A multimodal elastic trade coefficients MRIO model for freight demand in Europe
Overview

- MRIO models for economies and freight

- The RUBM RIO model

- A multimodal European freight MRIO model
  - theoretical definition
  - trade coefficients model
  - multimodal supply model
  - applications

- Conclusions
• MRIO models are reliable and widely applied in the practice for modeling aggregate freight demand at regional/national levels

• significant theoretical developments in the transportation literature over the last decades:
  - integration with random utility models for the estimation of trade coefficients (RUBMRIO), e.g. by De La Barra (1989), Cascetta (2001) and Jin et al. (2003);
  - taxonomy of MRIO formulations accordingly with the assumptions on import/export flows to/from the external of the study area, by Marzano and Papola (2004) and Cascetta et al. (2008);
  - incorporation of selling price estimation/adjustment procedures through fixed-point approaches, as proposed for instance by Cascetta (2001) and Zhao and Kockelman (2004);
  - ...

• useful as both freight demand model and basic macroeconomic impact model (Cascetta et al. 2008)

• easily incorporable within transport DSSs
Leontief input-output equilibrium for sector $m$ in zone $i$:

\[ X^m_i + J_{REG}^m_i + J_{EXT}^m_i = \sum_n K^{mn}_i + Y^m_i + Y_{REG}^m_i + Y_{EXT}^m_i \]

- production
- imports
- intermediate re-usage
- final demand
- exports

Two kinds of coefficients need to be introduced:
- technical coefficients (inter-sectorial dependencies)

\[ a_{i}^{mn} = \frac{K_{i}^{mn}}{X^n_i} \]

- trade coefficients (geographical disaggregation)

\[ t_{ij}^m = \frac{N_{ij}^m}{\sum_r N_{rj}^m} \]

trade value of sector $m$ between $i$ and $j$
the functional form of the demand driven (i.e. production as dependent variable) MRIO model is the solution of a system of \( n_z \cdot n_s \) linear equilibrium equations:

\[
X = (I - TA)^{-1}[T(Y + Y_{EXT})]
\]

- data needed for estimation/application:
  - vectors of int. exports \( Y_{EXT} \) and final demand \( Y \)
  - matrices of technical \( A \) and trade coefficients \( T \)

- derivation of o-d matrix in value:

\[
N = TA \text{Dg}(X) + T \text{Dg}(Y)
\]

where \( \text{Dg}(\cdot) \) indicates the diagonalization operator.
The RUBMRIO Model

- **trade coefficients** should be modeled explicitly as a function of:
  - transportation level of service attributes
  - selling prices
  - ...

\[ t_{ij}^m = \frac{\exp(V_{ij}^m / \theta^m)}{\sum_k \exp(V_{kj}^m / \theta^m)} \]

- zone \( i \) is a compound alternative composed of the aggregation of a number \( ED_m \) of elementary origins for sector \( m \)

- a Nested Logit model may be used to model \( t_{ij}^m \)

\[ t_{ij}^m = \frac{\exp[(V_{ij}^m / \theta^m + sf_i^m) / \theta^m]}{\sum_k \exp[(V_{kj}^m / \theta^m + sf_k^m) / \theta^m]} \]

- various possible feedbacks:
  - short term: only trade coefficients elastic to transport LOS
  - long term: also significant macroeconomic feedbacks
The RUBMRIO model: long term

- Final demand by sector and country
- Technical coefficients
- GDP and macroeconomic variables

MRIO model

- Trade coefficients in value
  - Freight matrix in value
  - Trade coefficients model
  - Selling prices

Value/quantity transformation

- Freight matrix in quantity
- Other attributes

Mode choice model

- LOS
- Freight supply model

Freight matrix in quantity by mode

Mode choice logsums
The RUBMRIO model: long term

MRIO MODEL

- final demand by sector and country
- technical coefficients
- GDP and macroeconomic variables
- freight matrix in value
- freight matrix in quantity by mode
- freight matrix in quantity
- value/quantity transformation
- base reference matrix in quantity

TRANSPORT MODEL

- mode choice model
- mode choice logsums
- other attributes

MRIO MODEL

- selling prices model
- selling prices
- trade coefficients in value
- trade coefficients model
The RUBMRIO Model

- formally, if trade coefficients are some elastic function of production and prices:

\[ T = \tau(X, p) \quad \Rightarrow \quad X^* = (I - \tau(X^*, p) A)^{-1}[\tau(X^*, p)(Y + Y_{EXT})] \]

- prices in turn depend on acquisition costs, trade coefficients and technical coefficients (Cascetta et al. 2008):

\[ p = \psi(T, A) \quad \Rightarrow \quad p^* = \psi(\tau(X, p^*), A) \]

- technical coefficients may depend on prices and production:

\[ a = \alpha(X, p) \quad \Rightarrow \quad X^* = (I - \tau(X^*, p) \alpha(X^*, p))^{-1}[\tau(X^*, p)(Y + Y_{EXT})] \]

- ...

