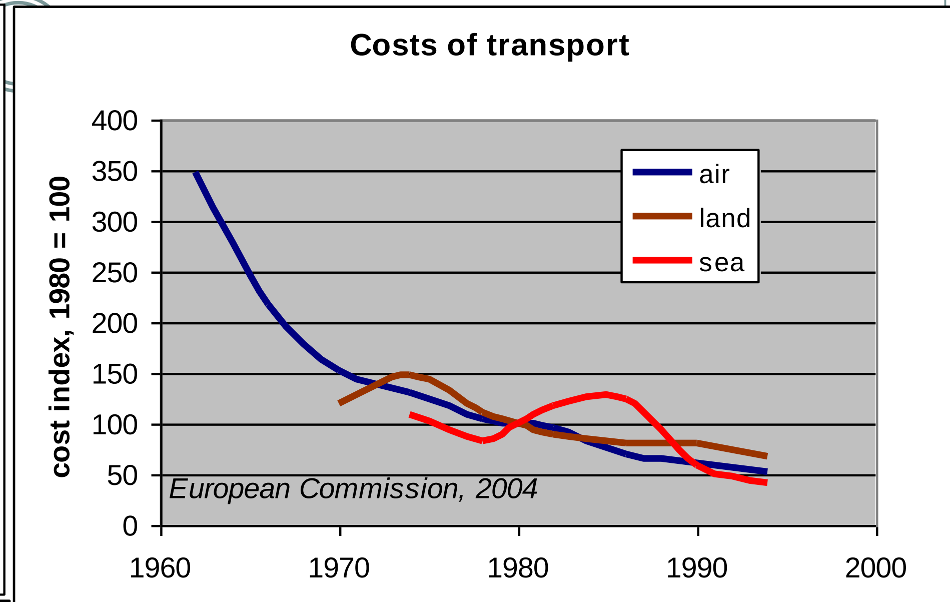
All in *Euro per year per sector*

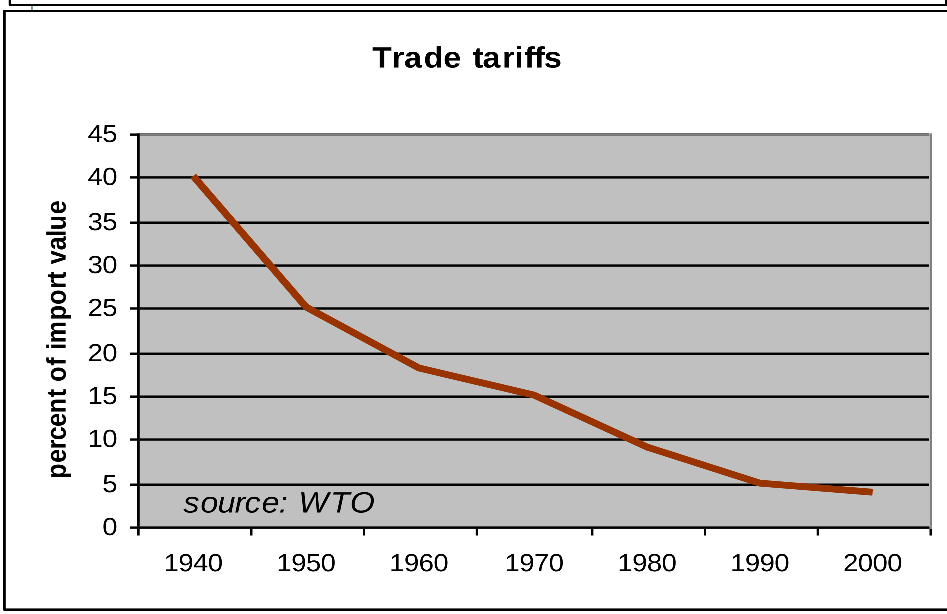
Distribution models

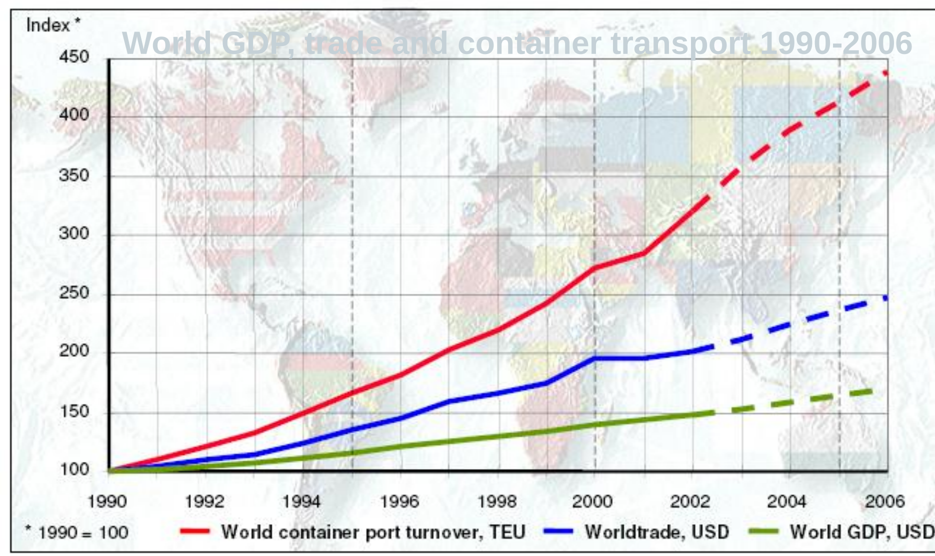


Trade depends also on costs of interaction



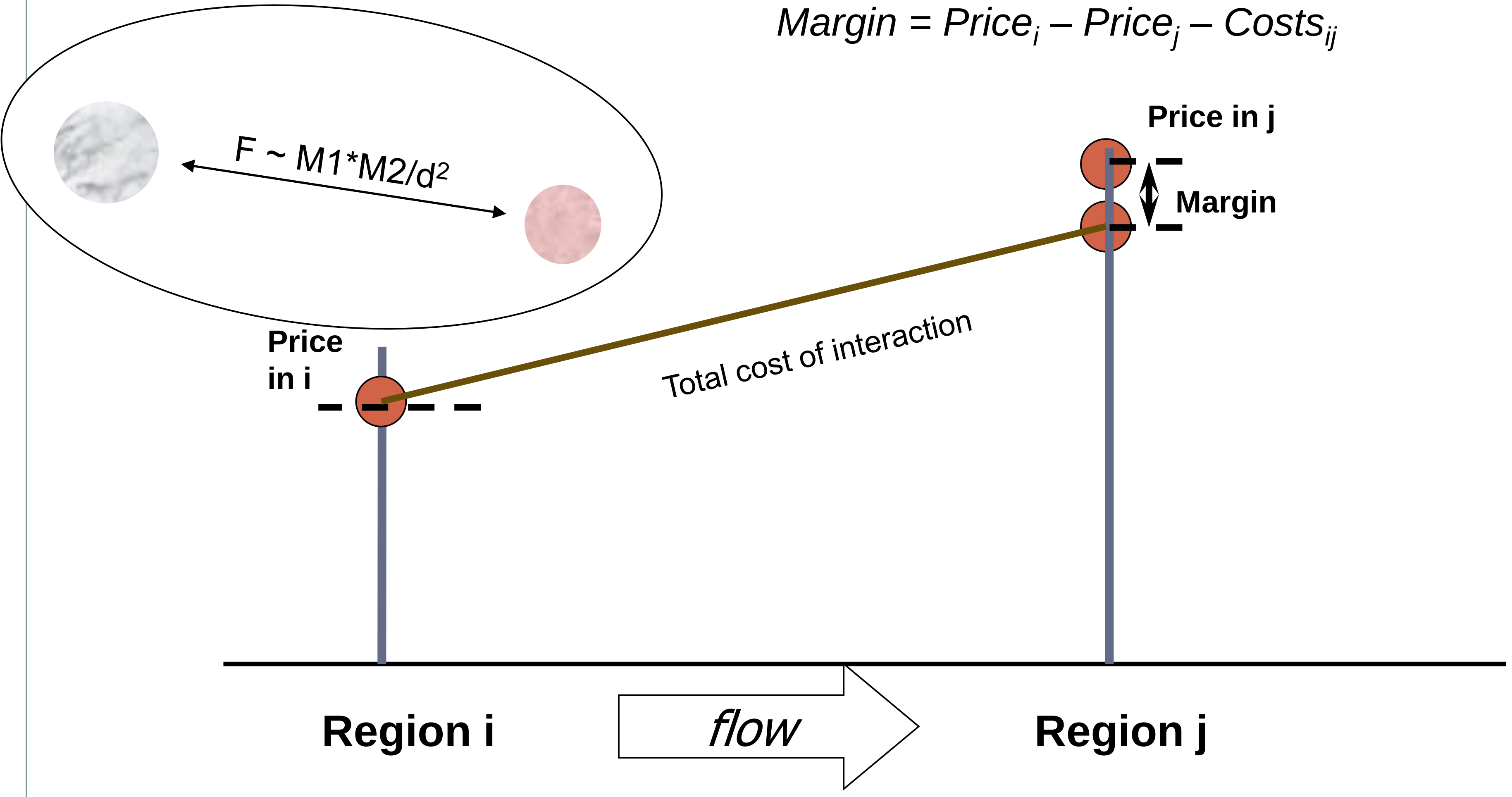






Understanding the gravity model (1)

Margin = Price$_i$ – Price$_j$ – Costs$_{ij}$



Understanding the gravity model (2)

M = margin,
p = price,
c = costs of interaction,
i & j: regions
T = total trade
A, B, ζ: constants

$\mathbf{M_{ij} = p_j - p_i - c_{ij}}$

Interregional trade
$\mathbf{T_{ij} = T * Pr\{_{ij}\}}$

Choice probabilty based on logit discrete choice model
$\mathbf{Pr\{_{ij}\} = exp\,(M_{ij}) / \Sigma_{ij}\, exp(M_{ij})}$

Then:

$\mathbf{T_{ij} = exp(p_j - p_i - c_{ij})^* T / \Sigma_{ij}\, exp(M_{ij})}$

Replace T/ Σ_{ij} exp(M_{ij}) bij ζ (constant) for convenience ➔

$\mathbf{T_{ij} = \zeta * exp(-p_i) * exp(p_j) * exp(-c_{ij}) = \zeta * A_i * B_j * exp(-c_{ij})}$

Economy/transport linkages

- LUTI model
  - Trip generation as simple regression function of accessibility
  - $T_{i*g} = f(A_{rs})$; e.g. 10% change in accessibility means 10% more trips
- Regional (quasi-) production function model
  - Trip generation changes via changes in regional GDP
  - $T_{i*g} = f(GDP_{is})$ and $GDP_{is} = f(L_i\ K_i\ R_i\ A_{is})$
- SCGE models
  - Trip generation as result of general spatial price equilibrium
  - $T_{ijg} = f(L_{i,j,s}\ K_{i,j,s}\ R_{i,j,s}\ t_{ijs})$

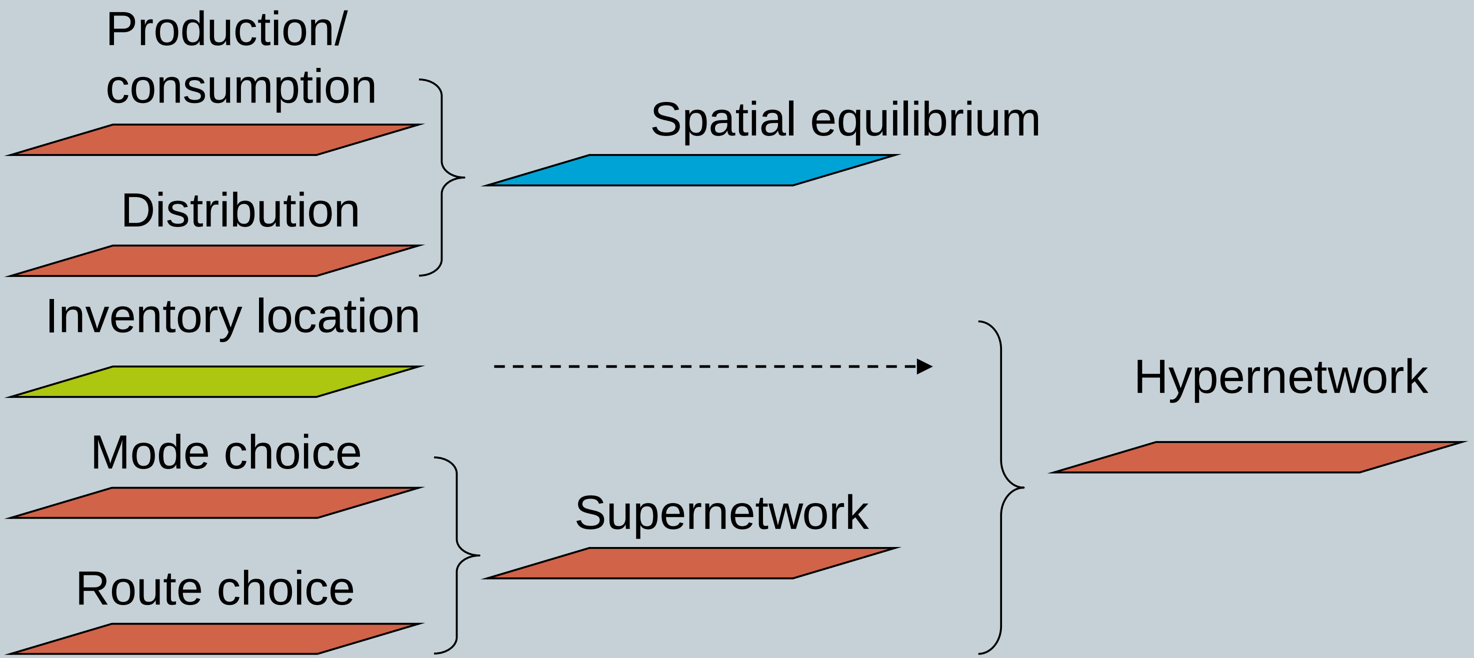
where

- **Ti*g = Trips from i to all other regions, for good *g***
- **A= Accessibility of sector *s* in region i**
- **L, K, R: Labor, Capital, Land**
- **i,j = short for all ij and sector pairs**

