Simulation-based optimization of congestion costs, noise damages and air pollution costs (CNA)

The impact of route and mode choice

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Amit Agarwal
Benjamin Kickhöfer
Agenda

1. History of agent-based internalization studies with MATSim

2. Case studies and results of CNA internalization approach

3. Summary and outlook
History of agent-based internalization studies with MATSim
What is internalization about?

• **Starting point**: Transport-related negative externalities are bothersome
  - Congestion
  - Air pollution
  - Noise
  - Accidents
  - …

• **Reason**: People do not consider marginal social but only marginal private costs

• **Goal**: Improve system efficiency, i.e. maximize social welfare

• **Approach**: Pricing the externalities in order to evoke behavioral changes
It all started in 2009 with air pollutant emissions,…

Calculating air pollutant emissions and mapping them back to agent’s home location

Kickhöfer and Nagel (2011)

Charging the responsible agents with individual, time-dependent tolls based on average air pollutant cost factors

Kickhöfer and Nagel (2012, 2016)
Distributing emission costs, weighting them with the dynamically changing number of affected agents, and charging the responsible agent(s) with individual, time-dependent tolls.

Kickhöfer and Kern (2015)

\[ C_{ex} = \sum_{i=1}^{N} \frac{T_{oct,i}}{T_{arg}} \cdot d_i \cdot C_{em} \]
Calculating time losses of PT users, identifying the responsible agent(s) and charging them accordingly

Kaddoura (2012)
Kickhöfer, Kaddoura, Neumann, and Tirachini (2012)
Kaddoura, Kickhöfer, Neumann, and Tirachini (2012)
Kaddoura, Kickhöfer, Neumann, and Tirachini (2013, 2015a, 2015b)
Calculating time losses of car users; identifying the responsible agent(s) and charging them accordingly

Kaddoura and Kickhöfer (2014)
Kaddoura (2015)
and comparing this to
Lämmel and Flötteröd (2009)

Comparing different agent-based pricing approaches to the Vickrey bottleneck model

Kaddoura and Nagel (2017a)
...noise damages, ...

Calculating noise immissions, and weighting them with the dynamically changing number of affected agents

Kaddoura, Kröger and Nagel (2017a)

Identifying the responsible agent(s) and charging them with individual, time-dependent tolls

Kaddoura, Kröger and Nagel (2017b)
...and eventually resulted in joint internalization studies.

<table>
<thead>
<tr>
<th>Study</th>
<th>Car congestion</th>
<th>PT congestion</th>
<th>Air pollution Flat</th>
<th>Air pollution Exposure</th>
<th>Noise</th>
<th>Accidents</th>
</tr>
</thead>
<tbody>
<tr>
<td>Agarwal and Kickhöfer (2014, 2015, 2016)</td>
<td>x</td>
<td></td>
<td>x</td>
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<td></td>
<td></td>
</tr>
<tr>
<td>Kaddoura and Nagel (2017b)</td>
<td>x</td>
<td></td>
<td></td>
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<td>x</td>
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<tr>
<td>This study (paper #21)</td>
<td>x</td>
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<td>x</td>
<td>x</td>
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<td>x</td>
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</tbody>
</table>

Case studies and results of CNA internalization approach
Real-world case studies

Greater Berlin Area
- Transport network: major roads
- Travel demand (1% sample):
  - Synthesized with CEMDAP based on Census 2011 data, commuters as O-D from German Federal Employment Office, and calibrated with Cadyts; validated against SrV 2008
  - No freight traffic
- Open data scenario, available through https://svn.vsp.tu-berlin.de/repos/public-svn/matsim/scenarios/countries/de/berlin/

Greater Munich Area
- Transport network: major roads
- Travel demand (1% sample):
  - Activity chains from MiD 2002; commuters as O-D from German Federal Employment Office
  - Basic freight traffic (long distance)
Results CNA: Exposure minimization through new routes

Berlin

Munich
Results CNA: Change in externalities for Berlin

Change in
NOx levels in g

Change in
L_{den} in db(A)

only route choice (r) mode and route choice (m+r)
Results CNA: Who are the bad guys in Berlin?

(a) Congestion toll payments

(b) Noise toll payments

(c) Air pollution toll payments

1st decile
2nd decile
3rd decile
4th decile
5th decile
6th decile
7th decile
8th decile
9th decile
10th decile
Results CNA: Who are the bad guys in Berlin?

