A strategic model for urban transport planning: policy exploration for the Paris region

Fabien LEURENT, Sheng LI
Ecole des Ponts ParisTech, Laboratoire Ville Mobilité Transport
Research objective

- Explore some scenarios of mobility policy for the Paris region
  • Economic instruments: transit tariff, energy tax and road charge
  • Transit network: structural composition and fleet size

- Based on a strategic quantitative model
  • Of transportation networks and their production means
  • Of mobility demand and its modal choices
  • Of environmental impacts
1. Model framework
Literature review

Supply’s synthetic description
- Transit network
  - Holroyd (1967)
  - Mohring (1972)
  - Daganzo (2010)
  - etc.
- Road network
  - Kraus (1981)
  - Geroliminis et al. (2008)
  - etc.

Demand management
- Pigou (1920)
- Knight (1924)
- Wardrop (1952)
- Strotz (1965)
- Arnott et al. (1993)
- etc.

Transport pricing
- Vickrey (1963)
- Arnott et al. (2000)
- De Palma et al. (2006)
- etc.

Modal choice
- McNamara (1973, 1974)
- Ben-Akiva (1978)

Welfare measurement
- Dupuit (1844)
- Marshall (1890)
- Hotelling (1938)
- Small et al. (1981)

Multimodal transportation network design/planning
- Basso et al. (2011)
- Estrada et al. (2012)
- Tirachini et al. (2014)
- Leurent et al. (2018)

Spatial and user segmentation

Mode choice

Environmental impacts
- Verhoef (1994)
- De Borger et al. (1997)
- Proost et al. (2001)
- Report Quinet (2013)
- etc.
STEM : Structural Technical-Economic Model

- Actors’ surplus
  - Consumer’s surplus ($P^u$)
  - Operators’ profits ($P^o$)
  - Environmental impacts ($P^e$)

- Optimization terms
  - Short run
  - Long run
Model framework

Users’ surplus $P^u$

Travel demand

Mode choice

Quality of service

Usage conditions and flow

Set up

Tariffs

Environment

Government

Users' surplus $P^u$

Transport supply

Transport network structure and performance

Road network structure and performance

Cost

Subsidy

Operator’s profit $P^o$

Revenue

Imacts

Tariffs

Set ups

Transport supply

Usage conditions and flow

Quality of service

Mode choice

Travel demand

Government

Subsidy

Cost

Users’ surplus $P^u$

Transport network structure and performance

Road network structure and performance

Tariffs

Set ups

Usage conditions and flow

Quality of service

Mode choice

Travel demand

Environment

Imacts

Operator’s profit $P^o$
Transportation components

Source: Driea 2010

Set $Z$:
- sub-regions
  - center
  - inner suburbs
  - outer suburbs

Set $R$:
- suburban rail network
- metro network
- road networks in Paris and inner suburbs
- road network in outer suburbs
- bus network
Demand segmentation

From the data of EGT 2010 (regional household travel survey)

- O/D
  - Paris
  - Inner suburbs
  - Outer suburbs

- Travel range
  - 0-3 km
  - 3-10 km
  - Beyond 10 km

- Path with respect to central area
  - Through traffic
  - By-pass

21 user groups

- Dependent or flexible users
  - Transit dependent ($Q_{i}^{TD}$)
  - Automobile dependent ($Q_{i}^{CD}$)
  - Flexible (transit/automobile) ($Q_{i}^{F}$)
### Supply, demand aggregates