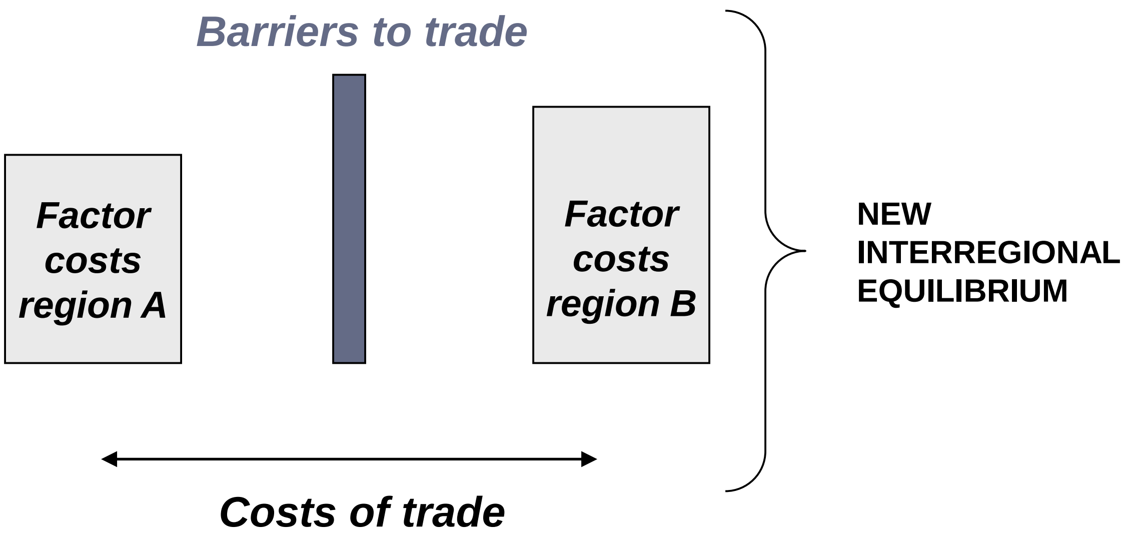
Evolution of spatial interaction models

<table>
<tr><th rowspan="2">Location of activities</th><th colspan="2">Interaction between activities</th><th rowspan="2">Intensity of economic activities</th></tr>
<tr><th>Spatial interactions</th><th>Sectoral interactions</th></tr>
<tr><td>Land Use models</td><td>Gravity type models</td><td rowspan="2">Input/Output models</td><td rowspan="3">Equilibrium models</td></tr>
<tr><td colspan="2">LUTI models: elasticities for regional trip generation</td></tr>
<tr><td></td><td colspan="2">Multi-regional I/O models (MRIO): stepwise IO & gravity</td></tr>
<tr><td></td><td></td><td colspan="2">Computable General Equilibrium models</td></tr>
<tr><td colspan="4">Spatial Computable General Equilibrium models</td></tr>
</table>

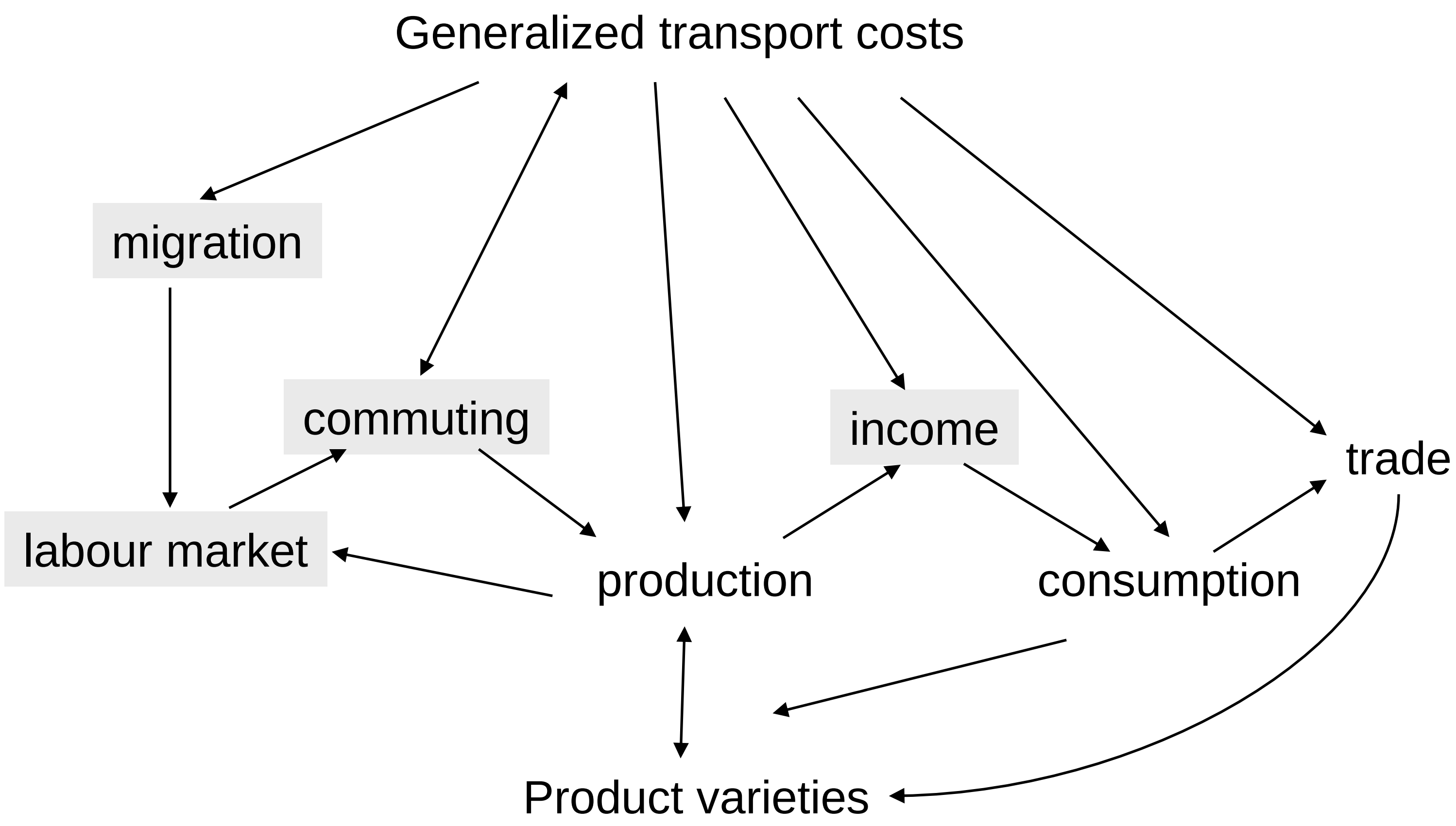
Spatial equilibrium models



Production, consumption and trade combined: spatial general equilibrium



Towards an integrated system model for passengers and freight



Intermediate conclusion

- Production and consumption: from I/O to production functions

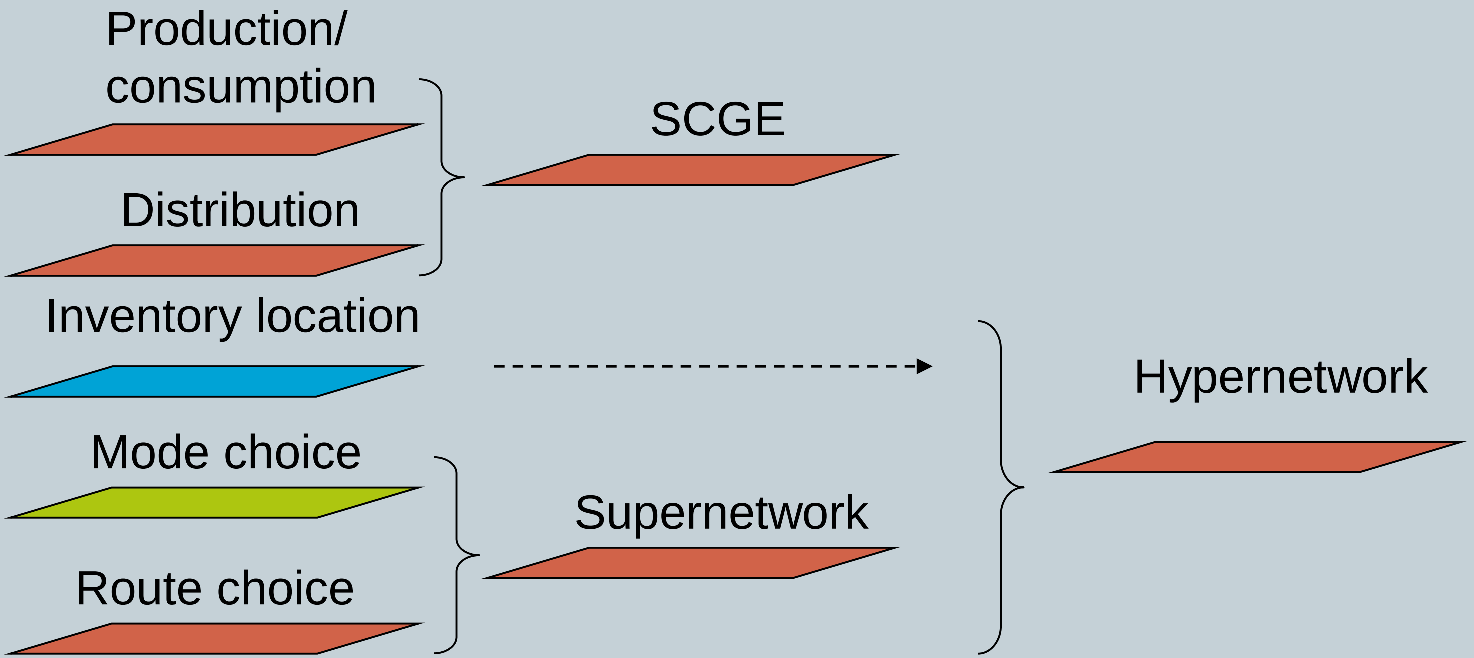
- Spatial interaction well described by the gravity model

- Gravity model can be replaced by disaggregate logit

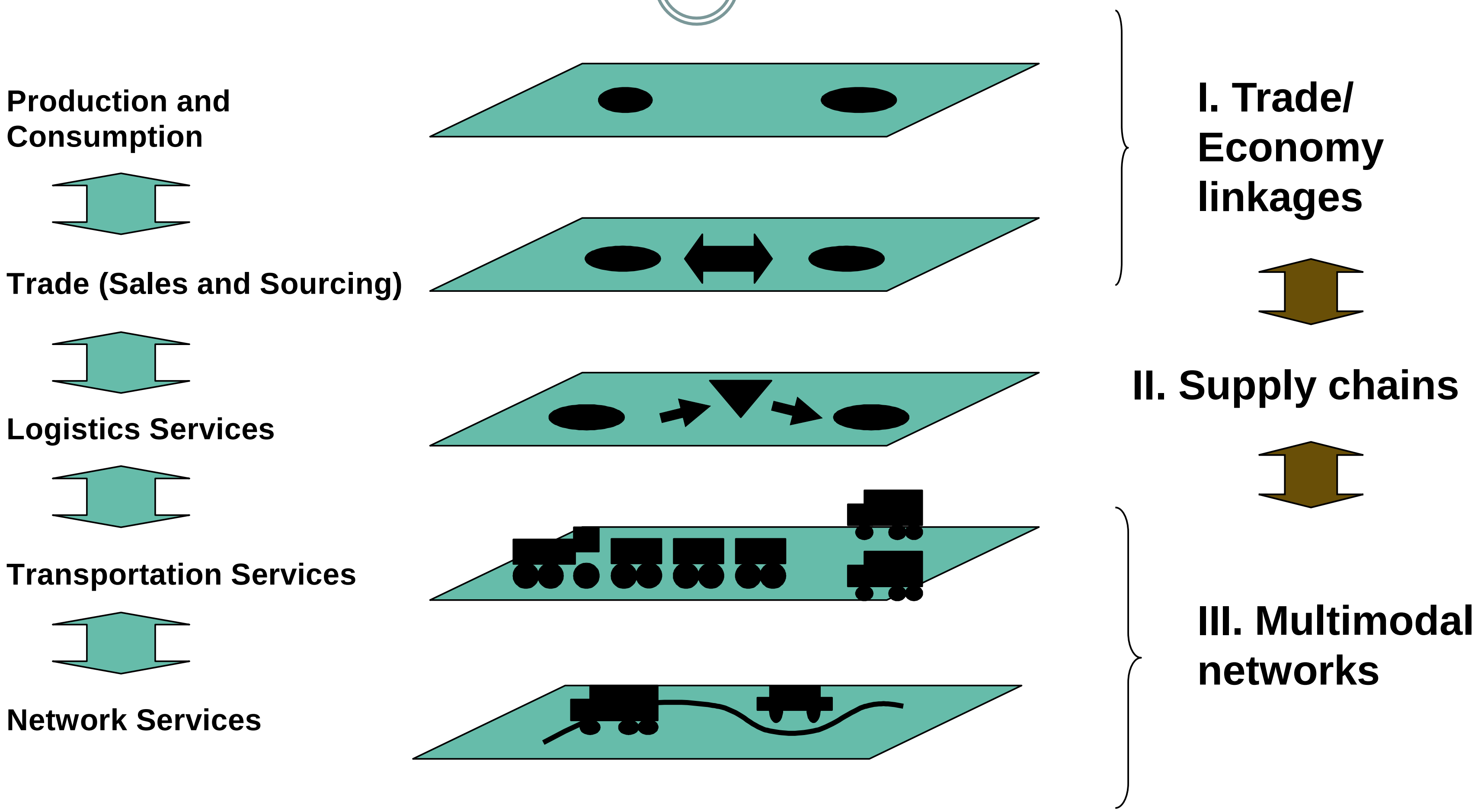
- I/O & gravity: MRIO (multiregional IO) models
- Land Use Transport Interaction models
- Linkage with production functions: spatial general equilibrium