...
Main topics of the paper

- implementation of an European multimodal MRIO model
- no evidence in the literature of consolidated transport-oriented MRIO models at a European level
- challenges in modeling trade coefficients as a function of transport LOS:
  - incorporating multimodal freight system into an elastic trade coefficients scheme
  - complexity in modeling freight supply (e.g. non additive fares and times, complex combinations of modes)
  - need to link NUTS3 transport models with NUTS0 MRIO models
Basic implementation at EU level

Type of data sources:
- input-output tables (for $Y_{\text{EXT}}$, $Y$, $A$)
- import/export trade flows in value (for $T$)

Both covered by EUROSTAT:
- input-output tables via ESA95 dataset:
  - non uniform EU27 coverage
  - several years (base year for model implementation: 2005)
  - 59 CPA sectors (29 tradable goods, 30 services/n.t.)
- import/export trade flows via COMEXT dataset:
  - from each EU27 State to/from each country in the world
  - trade flows in value and quantity up to 2011
  - more than 4000 commodity sectors (NC8 nomenclature)
  - allows value/quantity ratios calculation
Study area:
- 21 EU Countries (no uniform coverage by ESA95)*
- 2005 base year for model estimation

* extensions possible linking EUROSTAT and WTO/GTAP i-o datasets
An EU-based transport MRIO model

- final demand by sector and country
  - technical coefficients
- GDP and macroeconomic variables
- base reference matrix in quantity (NUTS0)
- freight supply model NUTS3
  - LOS (NUTS3)
- aggregated indicators

MRIO model (NUTS0)
- trade coefficients in value
- freight matrix in value (NUTS0)
- value/quantity transformation
  - freight matrix in quantity (NUTS0)
  - disaggregation

Trade coefficients model (NUTS0)
- other attributes
- mode choice logsums (NUTS0)
- aggregation

Freight matrix in quantity (NUTS3)
- mode choice model (NUTS3)
- freight matrix in quantity by mode (NUTS3)

Logsums (NUTS0)
- selling prices

Transport modes
- freight matrix in quantity (NUTS0)
- freight matrix in quantity (NUTS3)

Indicators
- GDP and macroeconomic variables
- other attributes
- mode choice logsums

Other attributes
- aggregated indicators
- aggregation
The RUBMRIO Model

- specification adopted in the paper:

\[ V_{ij}^m = \beta_1^m Y_{ij}^m + \beta_2^m b_i^m + \beta_3^m \ln X_i^m + \beta_4^m \delta_{SZ} \]