<table>
<thead>
<tr>
<th>Systems</th>
<th>Components</th>
<th>Supply</th>
<th>Demand and traffic</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Network length (km*lane)</td>
<td>Fluid speed (km/h)</td>
</tr>
<tr>
<td>Road networks</td>
<td>Paris</td>
<td>1870</td>
<td>38</td>
</tr>
<tr>
<td></td>
<td>inner suburbs</td>
<td>4417</td>
<td>51</td>
</tr>
<tr>
<td></td>
<td>outer suburbs</td>
<td>19097</td>
<td>67</td>
</tr>
<tr>
<td></td>
<td>Total</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Transit networks</th>
<th>Subarea</th>
<th>Mode</th>
<th>Supply</th>
<th>Demand and traffic</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>Network length (km)</td>
<td>Number of stations</td>
</tr>
<tr>
<td>Paris</td>
<td>Bus</td>
<td>598</td>
<td>1795</td>
<td>1295</td>
</tr>
<tr>
<td></td>
<td>Métro</td>
<td>171</td>
<td>248</td>
<td>572</td>
</tr>
<tr>
<td></td>
<td>RER</td>
<td>57</td>
<td>29</td>
<td>107</td>
</tr>
<tr>
<td></td>
<td>Transilien</td>
<td>13</td>
<td>6</td>
<td>22</td>
</tr>
<tr>
<td>inner suburbs</td>
<td>Bus</td>
<td>2894</td>
<td>7575</td>
<td>3078</td>
</tr>
<tr>
<td></td>
<td>Métro</td>
<td>39</td>
<td>52</td>
<td>111</td>
</tr>
<tr>
<td></td>
<td>RER</td>
<td>181</td>
<td>85</td>
<td>129</td>
</tr>
<tr>
<td></td>
<td>Transilien</td>
<td>123</td>
<td>40</td>
<td>90</td>
</tr>
<tr>
<td>outer suburbs</td>
<td>Bus</td>
<td>20032</td>
<td>25173</td>
<td>4271</td>
</tr>
<tr>
<td></td>
<td>RER</td>
<td>355</td>
<td>128</td>
<td>107</td>
</tr>
<tr>
<td></td>
<td>Transilien</td>
<td>761</td>
<td>187</td>
<td>207</td>
</tr>
<tr>
<td>Total</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
- Transit system
  • Fare ($\tau_i^T$)
  • Fleet size ($N_r$)
  • Line length ($L_r$)
  • Station number ($\sigma_r$)

- Road network
  • Energy tax ($\beta_c$)
  • Road charge ($\tau_i^C$)

- Optimization policies
  • $\max W_1 = P^o + P^u$
  • $\max W_0 = P^o + P^u + P^e$
  \[ s.t. \quad P^o + S \geq 0 \quad S: \text{subsidy} \]

<table>
<thead>
<tr>
<th>Group</th>
<th>Scenario</th>
<th>Scenario description</th>
</tr>
</thead>
<tbody>
<tr>
<td>1/ Economic instruments</td>
<td>1</td>
<td>Free transit</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>Fuel tax + 7c€/L</td>
</tr>
<tr>
<td></td>
<td>3</td>
<td>Road charge in Paris city</td>
</tr>
<tr>
<td></td>
<td>4</td>
<td>Road charge in Paris city</td>
</tr>
<tr>
<td>2/ Short-run optimization: transit tariffs &amp; fleet sizes</td>
<td>5</td>
<td>Under budget constraint, O+U</td>
</tr>
<tr>
<td></td>
<td>6</td>
<td>Under budget constraint, O+U+E</td>
</tr>
<tr>
<td></td>
<td>7</td>
<td>No budget constraint, O+U</td>
</tr>
<tr>
<td></td>
<td>8</td>
<td>No budget constraint, O+U+E</td>
</tr>
<tr>
<td>3/ Long-run optimization: transit tariffs, fleet sizes, stations, line lengths</td>
<td>9</td>
<td>Under budget constraint, O+U</td>
</tr>
<tr>
<td></td>
<td>10</td>
<td>Under budget constraint, O+U+E</td>
</tr>
<tr>
<td></td>
<td>11</td>
<td>No budget constraint, O+U</td>
</tr>
<tr>
<td></td>
<td>12</td>
<td>No budget constraint, O+U+E</td>
</tr>
</tbody>
</table>
2. Scenario design and simulation
### Scenario Assessment: group 1

- Different economic instruments

<table>
<thead>
<tr>
<th>Indicator</th>
<th>2010 State (Reference)</th>
<th>Scenario 1: Free transit fares</th>
<th>Scenario 2: Energy tax +7c€/L</th>
<th>3: Road charge for max W1</th>
<th>4: Road charge for max W0</th>
</tr>
</thead>
<tbody>
<tr>
<td>Transit fare revenues</td>
<td>2.38</td>
<td>2.4</td>
<td>2.4</td>
<td>2.4</td>
<td>2.5</td>
</tr>
<tr>
<td>Operator's profit Po</td>
<td>-5.72</td>
<td>△Po 2.5</td>
<td>0.4</td>
<td>0.4</td>
<td>1.0</td>
</tr>
<tr>
<td>Users' surplus Pu</td>
<td>-56.6</td>
<td>△Pu 2.9</td>
<td>-0.3</td>
<td>-0.4</td>
<td>-1.3</td>
</tr>
<tr>
<td>Environment surplus Pe</td>
<td>-5.28</td>
<td>△Pe 0.2</td>
<td>0.05</td>
<td>0.2</td>
<td>0.7</td>
</tr>
<tr>
<td>W1 = Pu+Po</td>
<td>-62.3</td>
<td>△Pou 0.4</td>
<td>0.04</td>
<td>0.1</td>
<td>-0.3</td>
</tr>
<tr>
<td>W0 = Pu+Po+Pe</td>
<td>-67.6</td>
<td>△Poue 0.6</td>
<td>0.09</td>
<td>0.3</td>
<td>0.4</td>
</tr>
<tr>
<td>TICPE revenues</td>
<td></td>
<td>△ER -0.08</td>
<td>0.4</td>
<td>-0.06</td>
<td>-0.15</td>
</tr>
<tr>
<td>Road charge revenues</td>
<td></td>
<td>△RCR</td>
<td></td>
<td>0.5</td>
<td>1.1</td>
</tr>
</tbody>
</table>