- Also link to integration with passenger transport modelling

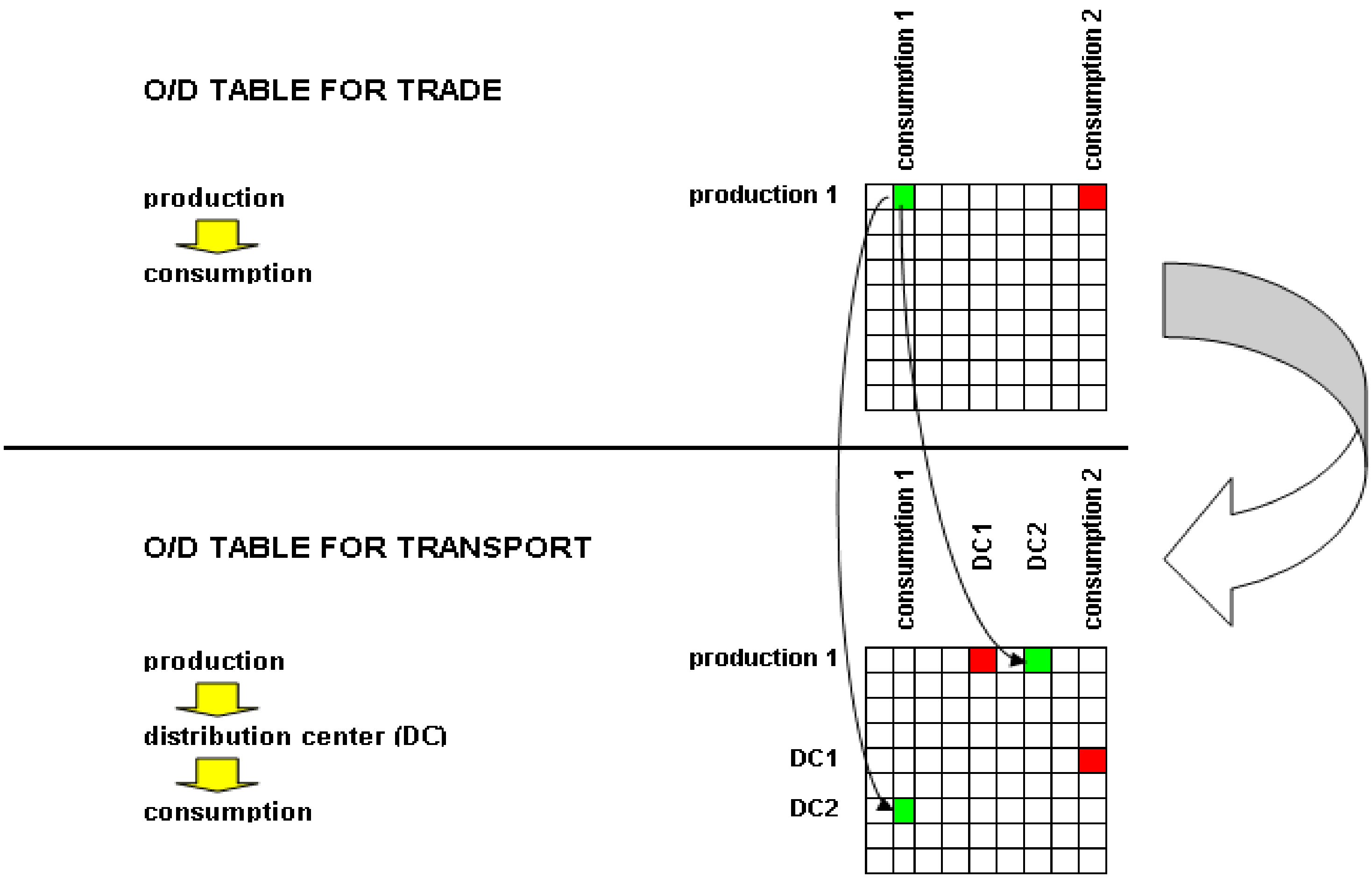
Modelling inventory chains



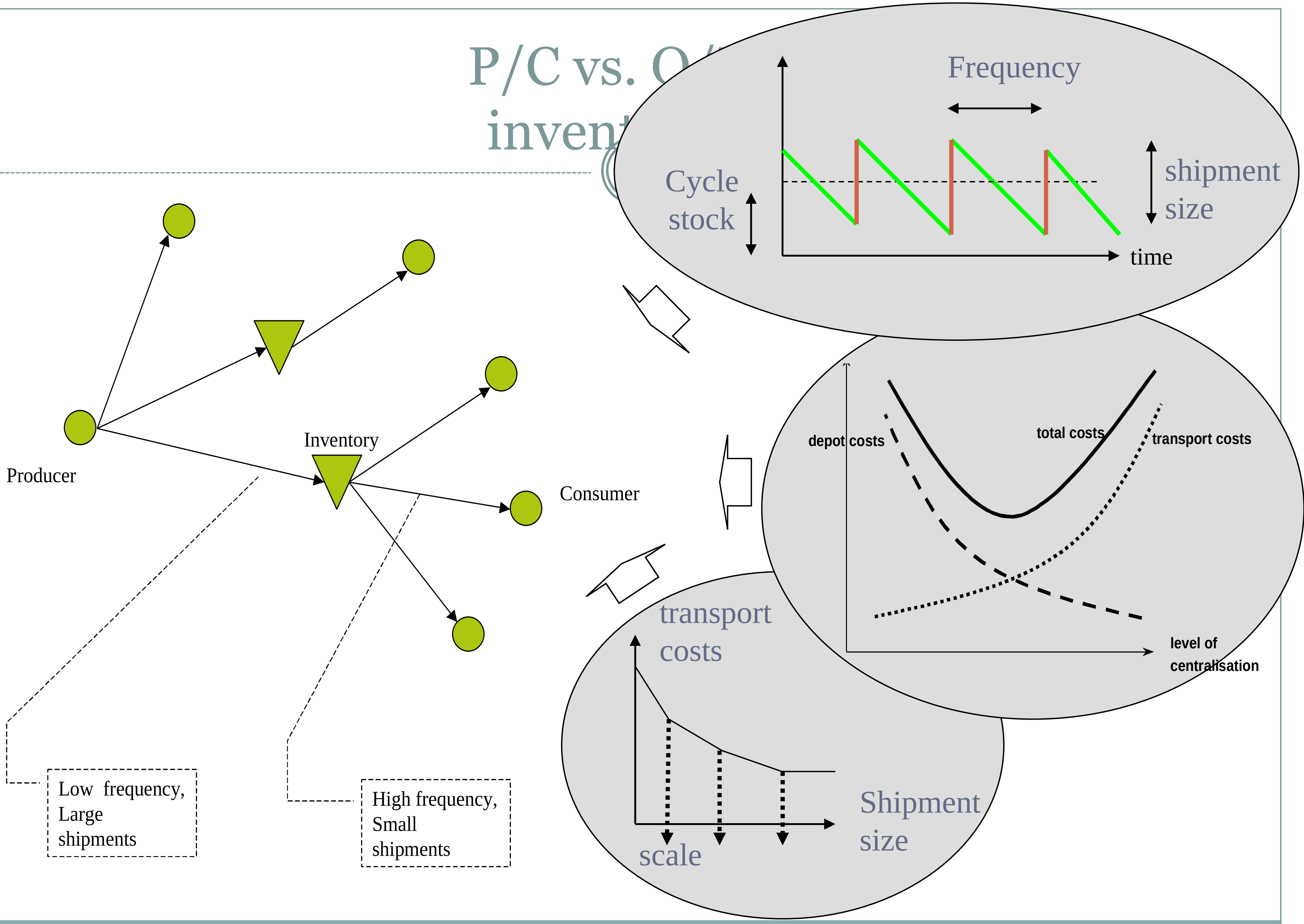
Positioning logistics within the 4 step model



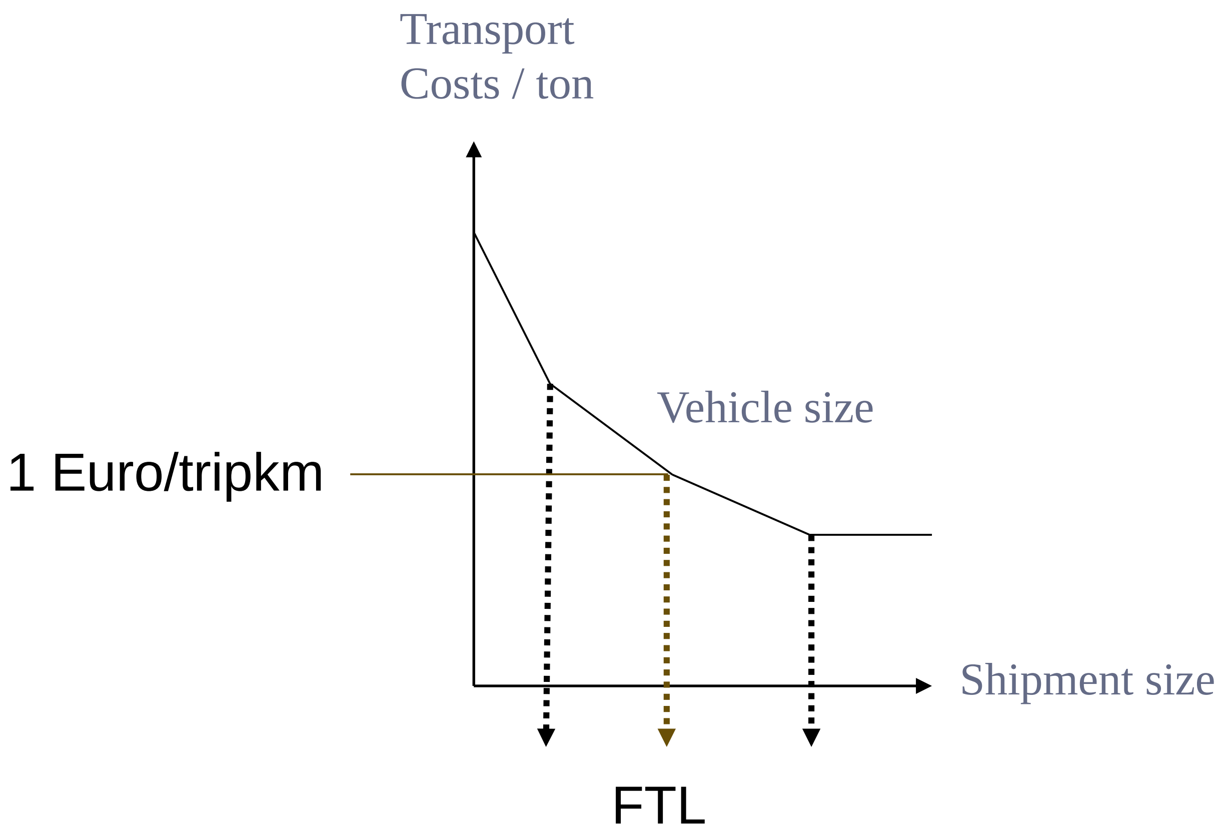
Inventories affect spatial flow patterns