mode choice logsum (NUTS0) average observed selling prices

<table>
<thead>
<tr>
<th>commodity sector (CPA nomenclature)</th>
<th>$\beta_1$</th>
<th>$\beta_2$</th>
<th>$\beta_3$</th>
<th>$\beta_4$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Products of agriculture, hunting and related services</td>
<td>5,839</td>
<td>-</td>
<td>6,000</td>
<td>-0.217</td>
</tr>
<tr>
<td>Products of forestry, logging and related services</td>
<td>2,366</td>
<td>-1,403</td>
<td>2,114</td>
<td>-</td>
</tr>
<tr>
<td>Fish and other fishing products; services incidental of fishing</td>
<td>0,430</td>
<td>-</td>
<td>0,665</td>
<td>-0.236</td>
</tr>
<tr>
<td>Coal and lignite; peat</td>
<td>0,055</td>
<td>-6,000</td>
<td>0,182</td>
<td>1,621</td>
</tr>
<tr>
<td>Crude petroleum and natural gas</td>
<td>0,351</td>
<td>-0,108</td>
<td>-</td>
<td>0,283</td>
</tr>
<tr>
<td>Uranium and thorium ores</td>
<td>0,990</td>
<td>-0,990</td>
<td>0,990</td>
<td>-</td>
</tr>
<tr>
<td>Metal ores</td>
<td>0,152</td>
<td>-0,749</td>
<td>0,125</td>
<td>0,921</td>
</tr>
<tr>
<td>Other mining and quarrying products</td>
<td>1,079</td>
<td>-5,619</td>
<td>0,714</td>
<td>-</td>
</tr>
<tr>
<td>Food products and beverages</td>
<td>3,110</td>
<td>-6,000</td>
<td>4,216</td>
<td>-0,284</td>
</tr>
<tr>
<td>Tobacco products</td>
<td>0,033</td>
<td>-</td>
<td>0,064</td>
<td>2,153</td>
</tr>
<tr>
<td>Textiles</td>
<td>0,062</td>
<td>-</td>
<td>0,448</td>
<td>1,117</td>
</tr>
<tr>
<td>Wearing apparel; furs</td>
<td>0,052</td>
<td>-</td>
<td>0,220</td>
<td>1,347</td>
</tr>
<tr>
<td>Leather and leather products</td>
<td>0,073</td>
<td>-0,004</td>
<td>0,372</td>
<td>0,913</td>
</tr>
<tr>
<td>Wood and products of wood and cork (except furniture)</td>
<td>0,842</td>
<td>-0,295</td>
<td>0,570</td>
<td>0,004</td>
</tr>
<tr>
<td>Pulp, paper and paper products</td>
<td>0,484</td>
<td>-</td>
<td>0,892</td>
<td>-0,285</td>
</tr>
<tr>
<td>Printed matter and recorded media</td>
<td>1,924</td>
<td>-0,311</td>
<td>1,107</td>
<td>-</td>
</tr>
<tr>
<td>Coke, refined petroleum products and nuclear fuels</td>
<td>1,728</td>
<td>-6,000</td>
<td>2,747</td>
<td>-0,409</td>
</tr>
<tr>
<td>Chemicals, chemical products and man-made fibres</td>
<td>0,035</td>
<td>-</td>
<td>0,279</td>
<td>1,736</td>
</tr>
<tr>
<td>Rubber and plastic products</td>
<td>0,946</td>
<td>-0,184</td>
<td>1,497</td>
<td>-0,460</td>
</tr>
<tr>
<td>Other non-metallic mineral products</td>
<td>5,176</td>
<td>-1,214</td>
<td>6,000</td>
<td>-0,287</td>
</tr>
<tr>
<td>Basic metals</td>
<td>5,690</td>
<td>-</td>
<td>6,000</td>
<td>-0,839</td>
</tr>
<tr>
<td>Fabricated metal products, except machinery and equipment</td>
<td>4,157</td>
<td>-3,167</td>
<td>6,000</td>
<td>-0,404</td>
</tr>
<tr>
<td>Machinery and equipment n.e.c.</td>
<td>0,067</td>
<td>-0,013</td>
<td>0,385</td>
<td>1,181</td>
</tr>
<tr>
<td>Office machinery and computers</td>
<td>2,670</td>
<td>-3,026</td>
<td>3,408</td>
<td>3,538</td>
</tr>
<tr>
<td>Electrical machinery and apparatus n.e.c.</td>
<td>0,056</td>
<td>-0,024</td>
<td>0,490</td>
<td>1,255</td>
</tr>
<tr>
<td>Radio, television and communication equipment and apparatus</td>
<td>0,098</td>
<td>-6,000</td>
<td>5,674</td>
<td>1,271</td>
</tr>
<tr>
<td>Medical, precision and optical instruments, watches and clocks</td>
<td>2,809</td>
<td>-3,683</td>
<td>2,542</td>
<td>5,069</td>
</tr>
<tr>
<td>Motor vehicles, trailers and semi-trailers</td>
<td>0,065</td>
<td>-0,017</td>
<td>0,429</td>
<td>1,032</td>
</tr>
<tr>
<td>Other transport equipment</td>
<td>0,154</td>
<td>-2,554</td>
<td>-</td>
<td>1,098</td>
</tr>
<tr>
<td>Furniture; other manufactured goods n.e.c.</td>
<td>0,043</td>
<td>-0,012</td>
<td>0,155</td>
<td>1,714</td>
</tr>
</tbody>
</table>
Multimodal supply model: zones

- 1508 traffic zones (NUTS3)
- compliant with TransTools
Multimodal supply model: graphs

ROAD

RAIL

IWW

SEA
## Multimodal supply model: graphs

<table>
<thead>
<tr>
<th>mode</th>
<th># links</th>
<th>km links</th>
<th># nodes</th>
</tr>
</thead>
<tbody>
<tr>
<td>road</td>
<td>63.109</td>
<td>704.988</td>
<td>50.870</td>
</tr>
<tr>
<td>sea</td>
<td>28.319</td>
<td>n.s.</td>
<td>2.147</td>
</tr>
<tr>
<td>inland waterways</td>
<td>1.041</td>
<td>22.347</td>
<td>966</td>
</tr>
<tr>
<td>rail</td>
<td>90.259</td>
<td>406.973</td>
<td>83.462</td>
</tr>
</tbody>
</table>
Multimodal supply model: issues

- significant presence of non-additive transport costs:
  - EU regulation EC 561/2006 on rest/stop times for drivers
    - daily driving period shall not exceed 9 hours, with an exemption of twice a week when it can be extended to 10 hours
    - 2 drivers can sum basically their driving times
    - ...
  - fares/tariffs

- need to account for characteristics leading to numerous supply segments, e.g. for road/sea Ro-Ro transport:
  - 1 driver/2 drivers
  - own account/hiring
  - accompanied/unaccompanied
  - ...