0.26 €/km 0.77 €/km
### Scenario Comparison

<table>
<thead>
<tr>
<th>Scenario</th>
<th>ΔU</th>
<th>ΔO</th>
<th>ΔE</th>
<th>ΔΣ</th>
</tr>
</thead>
<tbody>
<tr>
<td>1/ Free transit fares</td>
<td>+2.9</td>
<td>-2.5</td>
<td>+0.2</td>
<td>+0.6</td>
</tr>
<tr>
<td>2/ Energy tax +7c€/L</td>
<td>-0.3</td>
<td>+0.37</td>
<td>+0.05</td>
<td>+0.1</td>
</tr>
<tr>
<td>3,4/ Road charge in central area, 0.26 or 0.77€/km</td>
<td>-0.4</td>
<td>+0.4</td>
<td>+0.2</td>
<td>+0.3</td>
</tr>
<tr>
<td></td>
<td>-1.3</td>
<td>+0.1</td>
<td>+0.7</td>
<td>+0.4</td>
</tr>
<tr>
<td>5-8/ Short-run optimization, under budget constraint or not</td>
<td>+1</td>
<td>0</td>
<td>+0.25</td>
<td>+1.3</td>
</tr>
<tr>
<td></td>
<td>+4</td>
<td>-3</td>
<td>+0.3</td>
<td>+1.4</td>
</tr>
<tr>
<td>9-12/ Long run optimization, under budget constraint or not</td>
<td>+3</td>
<td>0</td>
<td>+0.25</td>
<td>+3.6</td>
</tr>
<tr>
<td></td>
<td>+6</td>
<td>-2.7</td>
<td>+0.3</td>
<td>+3.9</td>
</tr>
</tbody>
</table>

### Synthesis of scenarios

- To Max W0 or W1 has little consequences at the most aggregate level, yet it changes the balance between transit sub-modes either bus or rail.
Physical factors

- Current
- S-run W0
- L-run W0

Line length

- Paris center
- Inner suburbs
- Outer suburbs

Station density

Service frequency

- Bus Center
- Metro Center
- RER Center
- Transilien Center
- Bus I suburbs
- Metro I suburbs
- RER I suburbs
- Transilien I suburbs
- Bus O suburbs
- RER O suburbs
- Transilien O suburbs
- To Transit service supplier and to the Environment

Supply cost: around $0.4/\text{pax} \cdot \text{km}$ by bus, $0.35$ by metro, $0.15$ by rail in inner suburbs but $0.3$ in outer suburbs: nearly equivalent to private cost by car.

Environmental costs: below $0.01/\text{pax} \cdot \text{km}$ for rail modes, $0.1$ by bus in dense area, vs. $0.5 / 0.2$ per car.km.
Under Scenario 6: Maximize Collective Welfare with respect to transit fleet sizes and O-D tariffs, subject to transit budget:

- One fare per O-D pair between O-D sub-regions and also by range interval either [0, 3] or [3-10] or 10+ km

Main results:

- Long trips above 10 km => Null fares, probably so to foster modal split and avoid long trips using private cars
- Short trips less than 3 km: fares of 2 or 3 €/trip, probably so to yield sufficient commercial revenues
- Medium range trips from 3 to 10 km: intermediary fare levels from .5 to 2, except for outer suburbs at 6 €/trip

Comments:

- The effect of transit distance is paradoxical
- Only related road charging would enable to set up fair tariffs to orient demand
3. Conclusion
Conclusions

- Some indications for mobility policies in Paris region
  - In the central part, high density calls for eco-friendly modes
  - Transit modes: need for more high-capacity modes
  - Roadway network: substantial evidence of high social costs

- Modeling issues
  - In its current state, the model captures major features of motorized transportation
  - Synthesis of spatial conditions: by network components and O-D types

- Next steps
  - Temporal distribution to model traffic peaks
  - Road network: structural vs. capillary
  - Firm-related issues: reimbursement of some transportation expenditures
Thank you for your attention