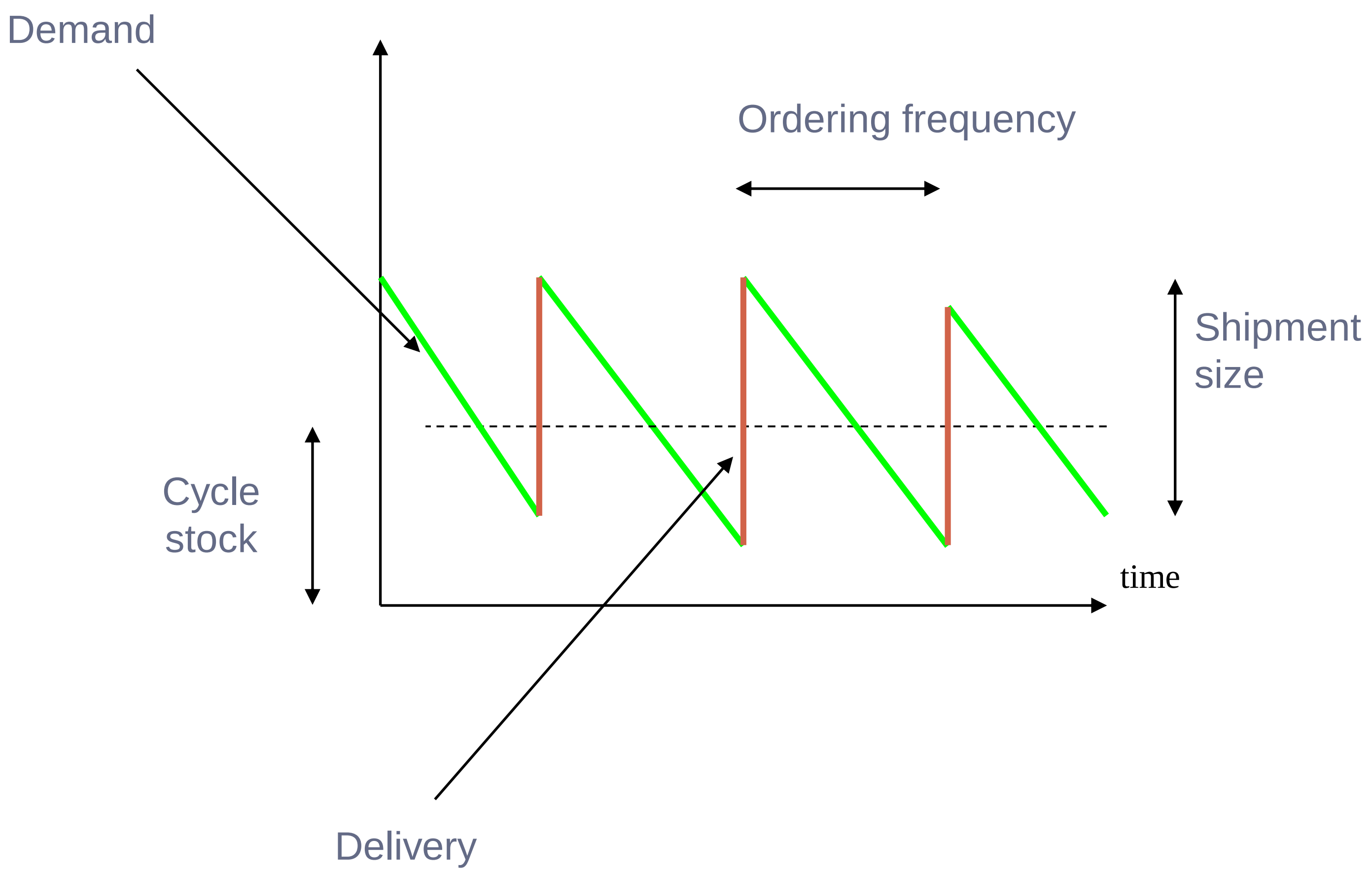
P/C vs. Q/ invent



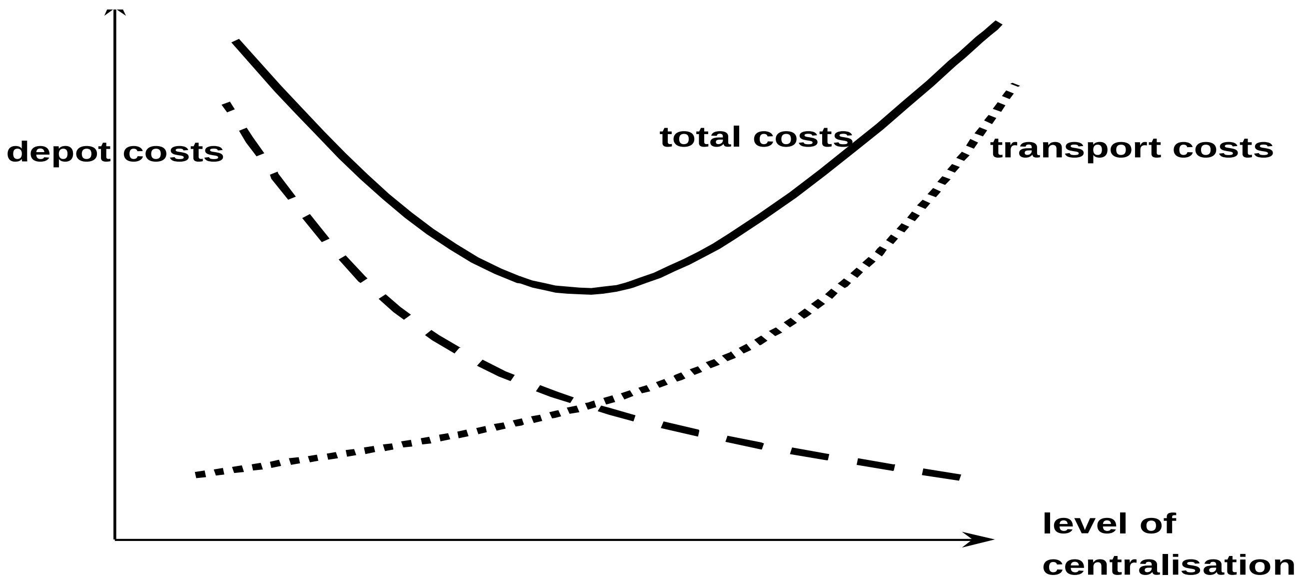
Mechanism 1: economies of scale

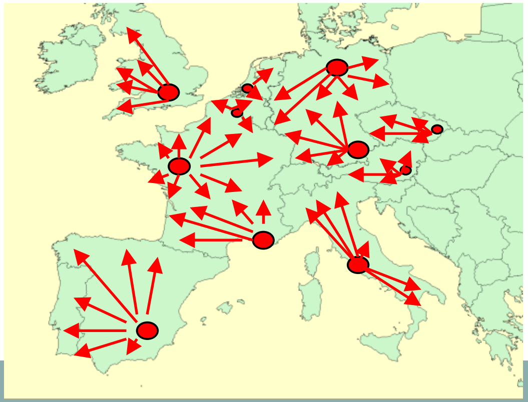


Mechanism 2: inventory policy

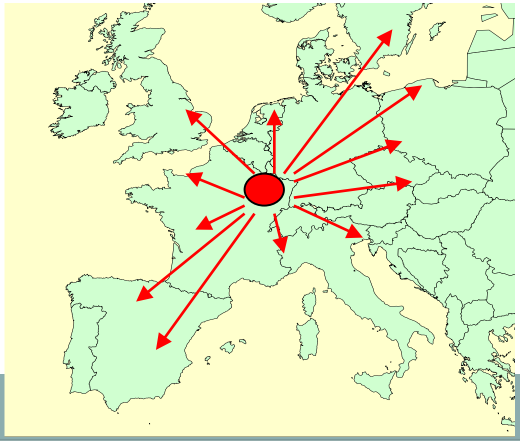


Supply chain changes in Europe

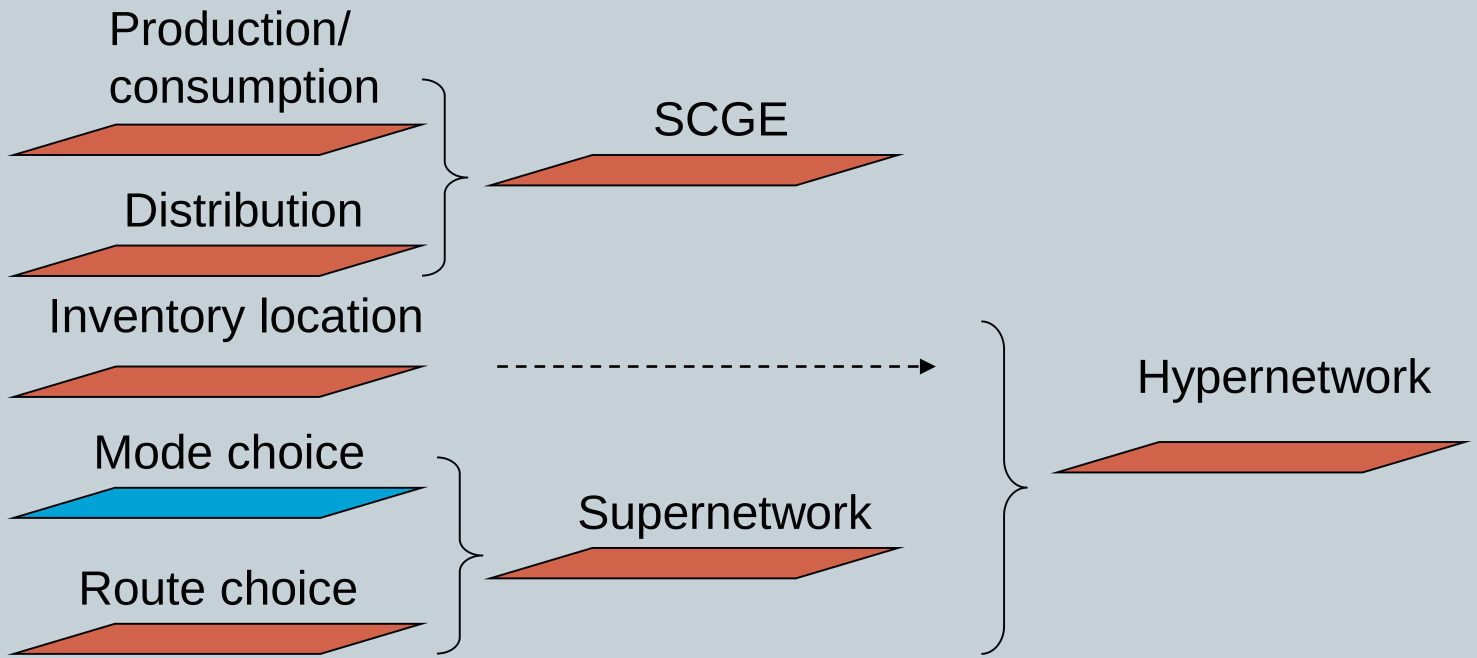




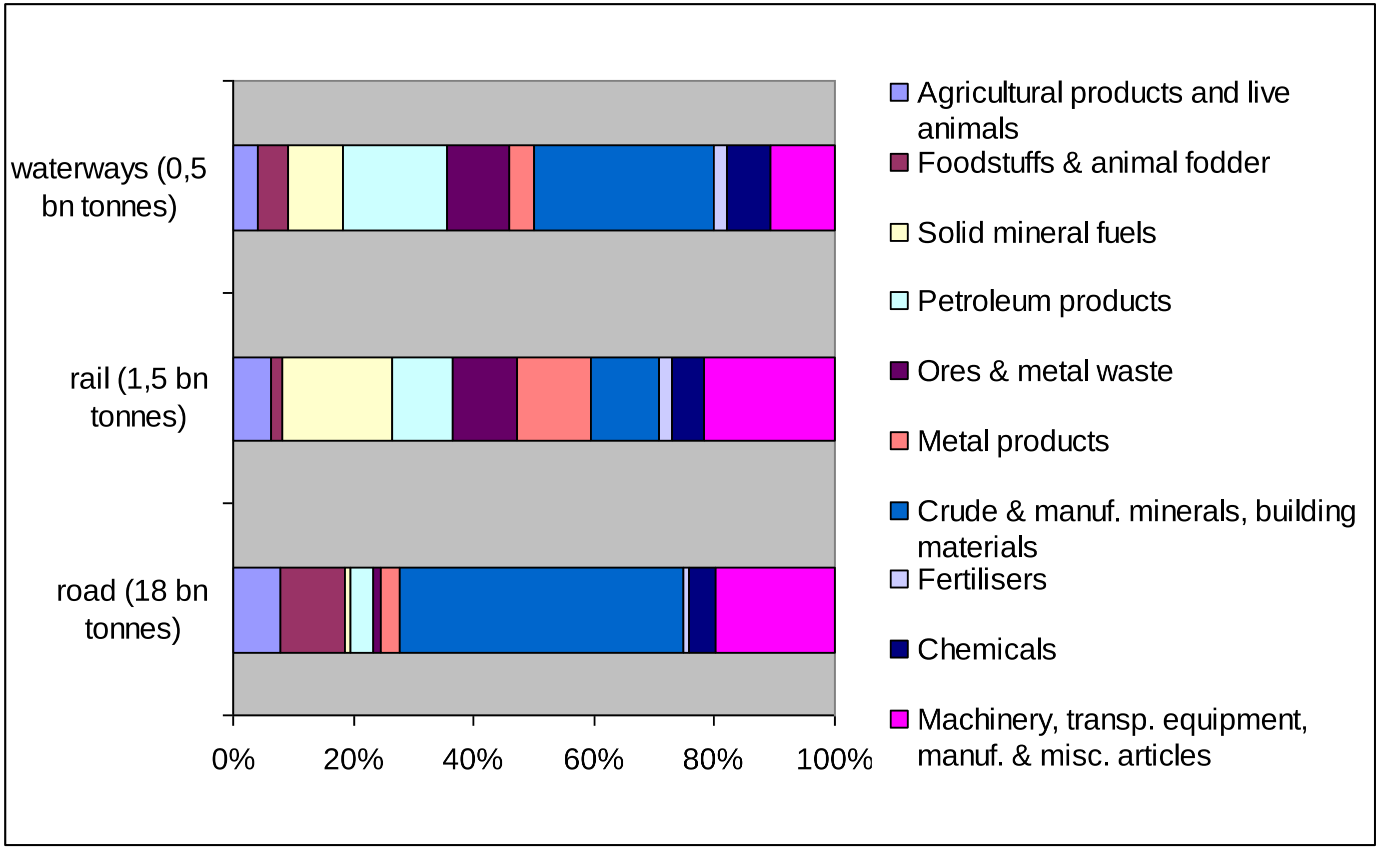
CENTRALITY



Mode choice models



Mode choice: some stats



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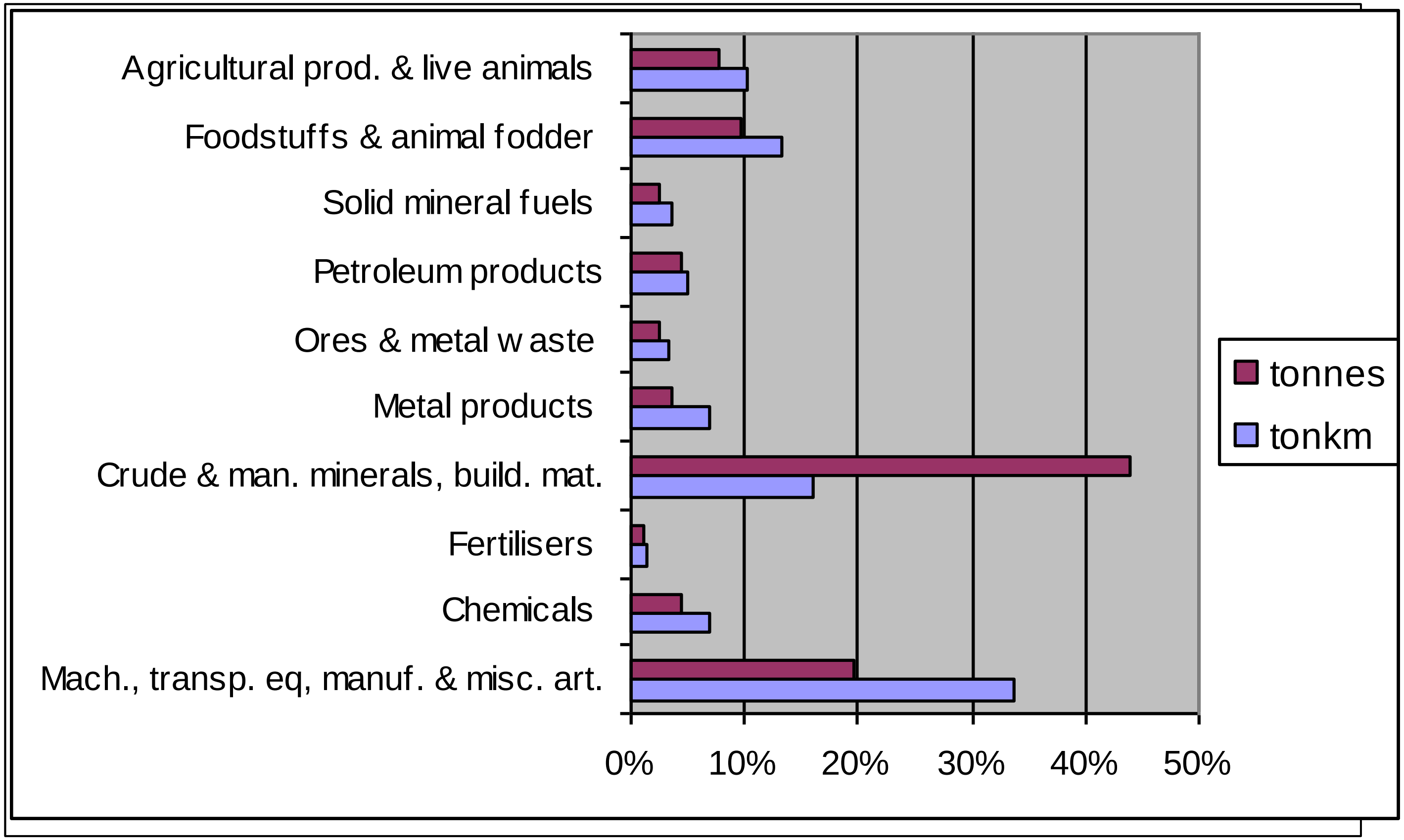
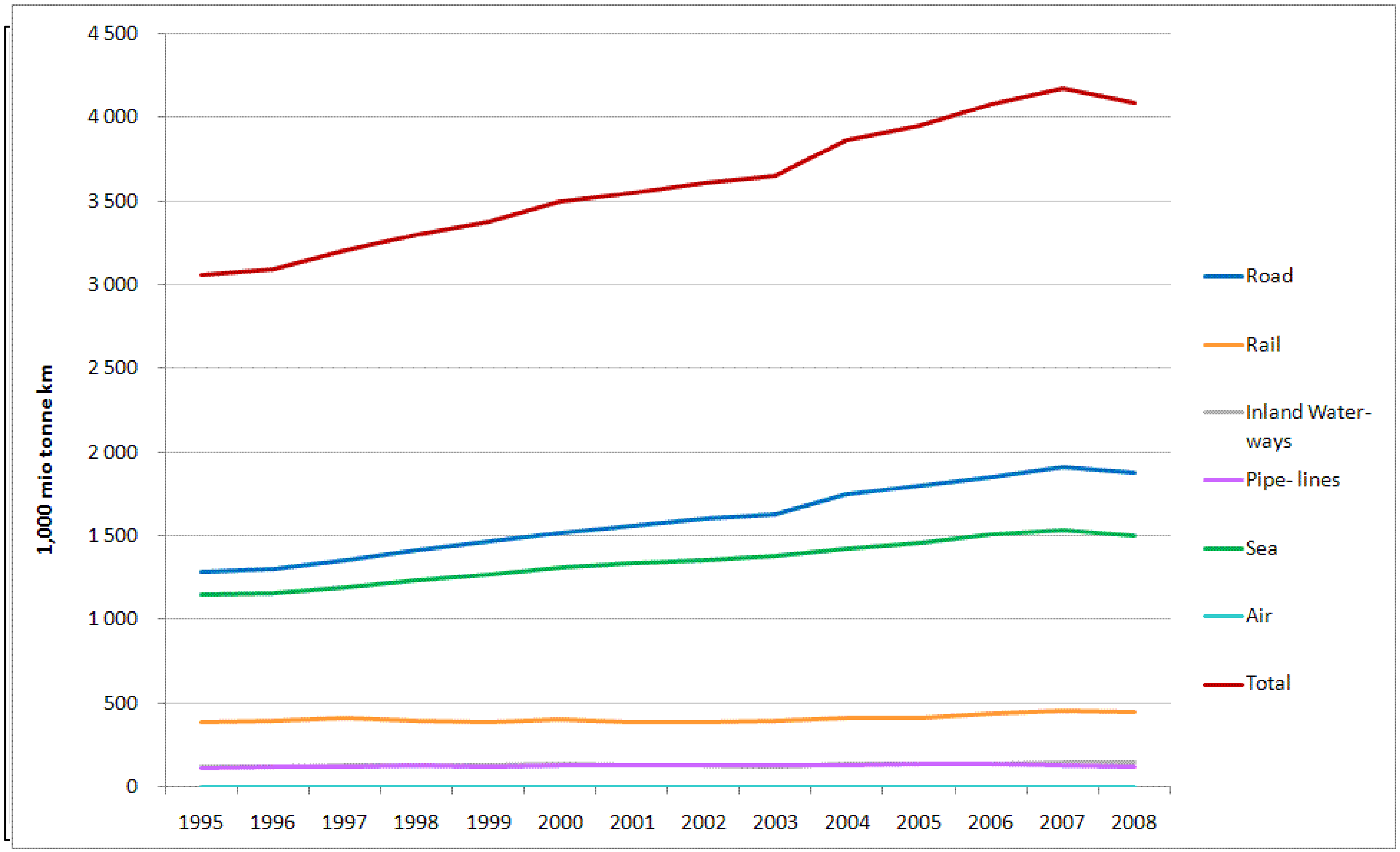


Mode choice: some stats



Mode choice models

- Mode attributes (=> *which ones?)*
- Commodity attributes (=> *which ones?)*

- Behavioural models
- Discrete choice models
- Total logistics costs based
  - Include inventory costs
  - In transport
  - At shipper

Table 2.1: Qualitative overview of modal characteristics, taken from (T.E. Platz, 2009)

	Feature	Road	Rail	Inland Waterway
Users				
1	Transport costs per unit	-	+	+
2	Ability to achieve the transport of large volumes	-	+	+
3	Transport speed	+	0	-
4	Network connectivity	+	0	-
5	Predictability of transport process	0	0	+
6	Transport frequency	0	0	0
7	Transport safety	-	+	+
8	Transport security	-	0	+
9	Convenience and flexibility	+	-	-
10	Resistance to extreme weather conditions	-	0	-
11	Limitation of infrastructure capacity, congestion	-	0	+
Governments				
A	Energy-use per ton-km	-	0	+
B	Emission of harmful substances	-	+	0
C	Emission of greenhouse gas	-	+	+
D	Noise, negative effects on ground and water	-	-	+

Legend: + relatively good performance, 0 medium performance, - weak performance.