(a) Congestion toll payments

(b) Noise toll payments

(c) Air pollution toll payments
Results CNA: contributions to the overall externality over time of day

(a) only route choice  
(b) Route and mode choice
## Changes in externalities for different scenarios (Berlin)

### Route choice

<table>
<thead>
<tr>
<th>Change in...</th>
<th>C</th>
<th>N</th>
<th>A</th>
<th>CNA</th>
</tr>
</thead>
<tbody>
<tr>
<td>delay [h]</td>
<td>-44,225</td>
<td>7,336</td>
<td>32,246</td>
<td>-18,455</td>
</tr>
<tr>
<td>noise costs [EUR]</td>
<td>153</td>
<td>-2,257</td>
<td>769</td>
<td>-532</td>
</tr>
<tr>
<td>air pollution costs [EUR]</td>
<td>449,879</td>
<td>451,934</td>
<td>-1,081,635</td>
<td>-1,107,170</td>
</tr>
<tr>
<td>system welfare [EUR]</td>
<td>-103,843</td>
<td>-907,807</td>
<td>-28,071</td>
<td>909,422</td>
</tr>
</tbody>
</table>

### Route and mode choice

<table>
<thead>
<tr>
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<th>N</th>
<th>A</th>
<th>CNA</th>
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</thead>
<tbody>
<tr>
<td>delay [h]</td>
<td>-107,758</td>
<td>-21,836</td>
<td>-230,886</td>
<td>-252,741</td>
</tr>
<tr>
<td>noise costs [EUR]</td>
<td>-16,530</td>
<td>-12,378</td>
<td>-199,073</td>
<td>-227,027</td>
</tr>
<tr>
<td>air pollution costs [EUR]</td>
<td>-608,372</td>
<td>364,058</td>
<td>-9,676,897</td>
<td>-10,077,616</td>
</tr>
<tr>
<td>toll revenues [EUR]</td>
<td>3,552,489</td>
<td>244,086</td>
<td>7,112,679</td>
<td>8,188,642</td>
</tr>
<tr>
<td>system welfare [EUR]</td>
<td>3,795,859</td>
<td>-18,674</td>
<td>11,908,806</td>
<td>12,890,934</td>
</tr>
</tbody>
</table>

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**MATSim user meeting at hEART 2017 > Simulation-based optimization of CNA • Benjamin Kickhöfer • 11.09.2017**
Summary and outlook
Summary and outlook

• Simultaneous external cost pricing (CNA) reduces all externalities and increases system welfare

• Isolated external cost pricing may result in welfare losses; Reason: negative correlation of different external effects

• Choice dimensions:
  • Route choice only implies very low elasticities > almost no changes
  • Route and mode choice imply very high elasticities > very strong changes
  • Introducing time choice seems crucial for capturing the right elasticities
References (journal articles)

References (proceedings and working papers)


Thank you.
## Results: mode switchers

### Table 3: Berlin: Car trip analysis of all car users vs. mode switchers; CNA; r; upscaled to full population size

<table>
<thead>
<tr>
<th>Considered users</th>
<th>Contribution of each external effect</th>
<th>∑</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Congestion</td>
<td>Noise</td>
</tr>
<tr>
<td>Average toll per trip</td>
<td>Car retainers</td>
<td>0.57</td>
</tr>
<tr>
<td>Average toll per trip</td>
<td>Car to non-car switchers</td>
<td>1.40</td>
</tr>
</tbody>
</table>

### Table 4: Munich: Car trip analysis of all car users vs. mode switchers; CNA; r; upscaled to full population size

<table>
<thead>
<tr>
<th>Considered users</th>
<th>Contribution of each external effect</th>
<th>∑</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Congestion</td>
<td>Noise</td>
</tr>
<tr>
<td>Average toll per trip</td>
<td>Car retainers</td>
<td>2.11</td>
</tr>
<tr>
<td>Average toll per trip</td>
<td>Car to non-car switchers</td>
<td>2.89</td>
</tr>
</tbody>
</table>
Noise computation approach + Validation

big circles: own calculation
small circles: SenStadt model

- < 35 dB(A)
- 35 - 40 dB(A)
- 40 - 45 dB(A)
- 45 - 50 dB(A)
- 50 - 55 dB(A)
- 55 - 60 dB(A)
- 60 - 65 dB(A)
- 65 - 70 dB(A)
- > 70 dB(A)