Multimodal supply model: issues

For a single mode impedances are sub-additive:
- sub-additive impedances can be calculated through post-processing of the additive shortest paths

E.g. road transport:

Topologic model
Additive impedances
Functional characteristics

Shortest additive time path
Additive cost of shortest time path

Calculation of non-additive time for 1 driver/2 drivers

Total cost of the shortest time path for own account
Calculation of total time and cost for 1 driver/2 drivers own account

Total cost of the shortest time path for hiring
Calculation of total time and cost for 1 driver/2 drivers hiring

Calculation of time-dependent costs for 1 driver/2 drivers
Multimodal supply model: issues

- sub-additivity does not hold anymore for paths on the multimodal network:
  - need for “virtual” networks with macro-links representing overall o-d trade
- need for calculating LOS related to specific mode sequences:

![Diagram showing multimodal supply model]

- road macrolinks
- mode transfer links
- sea macrolinks
- centroids
- terminals
- “cloned” terminals
Multimodal supply model: issues

lower VTTS for unaccompanied leads to longer maritime routes
Multimodal supply model: issues

- lower VTTS for unaccompanied leads to longer maritime routes
- the 1 driver/2 drivers option changes the maritime route
Two examples of application of the proposed system of models:

- **Scenario 1**: 10% increase in road costs, e.g. coming either from an increase of oil price or from a reduction of public subsidies for lorries
- **Scenario 2**: 20% reduction of maritime fares, so as to mimic a policy of public subsidies towards motorways of the sea within the European Union
tons/km²/year generated by NUTS3 zone in the base scenario
### Applications: Results

Absolute values of NUTS0 attracted/generated tons/year for the base scenario and % variations for the project scenarios

<table>
<thead>
<tr>
<th>Country</th>
<th>Million tons/year</th>
<th>% Variation</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Base attracted</td>
<td>Generated</td>
</tr>
<tr>
<td>Austria</td>
<td>56,5</td>
<td>38,2</td>
</tr>
<tr>
<td>Belgium</td>
<td>174,3</td>
<td>163,5</td>
</tr>
<tr>
<td>Czech Republic</td>
<td>31,6</td>
<td>42,4</td>
</tr>
<tr>
<td>Denmark</td>
<td>26,2</td>
<td>32,7</td>
</tr>
<tr>
<td>Estonia</td>
<td>3,3</td>
<td>9,0</td>
</tr>
<tr>
<td>Finland</td>
<td>15,2</td>
<td>17,9</td>
</tr>
<tr>
<td>France</td>
<td>184,8</td>
<td>151,5</td>
</tr>
<tr>
<td>Germany</td>
<td>305,6</td>
<td>261,4</td>
</tr>
<tr>
<td>Greece</td>
<td>11,8</td>
<td>7,4</td>
</tr>
<tr>
<td>Hungary</td>
<td>16,7</td>
<td>17,8</td>
</tr>
<tr>
<td>Irish Republic</td>
<td>29,3</td>
<td>12,1</td>
</tr>
<tr>
<td>Italy</td>
<td>94,5</td>
<td>77,8</td>
</tr>
<tr>
<td>Lithuania</td>
<td>3,2</td>
<td>10,8</td>
</tr>
<tr>
<td>Netherlands</td>
<td>177,7</td>
<td>258,7</td>
</tr>
<tr>
<td>Poland</td>
<td>38,5</td>
<td>55,5</td>
</tr>
<tr>
<td>Portugal</td>
<td>26,2</td>
<td>17,6</td>
</tr>
<tr>
<td>Slovakia</td>
<td>15,1</td>
<td>21,8</td>
</tr>
<tr>
<td>Slovenia</td>
<td>12,1</td>
<td>7,6</td>
</tr>
<tr>
<td>Spain</td>
<td>86,4</td>
<td>62,9</td>
</tr>
<tr>
<td>Sweden</td>
<td>42,6</td>
<td>56,4</td>
</tr>
<tr>
<td>United Kingdom</td>
<td>98,1</td>
<td>126,7</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>1449,8</strong></td>
<td></td>
</tr>
</tbody>
</table>
Applications: results