Q: with all these "-"scores, how come road is so popular?

Mode choice modelling approaches

- Inventory (cost based, all-or-nothing) models

- Behavioural models:

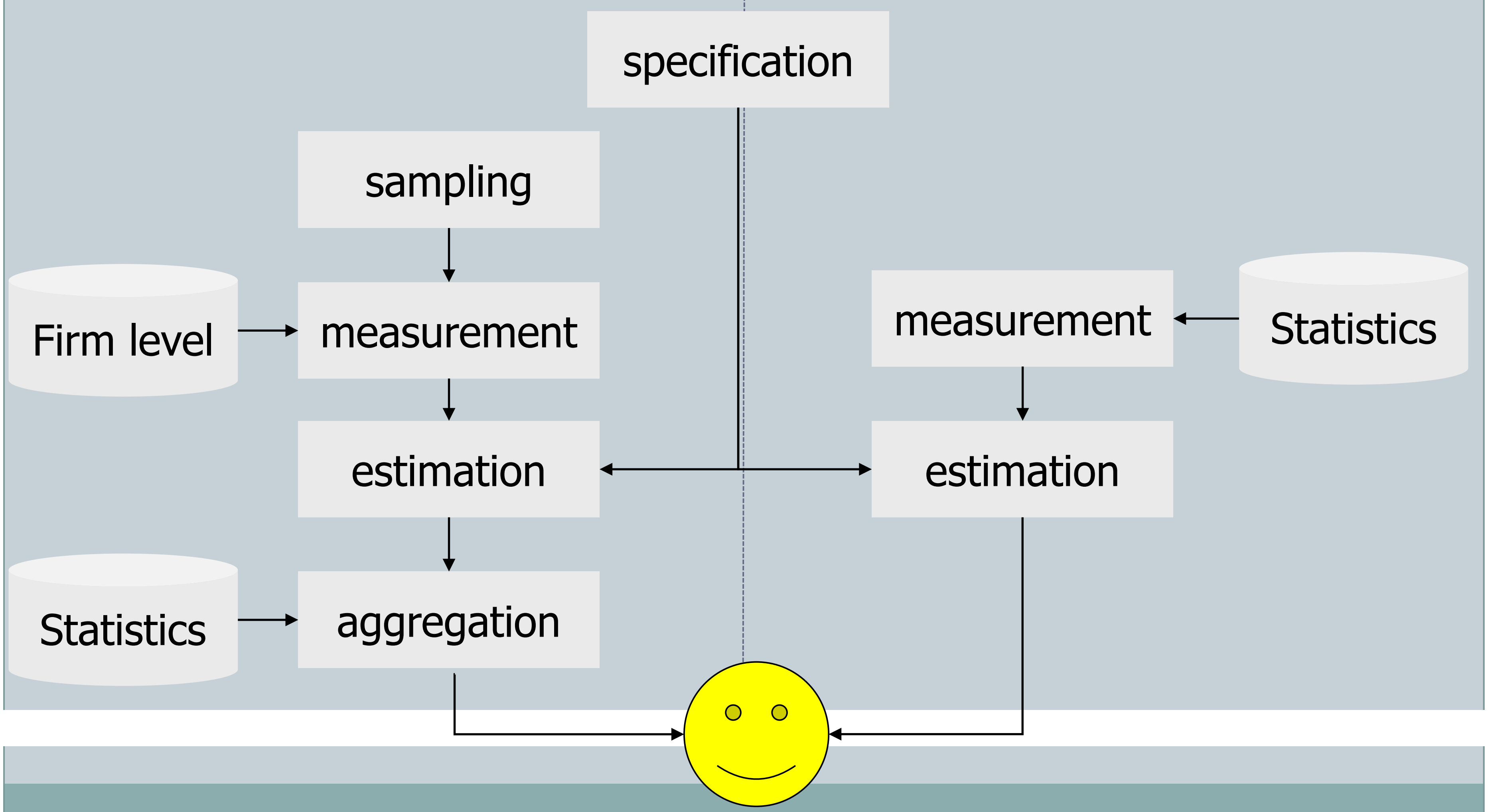
  Minimize out-of-pocket costs (K) ➔ utility maximization U = -K
  $V = K_m + \alpha T_m$

  Probabilistic approach discrete choice
  $U_m = K_m + \alpha T_m + \underline{\varepsilon}$

  Deterministic choice & random preferences
  $U_m = K_m + \underline{\alpha} T_m$

$$U_m = K_m + \underline{\alpha} T_m + \underline{\varepsilon}$$

Disaggregate vs. aggregate models



Operational approaches depend on data used

Aggregate Data
- Land use data
- Trade statistics
- Transport statistics
- Time and costs

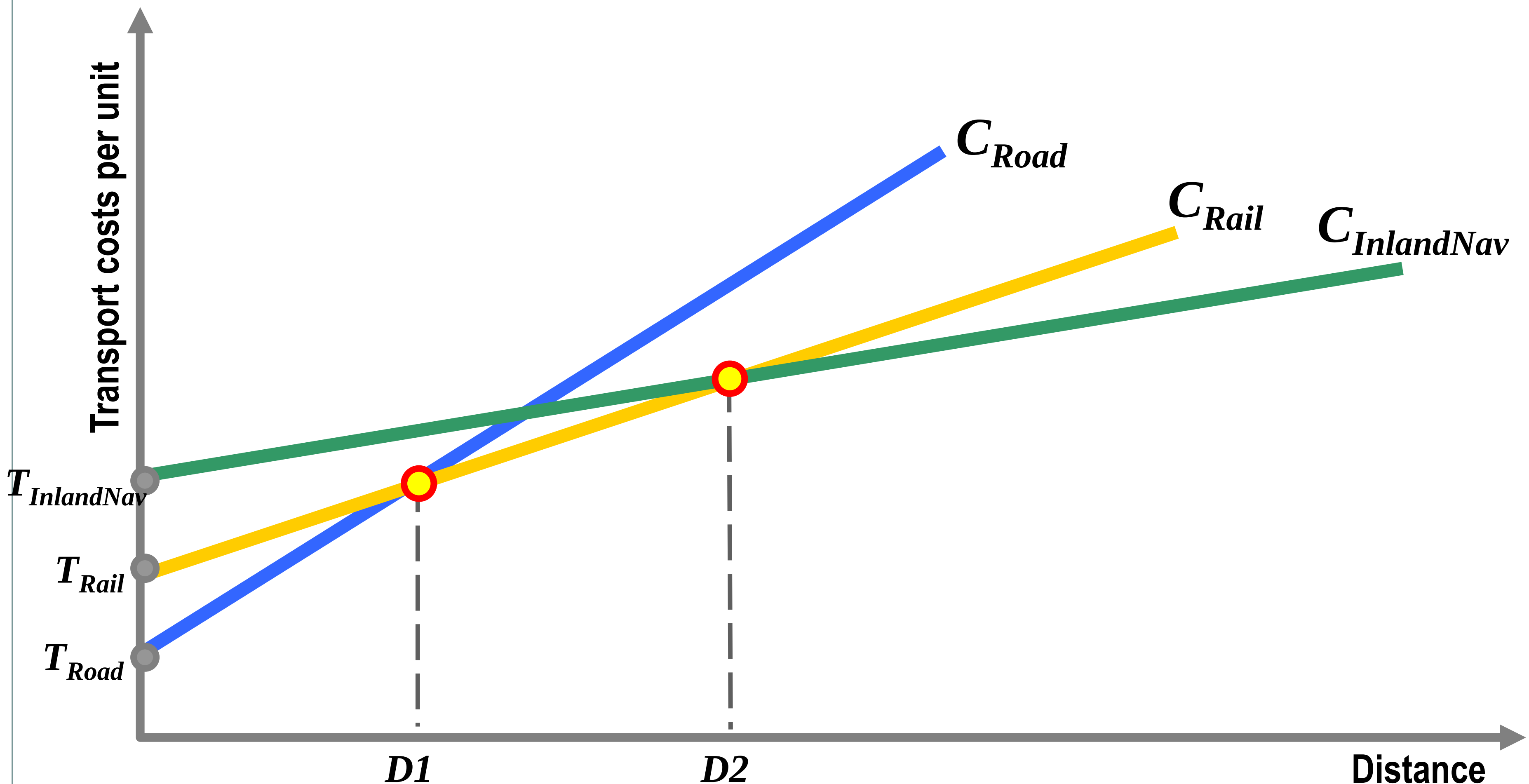
Disaggregate data
- Company surveys
- Shipment records
- Goods attributes
- Time and cost data

