Innovative o-d based rail freight subsidies compensating infrastructural gaps: methodological issues and practical implementation in Italy

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Motivation and background

- Rail freight transport largely acknowledged as potentially cost-effective and environmentally sustainable
- Many EU policies and funds to support rail freight and improve performance of EU freight railway network
- Italy:
  - Up to 2014: dramatic decreasing trend (-50% w.r.t. 2007 traffic)
  - Since 2015: an integrated set of policies to relaunch rail freight, based on three pillars:
    - Infrastructure improvements
    - Regulation/simplification
    - Incentives
Incentive-based policies in Italy

- earlier incentives (2005-2007): L 166/02
- *ferrobonus* (2010 – to date): to *shippers and MTOs*
  - compensation of 1.08 €/train·km for new services
  - positive impact: +17% increase in rail freight traffic in 2012 w.r.t. 2009
  - re-newed by the Italian Government for 2017-2021, up to 2.5 €/train·km
- *sconto pedaggio* (2015 – to date): to *railway undertakings*
  - discount of the access charge to the rail infrastructure manager
  - based on former state aids to the ex incumbent operator Trenitalia Cargo
  - *watering-can principle, irrespective of network performances*
  - up to 2.5 €/train·km for train services on the entire Italian rail network
  - additional incentive to/from South (larger market share of Trenitalia Cargo)
An equitable **sconto pedaggio**

- **research question:** watering-can distribution not leading to equitable market conditions for railway undertakings
  - performance of the Italian freight rail network very heterogeneous amongst o-d pairs
  - railway undertakings receive the same incentive irrespective of the *infrastructural gap* with respect to EU standard
    - 750 metres, 2000 tons, PC80 gauge
- **proposition of an equitable sconto pedaggio:**
  - an o-d pair basis incentive
  - proportional to the infrastructural gap on the o-d pair with respect to the performance of the EU-standard freight train
An equitable *sconto pedaggio*: definition

- performance of a freight train of type $t$ (e.g. intermodal) on path $k$

### INFRASTRUCTURAL CHARACTERISTICS

- permissible train weight ($w_{tk}$)
- maximum train length ($l_{tk}$)
- loading gauge ($g_{tk}$)
- slope ($s_{tk}$)

### OPERATIONAL CHARACTERISTICS

- number of locomotives ($n_{loc}$)
- locomotive weight ($w_{tloc}$)
- locomotive length ($l_{tloc}$)
- freight railcar total weight ($w_{tcar}$)
- unladen weight ($w_{u_{tcar}}$)
- freight railcar length ($l_{tcar}$)

- $c^{tot}_{tk} \rightarrow$ total cost to operate the train $t$ on the path $k$
- $cap_{tk} \rightarrow$ train payload capacity

### Unit weight cost

**Current scenario**

$$cw^{unit}_{tk} = \frac{c^{tot}_{tk}}{cap_{tk}}$$

**EU standard scenario**

$$cw^{unit, opt}_{tk} = \frac{c^{tot, opt}_{tk}}{cap^{opt}_{tk}} \leq cw^{unit}_{tk}$$
Infrastructural gap and proposed incentive

• weight cost units (€/ton):
  \[ c_{\text{w} \text{unit}, \text{gap}}^{\text{unit}}_{\text{tod}} = \min_{k \in \text{Kod}} \{ c_{\text{w} \text{unit}}^{\text{unit}}_{\text{tk}} \} - \min_{k \in \text{Kod}} \{ c_{\text{w} \text{unit}, \text{opt}}^{\text{unit}}_{\text{tk}} \} \]

• distance units (€/train·km)
  \[ c_{\text{d} \text{unit}, \text{gap}}^{\text{unit}}_{\text{tod}} = c_{\text{w} \text{unit}, \text{gap}}^{\text{unit}}_{\text{tod}} \cdot \text{cap}^{*}_{\text{tk}} / \text{td}_{\text{od}} \]
  - \( \text{td}_{\text{od}} \), travel distance between \( o \) and \( d \)
  - \( \text{cap}^{*}_{\text{tk}} \), capacity of path \( k^{*} \) minimizing the \( c_{\text{w} \text{unit}}^{\text{unit}}_{\text{tk}} \) cost

• proposed unit incentive per o-d pair:
  \[ \text{inc}^{\text{km}}_{\text{tod}} = \min \{ \beta \cdot c_{\text{d} \text{unit}, \text{gap}}^{\text{unit}}_{\text{tod}} , \alpha \cdot \tau^{\text{km}} \} \]

EU regulation on cap for incentives

public budget constraint
Calculation of train capacity

Necessary condition for train t to operate on k: \( g_k \geq g_t^{\text{min}} \)

Hypthesize max length \( l_{tk} = l_k \)