Macroeconomic impacts generated by change in transport costs are very difficult to predict:

- countries with economic competitive advantages may benefit more from a decrease of transport costs (and vice versa), since in such a way they are able to increase their export
- competitive advantages may from different factors (availability of raw materials, of developed technologies, of low labor cost etc.) which are implicitly accounted for in the technical coefficients
- a *tout court* decrease of transport costs impacts differently on Countries depending on their geographical position within the study area, i.e. of their initial accessibility with respect to the other Countries
Applications: results

attracted tons - scenario 2

delta million tons/km²/year

- < -10
- -10 to -5
- -5 to 0
- 0 to 5
- 5 to 10
- 10 to 20
- 20 to 40
- > 40
distribution of tons/year by distance band and tons traded by road (base scenario and future scenarios)

<table>
<thead>
<tr>
<th>distance band</th>
<th>Million tons/year by distance band</th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>base scenario</td>
<td>scenario 1</td>
<td>scenario 2</td>
<td></td>
</tr>
<tr>
<td></td>
<td>total</td>
<td>road</td>
<td>total</td>
<td>road</td>
</tr>
<tr>
<td>up to 499 km</td>
<td>389,9</td>
<td>386,8</td>
<td>381,3</td>
<td>378,1</td>
</tr>
<tr>
<td>500 - 999 km</td>
<td>537,9</td>
<td>492,4</td>
<td>530,9</td>
<td>482,1</td>
</tr>
<tr>
<td>1000 - 1499 km</td>
<td>279,2</td>
<td>209,9</td>
<td>278,7</td>
<td>202,6</td>
</tr>
<tr>
<td>1500 - 1999 km</td>
<td>140,6</td>
<td>71,4</td>
<td>140,2</td>
<td>64,6</td>
</tr>
<tr>
<td>2000 - 2499 km</td>
<td>65,7</td>
<td>34,9</td>
<td>65,3</td>
<td>31,3</td>
</tr>
<tr>
<td>2500 km and more</td>
<td>36,3</td>
<td>13,1</td>
<td>36,4</td>
<td>11,0</td>
</tr>
<tr>
<td>total</td>
<td>1449,6</td>
<td>1208,5</td>
<td>1432,8</td>
<td>1169,7</td>
</tr>
</tbody>
</table>

% variations in tons/year by distance band and road mode share (base scenario and future scenarios)

<table>
<thead>
<tr>
<th>distance band</th>
<th>base scenario</th>
<th>scenario 1</th>
<th>scenario 2</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>modal split (road)</td>
<td>% var tons</td>
<td>modal split (road)</td>
</tr>
<tr>
<td>up to 499 km</td>
<td>99,20%</td>
<td>-2,20%</td>
<td>99,15%</td>
</tr>
<tr>
<td>500 - 999 km</td>
<td>91,55%</td>
<td>-1,29%</td>
<td>90,80%</td>
</tr>
<tr>
<td>1000 - 1499 km</td>
<td>75,16%</td>
<td>-0,19%</td>
<td>72,70%</td>
</tr>
<tr>
<td>1500 - 1999 km</td>
<td>50,77%</td>
<td>-0,30%</td>
<td>46,05%</td>
</tr>
<tr>
<td>2000 - 2499 km</td>
<td>53,13%</td>
<td>-0,62%</td>
<td>47,99%</td>
</tr>
<tr>
<td>2500 km and more</td>
<td>36,11%</td>
<td>0,27%</td>
<td>30,21%</td>
</tr>
<tr>
<td>total</td>
<td>83,37%</td>
<td>-1,16%</td>
<td>81,63%</td>
</tr>
</tbody>
</table>
absolute variations of tons/year by distance band w.r.t. base scenario

Applications: results

Distance band
- up to 499 km
- 500 - 999 km
- 1000 - 1499 km
- 1500 - 1999 km
- 2000 - 2499 km
- 2500 km and more

Million otns/year (delta)

scenario 1
scenario 2
Conclusions

• a multimodal elastic trade coefficients MRIO model for freight demand in Europe was presented
• theoretical issues related to both demand and supply modelling were discussed
• the complexity of multimodal freight networks requires explicit models accounting for non additive costs
• scenario analysis revealed that complex interactions between countries and sectors may be revealed by a MRIO approach
• research needs:
  - testing the approximation of additive cost models w.r.t. non additive models from both supply and demand sides
  - more applications
  - modelling long term effects
References