Combine
- Split aggregate flow data using firm size onto firm level

Or
- Make aggregate distributions of goods' attributes

Choice model
- Mode
- Shipment size
- Inventories
- Routing

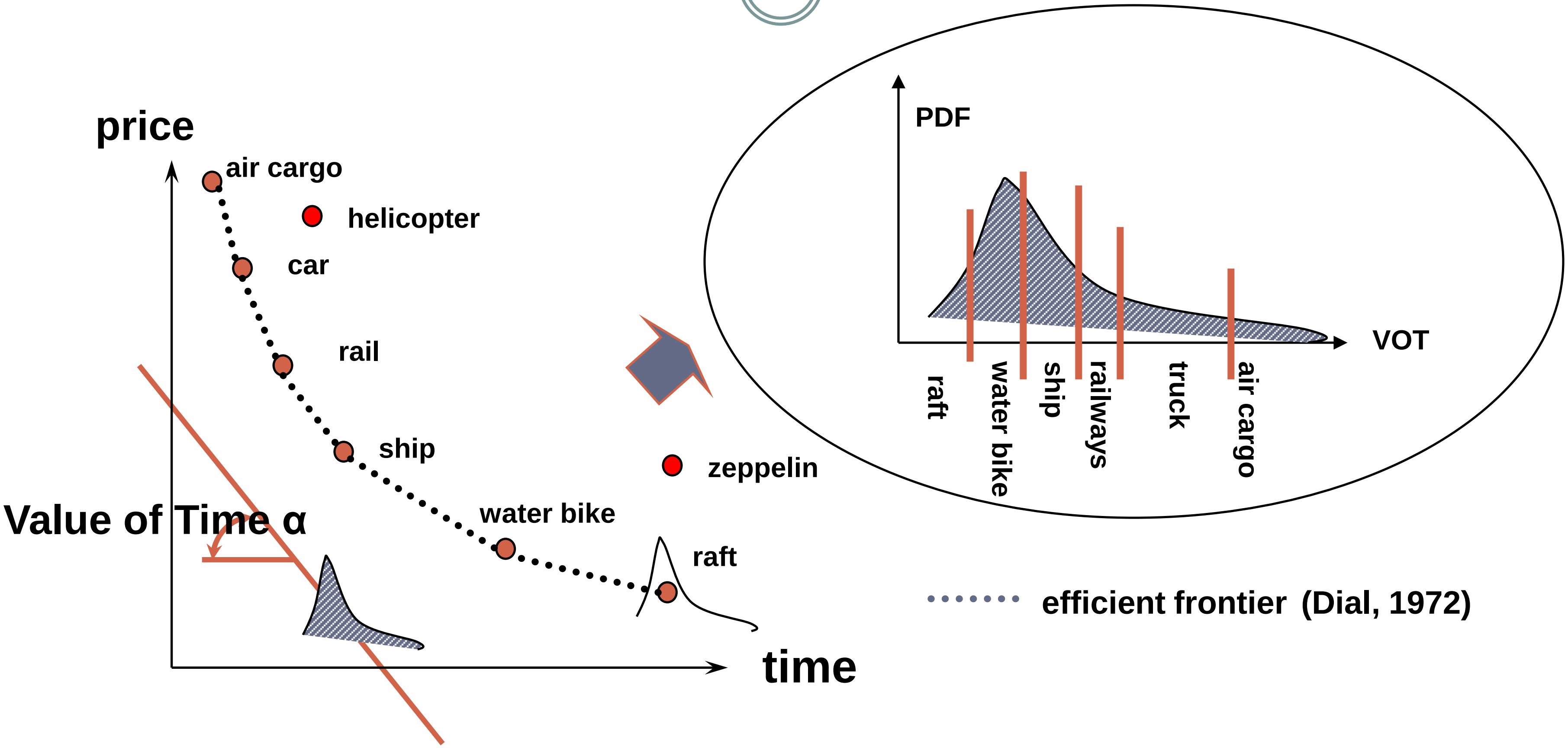
Transport costs



D1: break-even point Road/Rail *D2*: break-even point Rail/Inland navigation

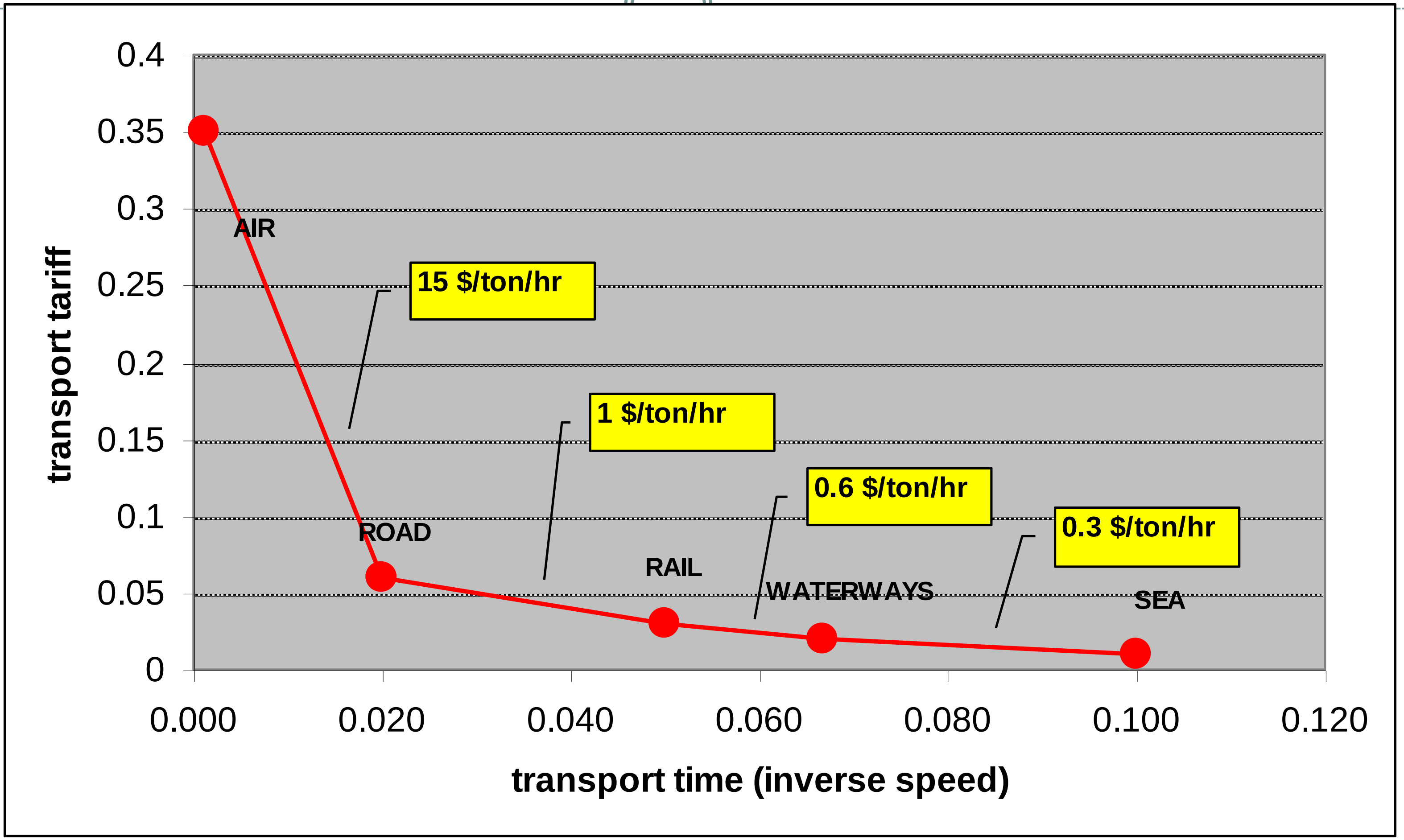
Tx: terminal costs (load/unload costs) *Cx*: cost function mode x

Trade-offs through value of service



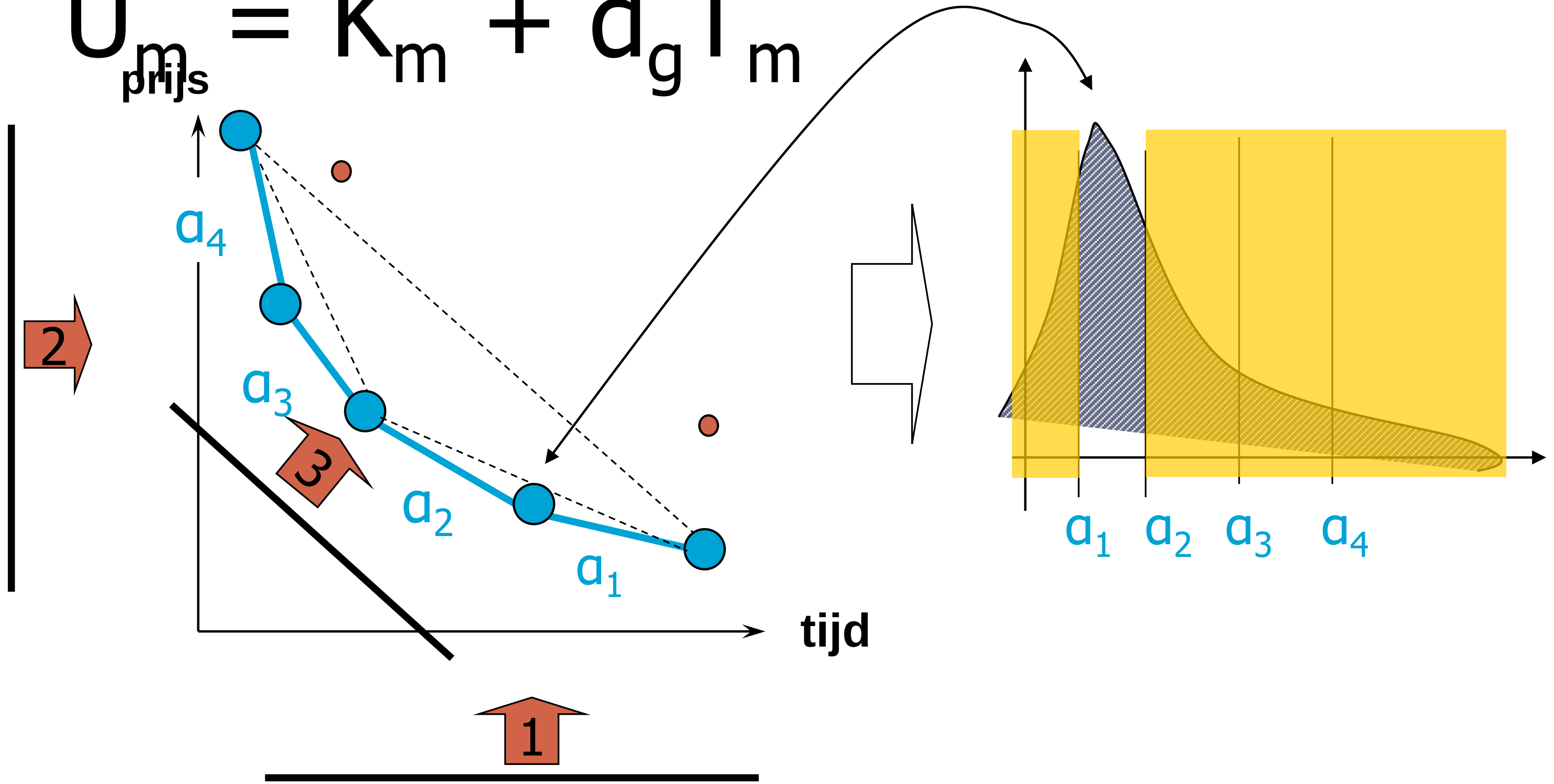
$$U_{mg} = \underline{\alpha}_g * T_m + P_m + \underline{\varepsilon}_m$$

Typical VOT switching values between modes



Determination of market shares

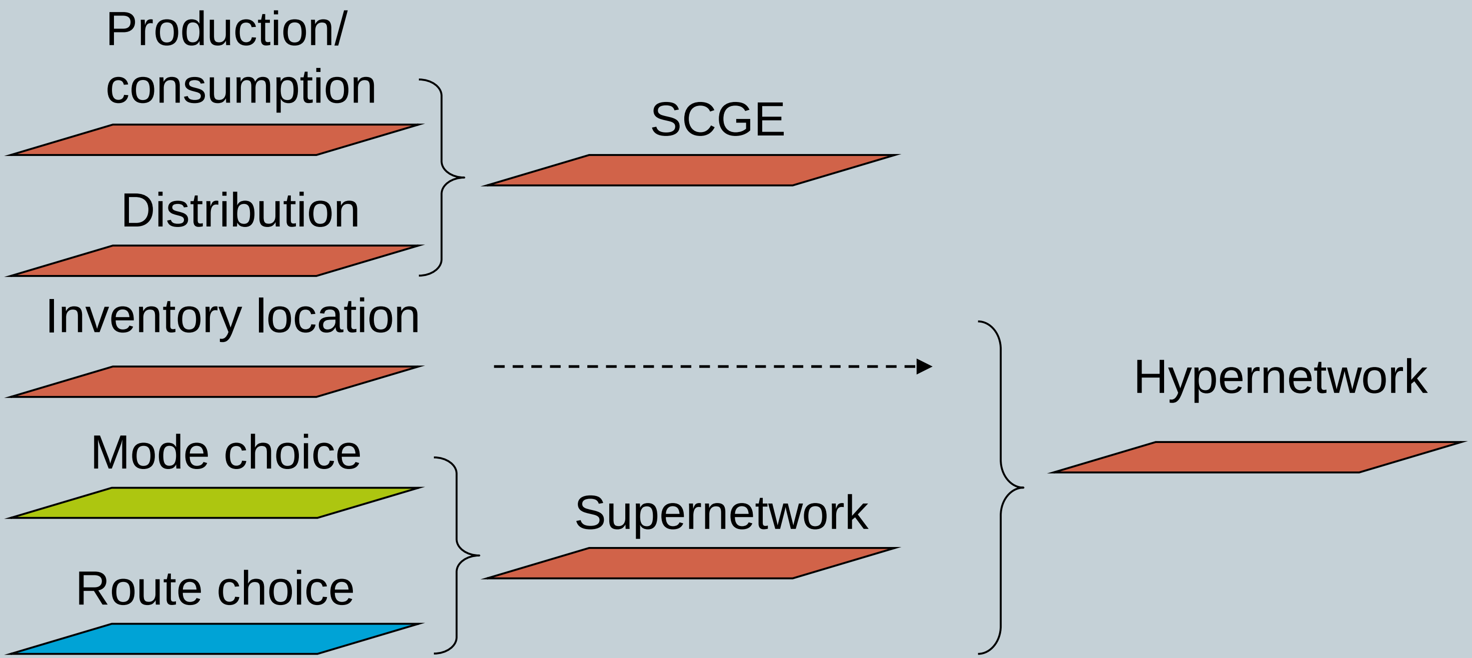
$$U_m = K_m + a_g T_m$$



Ways to measure the value of time

- Accounts based
  - Factor costs or market prices
- Behavioural analysis (experimental)
  - Aggregate vs. Disaggregate
  - Revealed and Stated Preferences
  - *Between* mode or *Within* mode choice experiments
  - Discrete choice modelling in trade-off situations
  - various alternative choice models
  - other choice situations than mode choice possible
- Disaggregate measurements: *sampling* and *aggregation*
- Aggregate approach: based on *statistics*

Route choice models

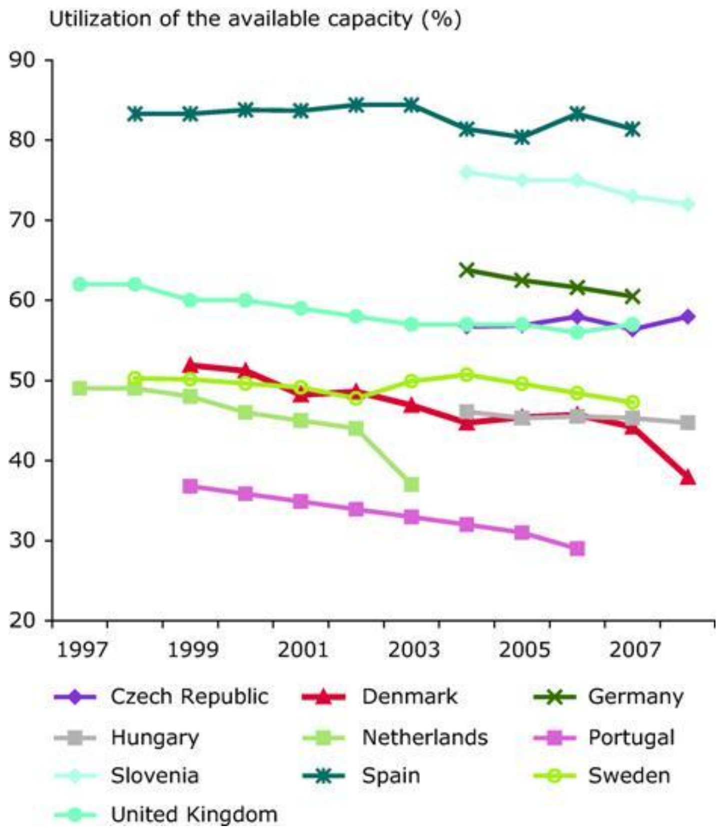


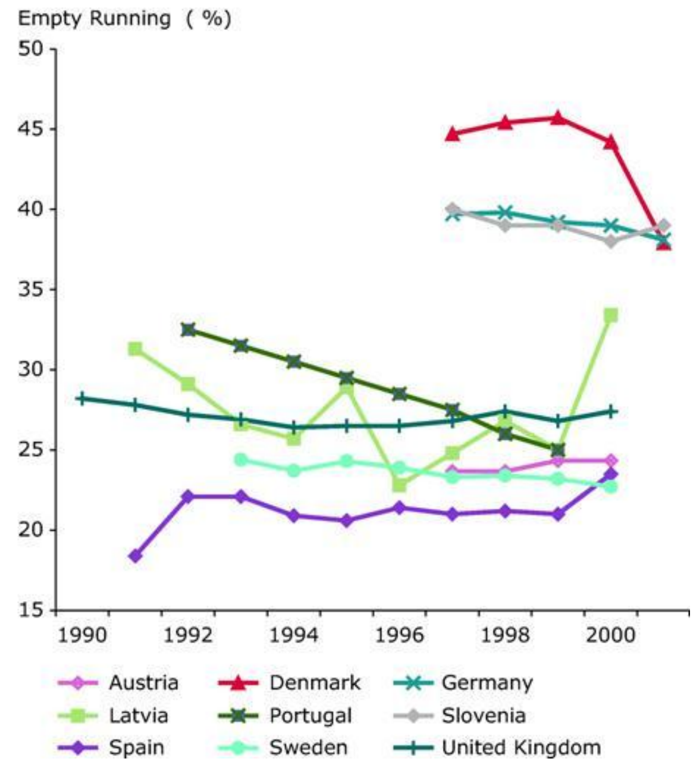
Route choice for freight

- Most freight models apply similar route choice techniques as in passenger transport (e.g. Dijkstra alogorithm)