Calculation of corresponding:
• maximum number of freight railcar
• candidate train weight

Consistency with weight upper bounds:
• maximum permissible weight per axle
• slope and power traction (# locomotives)

No \( \rightarrow \) weight is the limit

Yes \( \rightarrow \) length is the limit

Consistent with maximum permissible weight, calculation of:
• corresponding number of railcars
• maximum train length

Calculate payload capacity
Calculation of train costs

- cost of train driver(s) \( c_{\text{driv}} = n_{\text{driv}} \cdot t_{t_k} \cdot c_{\text{driv}}^h \)
  - number of drivers \( n_{\text{driv}} \)
  - \( c_{\text{driv}}^h \) hourly cost rate
- cost of locomotives \( c_{\text{loc}} = n_{\text{loc}} \cdot t_{t_k} \cdot c_{\text{loc}}^h \)
  - \( c_{\text{loc}}^h \) hourly cost of locomotive
- cost of rolling stock \( c_{\text{car}} = n_{\text{cars}}(l_{t_k}) \cdot t_{t_k} \cdot c_{\text{car}}^h(g_k) \)
  - \( n_{\text{cars}}(l_{t_k}) \) number of railcars allowed by train length \( l_{t_k} \)
  - \( c_{\text{car}}^h(g_k) \) hourly cost of rolling stock
- energy consumption and toll payment \( c_{\text{netw}} = \tau_{km}(w_{t_k}) \cdot t_{d_k} \)
  - \( t_{d_k} = v_t \cdot t_{t_k} \) travel distance between \( o \) and \( d \) along \( k \)
- other fixed costs (shunting costs, fixed administrative costs, etc.) \( c_{\text{fix}} \)

\[
c_{\text{tot}}^{t_k} = [n_{\text{driv}} \cdot c_{\text{driv}}^h + n_{\text{loc}} \cdot c_{\text{loc}}^h + n_{\text{cars}}(l_{t_k}) \cdot c_{\text{car}}^h(g_k) + \tau_{km}(w_{t_k}) \cdot v_t] \cdot t_{t_k} + c_{\text{fix}}
\]
Quantification of the incentive

• the proposed incentive requires calculation of shortest unit path costs in the current and optimal scenarios

• a non-additive shortest path problem:
  – total cost $c_{tot}^{tk}$ and capacity $cap_{tk}$ based on performance of worst link for each of the relevant infrastructural characteristics (path-based costs)

• possible approaches:
  – brute force: enumerating all paths for each o-d pair and then calculating the corresponding train capacity and costs, practically infeasible also for small-size networks
  – more efficient solution algorithms ...

• key aspect: homogeneous infrastructural characteristics across links of the network imply homogeneous train performances irrespective of the specific path $k$ ...

• ... thus additive shortest path algorithms can be applied
Rationale:

1. discretize relevant infrastructural characteristics according to a limited number of thresholds:
   - L set of $n_l$ train length thresholds (as example $n_l=5$ thresholds $L\equiv\{750 \, \text{m}, 600 \, \text{m}, 500 \, \text{m}, 400 \, \text{m}, 300 \, \text{m}\}$)
   - G set of $n_g$ loading gauge thresholds
   - S set of $n_s$ slope thresholds
   - W set of $n_w$ permissible weight thresholds

2. define a set $\Omega$ containing all $n_\omega=n_g \cdot n_l \cdot n_s \cdot n_w$ combinations of thresholds
   - the generic combination $\omega_i \in \Omega$ defines an appropriate bound for infrastructural characteristics
3. identify subset $A_{\omega_i} \subseteq A$ of links of the network with at least the characteristics defined by $\omega_i$

4. hypothesize homogeneous characteristics defined by $\omega_i$ for all links in $A_{\omega_i}$

5. calculate the lowest unit cost paths on $A_{\omega_i}$ via standard additive shortest path algorithms

• iterating across $\Omega$ yields the global shortest unit path cost with the corresponding best infrastructural performances
Algorithm

\[ \forall \# \text{ locomotives } (n_{loc}) \]

- Step 1 – calculation of shortest paths and unit costs in the current scenario
- Step 2 – calculation of the optimal cost and of the infrastructural gap
  - Repeat Step #1 for the EU standard combination of infrastructural characteristics
- Step 3 – quantification of the incentive
Case study: Italy (baseline 2015)
Case study: Italy (baseline 2015)