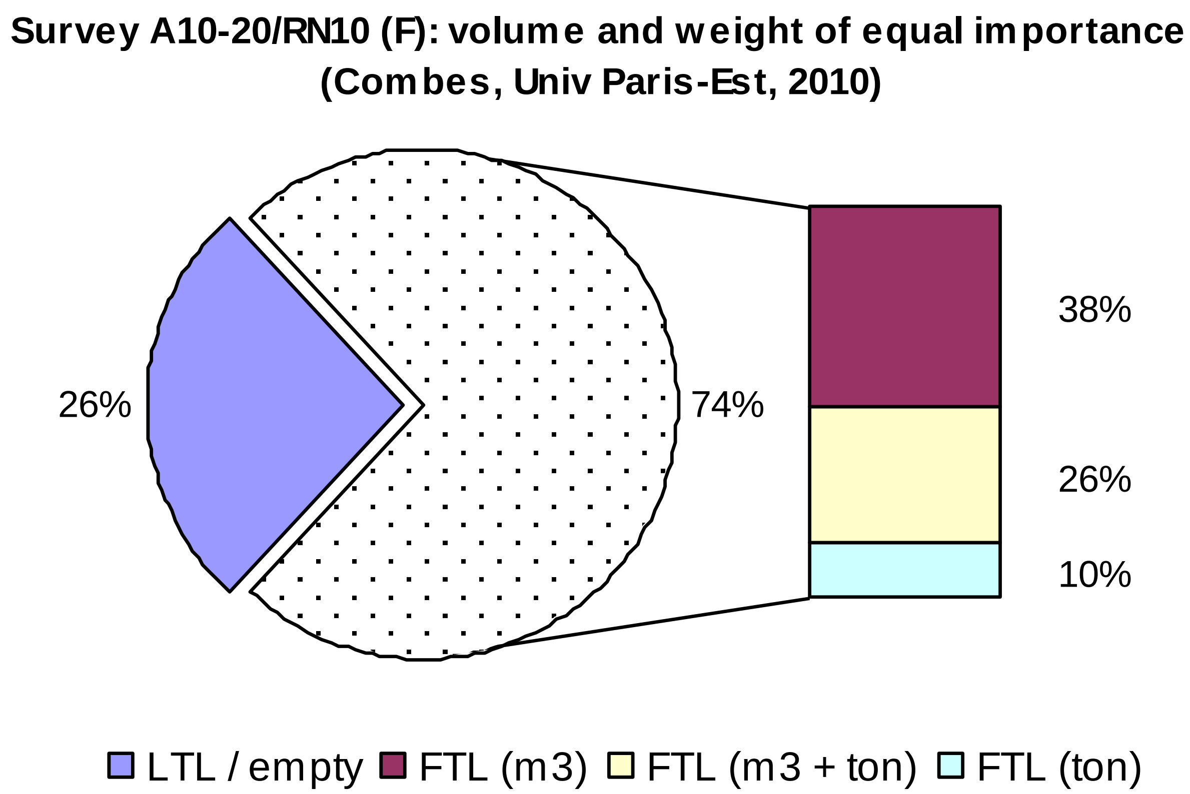
- Specific concerns for freight:
  - Road: round trips (TSP); restrictions: weight & size regulations
  - Rail: train paths; restrictions: gauge width; voltage; priorities
  - Waterways: waterways sizes & ship classes
  - Sea: shipping line & feeder services; restrictions: port depth
  - Air: hub & spoke networks; flight level 0 (trucking)

Dynamics in efficiency

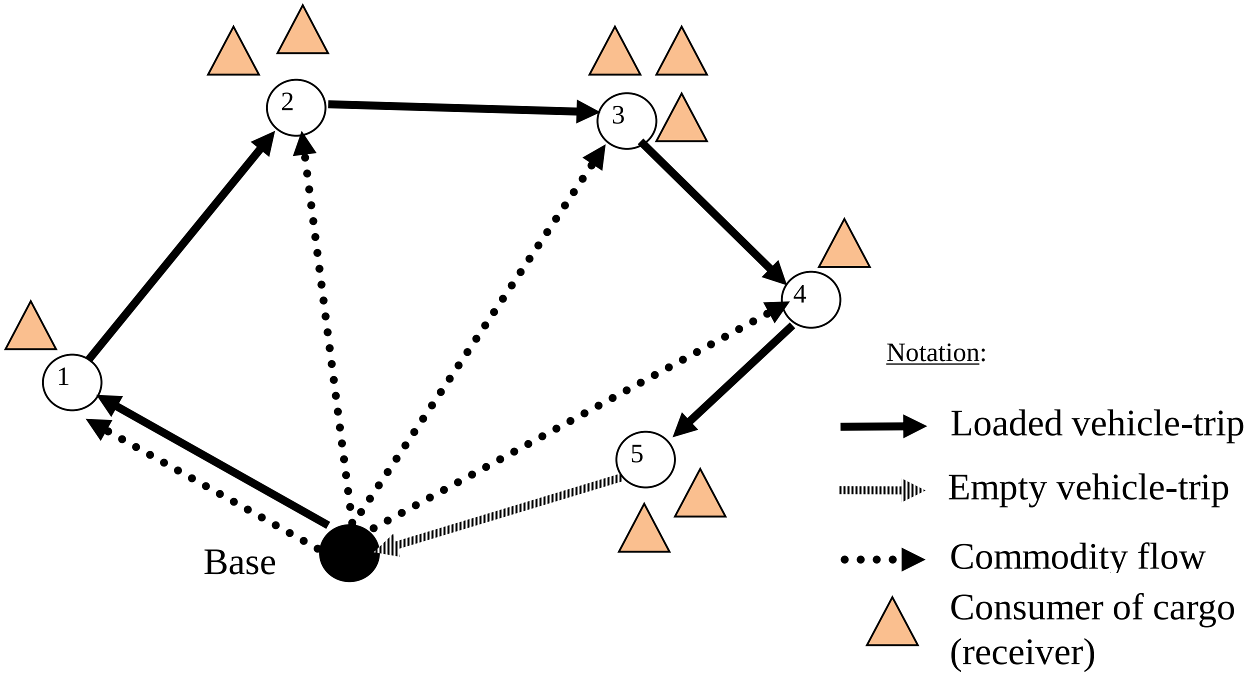




A note on the degree of loading

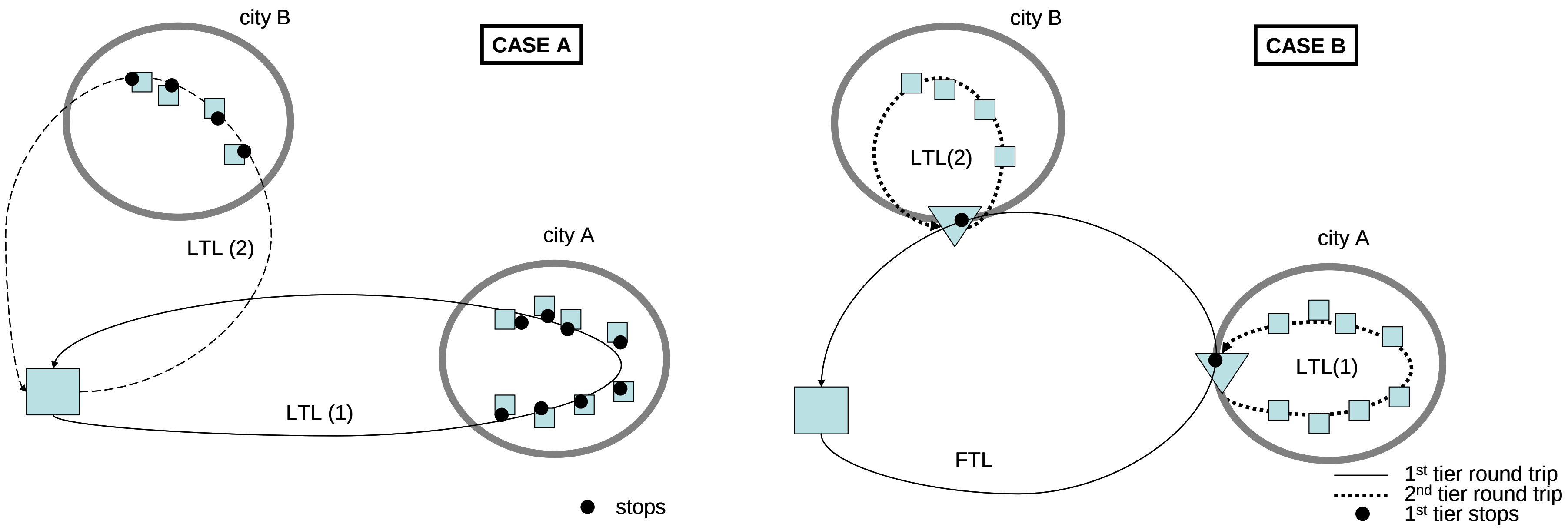


Simple route vs. round trips



NCFRP 25. Holguin Veras et al, 2010

Transport reorganization: routing



Models for empty trips

Classic model Noortman & Van Es (1978)

Empty trips (i,j) ~ laden trips (j,i)

- laden trips (i,j) = m_{ij}/a
- empty trips (i,j) = p^*m_{ji}/a

$$z_{ij} = \frac{1}{a_{ij}}(m_{ij} + p_0 m_{ji})$$

where:
m_{ij} = *goods flow (tons)*
a_{ij} = *avg. load (tons/truck)*
z_{ij} = *total flow*
p = *constant*

But this leads to differences in # of trucks moving

(why? why is this a problem?)

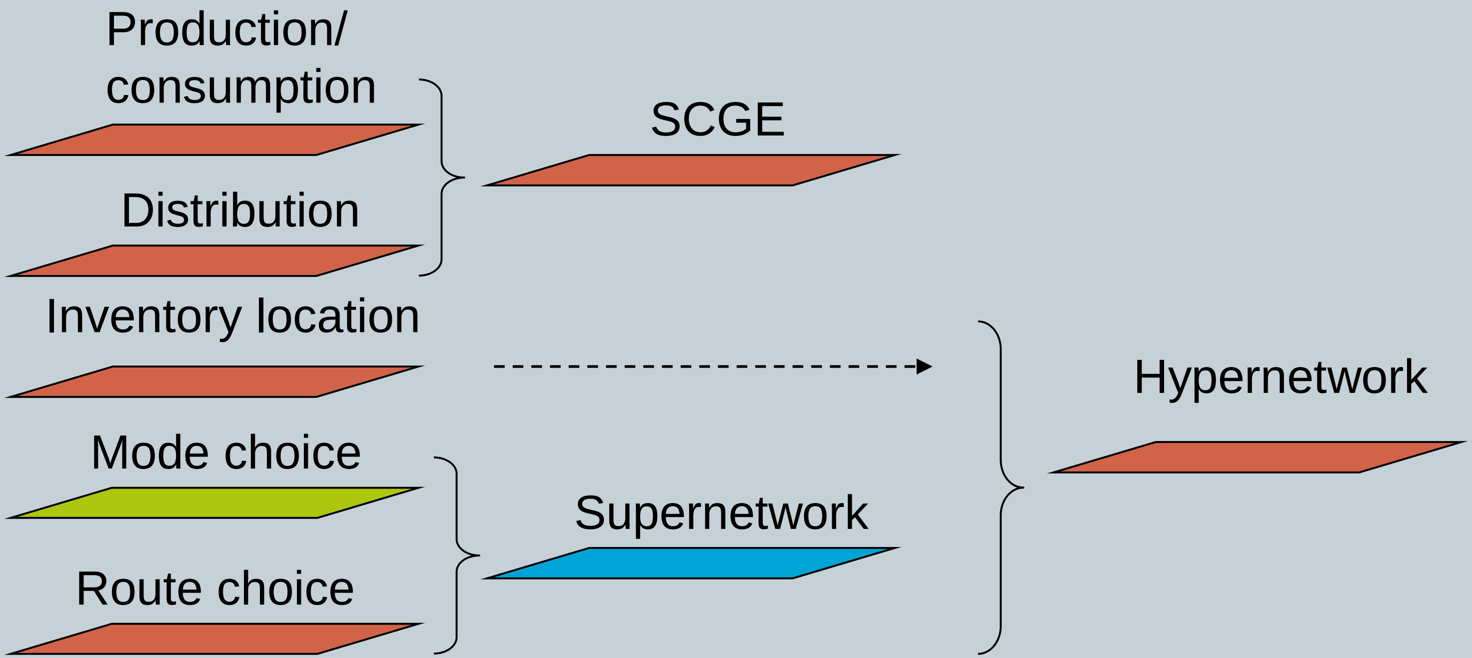
Alternative formulation (Hautzinger, 1984)

$$z_{ij} = \frac{(p_i m_{ij} + p_j m_{ji})}{a(1-(1-p_i)(1-p_j))}$$

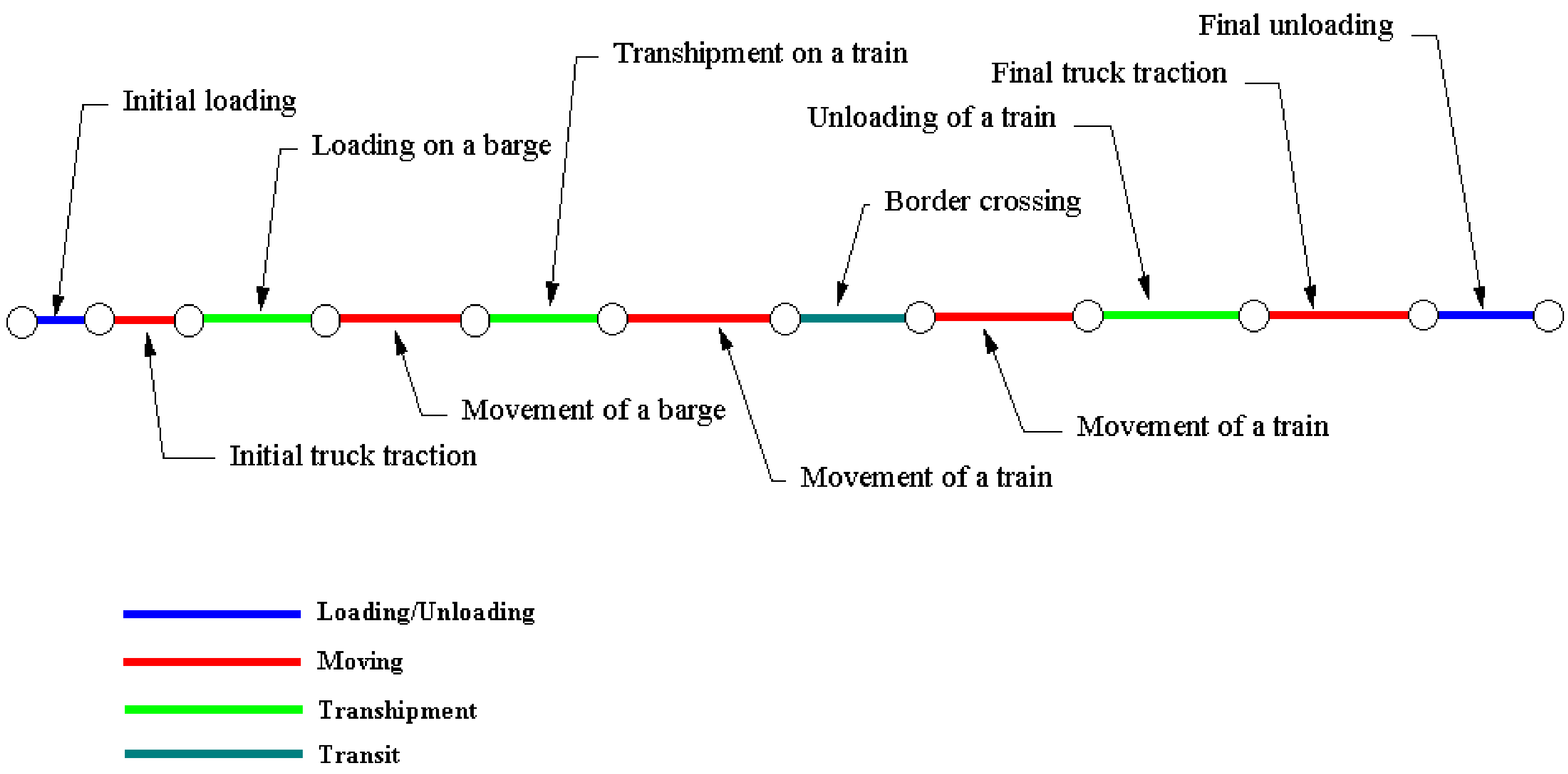
where:
p_{ij} = *probability of vehicle from* i *to return empty from* j
and $p_{ij} = f(m_{jij}/m_{ij}, d_{ij})$

Extensions for trip chain models

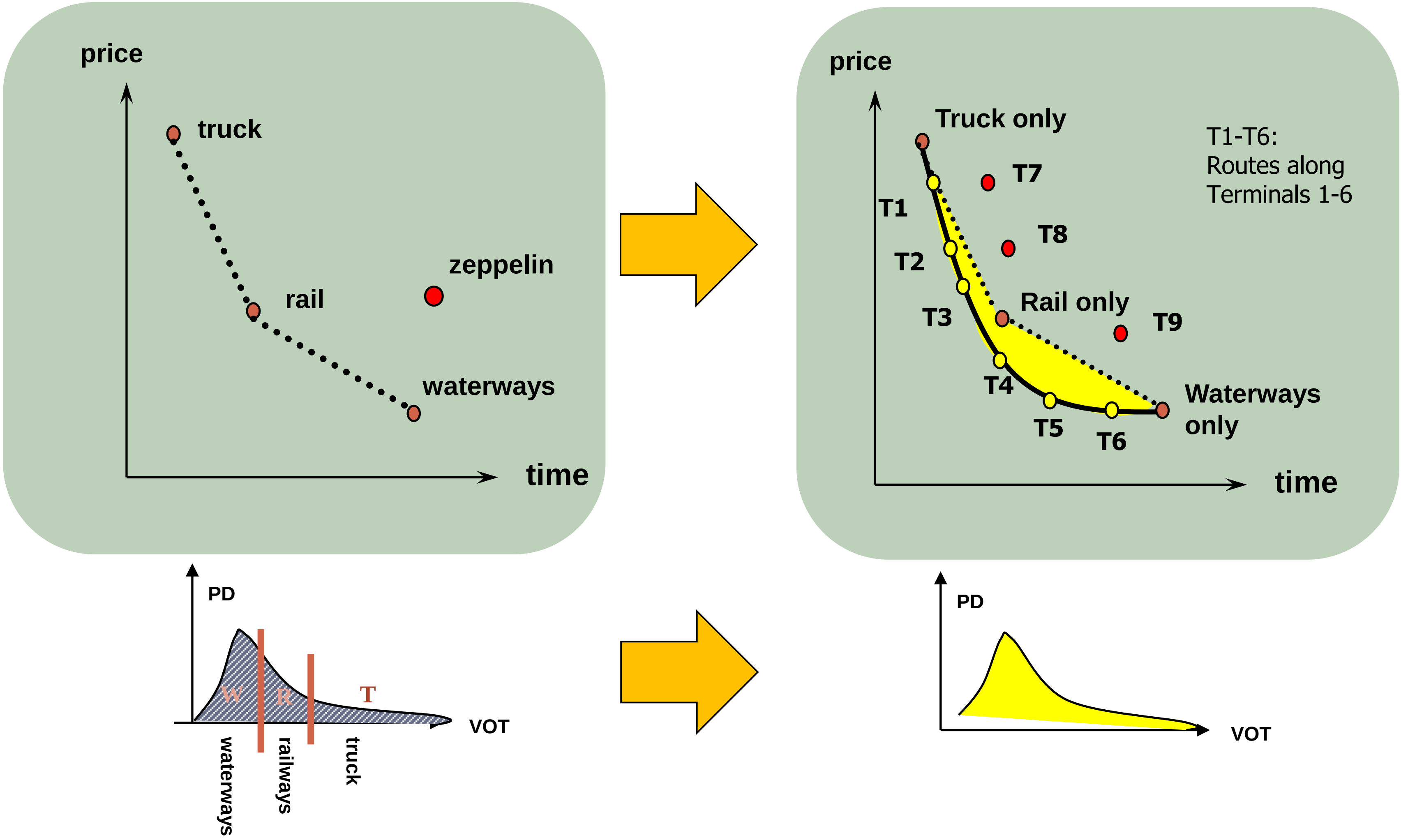
Supernetworks



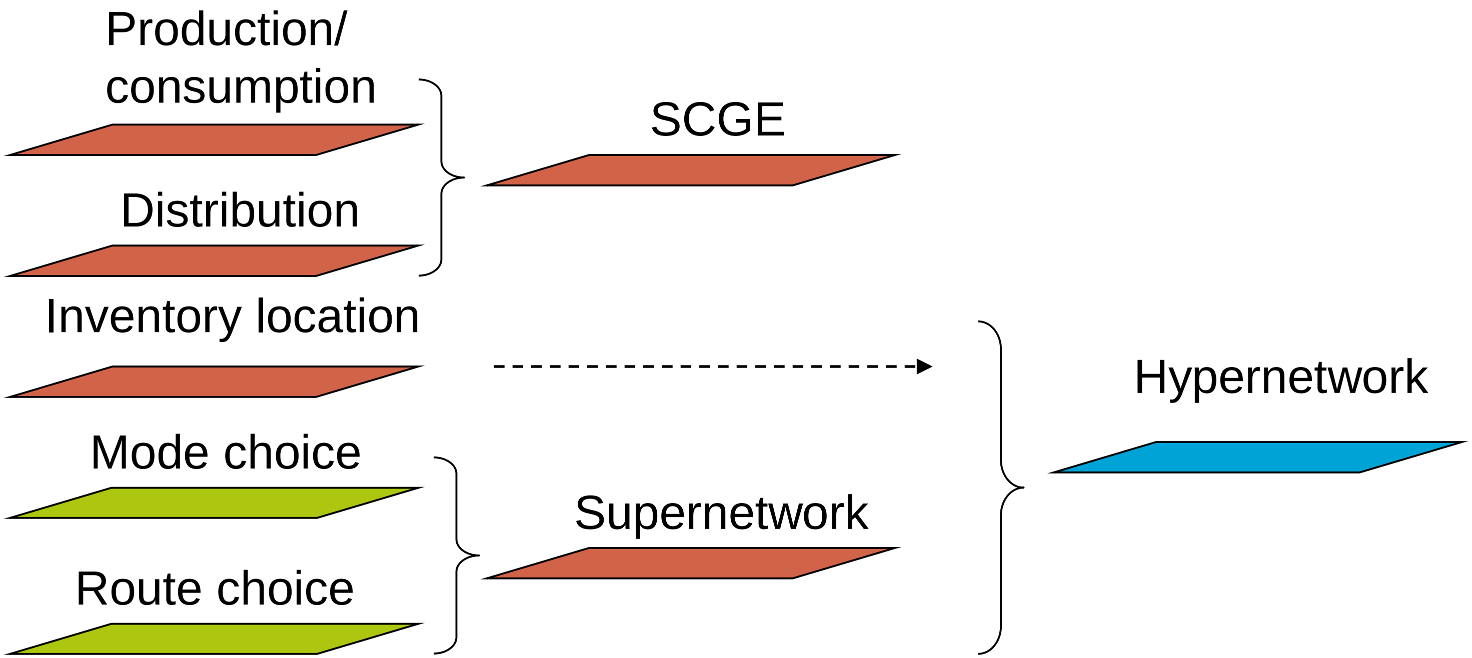
Combined mode & route choice



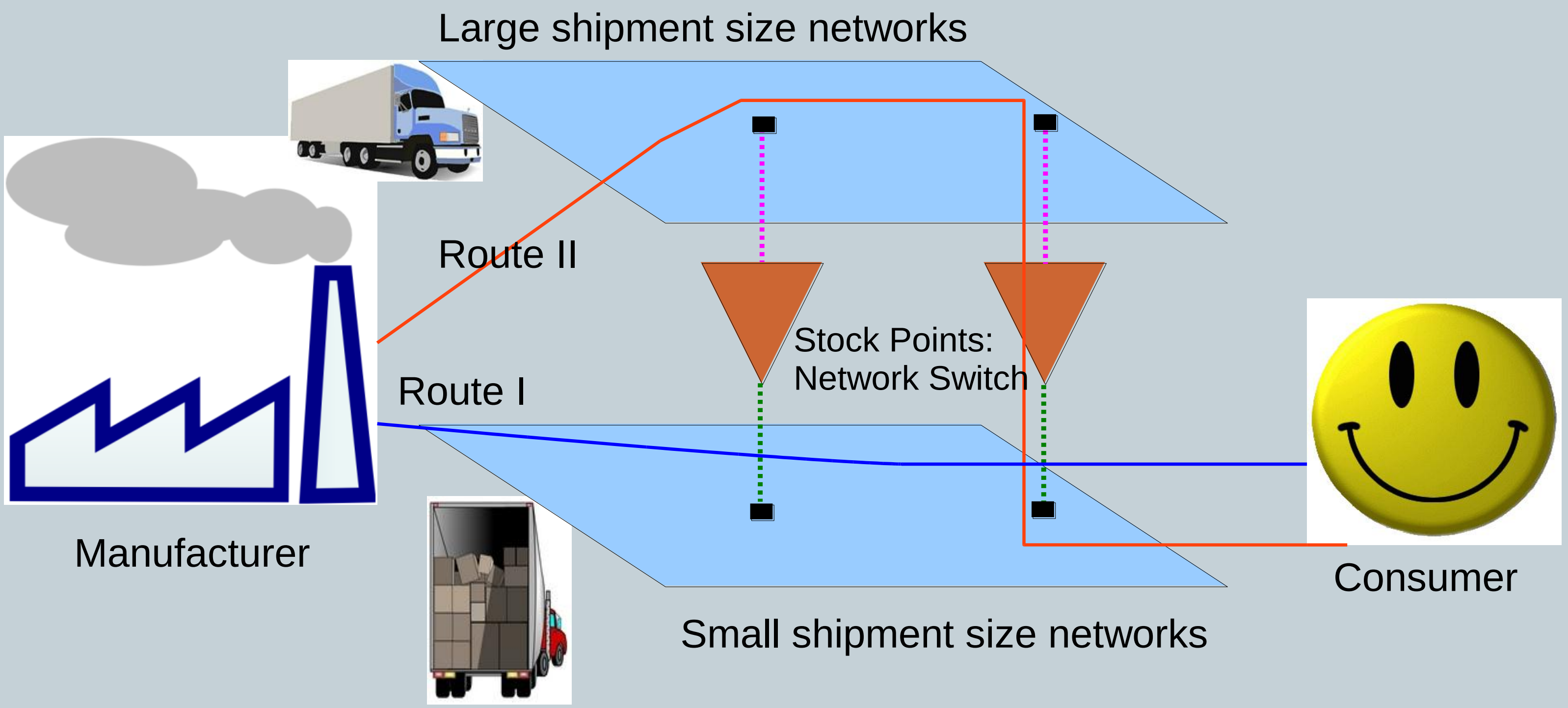
Synchromodal network services with dryports & extended gates



Hypernetwork models (briefly)



Combining choices in hypernetworks



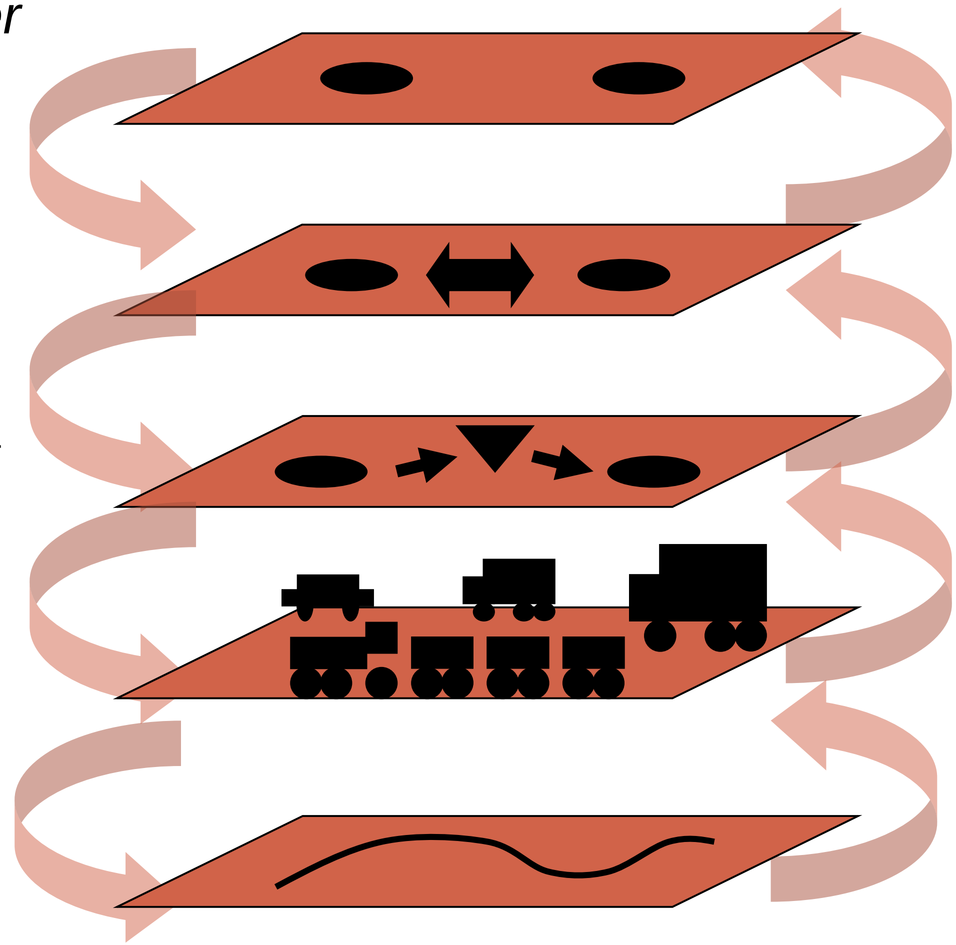
On hypernetwork models

- Advantages
  - Elegant & simple method (all in one)
  - Close to physical representation, increases first sight acceptance
  - Behavioural principles aligned between subproblems
- But…
  - Complexity is high; longer calculation times
  - Difficult to find one good parameter setting for 3 choice problems
  - Difficult to calibrate due to many degrees of freedom

Concluding remarks

- A brief introduction into freight demand modelling
- Focus was on descriptive, static, deterministic, aggregate models
- Further studying:
  - Static vs. dynamic models
  - Equilibrium vs. disequilibrium approaches
  - Supply models: capacity, scale economies, prices and service levels
  - Aggregate (region) vs. disaggregate (firm level) models
  - Accounting for heterogeneity and uncertainty
- Reading material for exam on the blackboard
  - Introduction in Willumsen & Ortuzar
  - Review papers

Summary, questions



	Decision maker	*Decision*
"shipper"	Producent / plant mgr. Consumers	Production Location choice Type of product Production volume Consumer choices
	Sales managers Sourcing managers	Trading contracts
	Logistics service provider Logistics manager	Shipment sizes, frequencies Location en volume of inventory Distribution channels
"carrier"	Logistics manager Transport manager Forwarder	Mode(s) of transport DIY or Hire & Reward? Long term or spot contract? Means of transport
	Transport planner Driver	Routing and scheduling Time of departure Capacity planning

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