160 combinations of infrastructural characteristics

- length: $n_l=5$, set $L\equiv\{700 \text{ m}, 600 \text{ m}, 500 \text{ m}, 400 \text{ m}, 300 \text{ m}\}$
- loading gauge: $n_g=4$, set $G\equiv\{\text{PC80}, \text{PC45}, \text{PC22}, \text{PC00}\}$
- slope: $n_s=4$, set $S\equiv\{10\%, 15\%, 21\%, 50\%\}$
- weight: $n_w=2$, set $W\equiv\{8.0 \text{ tons/m}, 2.0 \text{ tons/m}\}$

intermodal train characteristics

- locomotive:
  - mass $w_{loc}=106$ tons
  - length $l_{loc}=18$ m

- freight railcar:
  - total weight $w_{car}=50$ tons
  - unladen weight $w_{u\, car}=17.5$ tons
  - length $l_{car}=20$ m

operational costs

- cost of train driver(s): $n_{driv}=2$ (according to the Italian regulations); $c^h_{driv}=25$ €/h (gross yearly salary of 55,000 €; 2200 working hours/year)
- cost of locomotives: $c^h_{loc}=22.83$ €/h
- cost of rolling stock: $c^h_{car}=0.36$ €/h for a standard railcar; $c^h_{car}=0.43$ €/h for a low-loader railcar
- energy consumption and toll payment: $\tau^km=3.26$ €/train-km (toll accounts for 2.82 €/train-km); $\tau^km$ is assumed independent of the train weight
- fixed costs: 2200 €/trip for shunting in origin and destination; 200 €/trip for administrative costs
Case study: implementation in Italy

• 90% of o-d pairs: infrastructural gap lower than 0.20 €/TEU·km
• only apparently low: ~ 200 €/TEU for a 1000 km o-d pair
## Case study: implementation in Italy

<table>
<thead>
<tr>
<th># trains/year per o-d pair</th>
<th># trains/year % distribution</th>
<th>infrastructural gap [€/TEU km]</th>
<th>smart incentive</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>mean</td>
<td>st. dev.</td>
</tr>
<tr>
<td>0-49</td>
<td>12%</td>
<td>0.14</td>
<td>0.23</td>
</tr>
<tr>
<td>50-99</td>
<td>5%</td>
<td>0.10</td>
<td>0.08</td>
</tr>
<tr>
<td>100-199</td>
<td>12%</td>
<td>0.14</td>
<td>0.27</td>
</tr>
<tr>
<td>200-499</td>
<td>12%</td>
<td>0.13</td>
<td>0.20</td>
</tr>
<tr>
<td>500 and more</td>
<td>58%</td>
<td>0.10</td>
<td>0.05</td>
</tr>
<tr>
<td>total</td>
<td>100%</td>
<td>0.14</td>
<td>0.22</td>
</tr>
</tbody>
</table>

- o-d pairs clustered by # trains/year

**cost of the “intermodal divide”** of railway transport in Italy with respect to the ideal standards of the EU.
Conclusions and research prospects

• an o-d equitable incentive to railway undertakings:
  – operational
  – dynamic: adjustable on a yearly basis to account for ongoing network improvements

• main challenge: non-additive costs → ad hoc procedure to calculate shortest paths

• research prospects:
  – embedding demand-side effects: modal split effect and generated demand effect
  – as objective function to maximize the modal shift
Thanks for your attention
Calculation of train capacity

- maximum number of freight railcar
  \[ n_{cars} = \text{int}\left[ \frac{l_k - n_{loc} \cdot l_{tloc}}{l_{tcar}} \right] \]

- candidate train weight
  \[ w_{tk}^* = n_{loc} \cdot w_{tloc} + n_{cars} \cdot w_{tcar} = n_{loc} \cdot w_{tloc} + \text{int}\left[ \frac{l_k - n_{loc} \cdot l_{tloc}}{l_{tcar}} \right] \cdot w_{tcar} \]

- consistency with weight upper bounds:
  - \( w_{tk} \leq w_k \cdot l_{tk} \)
  - \( w_{tk} \leq w_{tk}(n_{loc}, s_k) = \Psi_t(s_k) \cdot \phi(n_{loc}) \)
    - (Yes) \( w_{tk}^* \leq \min\{w_k \cdot l_{tk}, \Psi_t(s_k) \cdot \phi(n_{loc})\} \)
    - (No) \( w_{tk} = \min\{w_k \cdot l_{tk}, \Psi_t(s_k) \cdot \phi(n_{loc})\} \)

- number of railcars
  \[ n_{cars} = \text{int}\left[ \frac{w_{tk} - n_{loc} \cdot w_{tloc}}{w_{tcar}} \right] \]

- maximum train length
  \[ l_{tk} = n_{cars} \cdot l_{tcar} + n_{loc} \cdot l_{tloc} = \text{int}\left[ \frac{w_{tk} - n_{loc} \cdot w_{tloc}}{w_{tcar}} \right] \cdot l_{tcar} + n_{loc} \cdot l_{tloc} \]

- train payload capacity
  \[ C_{ap_{tk}} = w_{tk} - n_{cars} \cdot w_u_{car} - n_{loc} \cdot w_{loc} \]