Pricing local emission exposure of road traffic
An agent-based approach

Benjamin Kickhöfer | TU Berlin | mobil.TUM 2014

München, 19.05.2014
Motivation
### Costs Related to Exhaust Emissions

<table>
<thead>
<tr>
<th>Related to Population / Activity Location Density</th>
</tr>
</thead>
<tbody>
<tr>
<td>• Direct damages to human health (increased health costs, mortality, …)</td>
</tr>
<tr>
<td>• Indirect impacts on housing market (reduced property values, rents, …)</td>
</tr>
<tr>
<td>• Indirect impacts on quality of life, livability of the city</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>• Direct damages to building structure</th>
</tr>
</thead>
<tbody>
<tr>
<td>• Indirect impacts from global warming (weather extremes)</td>
</tr>
</tbody>
</table>
Optimal Pricing with MATSim

Optimal Pricing with MATSim

\[ V_p = \sum_{i=1}^{n} V_{\text{perf},i} + \sum_{i=1}^{n} V_{\text{tr},i} = 97 \text{ utils} \]

\[ V_p = \sum_{i=1}^{n} V_{\text{perf},i} + \sum_{i=1}^{n} V_{\text{tr},i} = 100 \text{ utils} \]

\[ V_p = \sum_{i=1}^{n} V_{\text{perf},i} + \sum_{i=1}^{n} V_{\text{tr},i} = 90 \text{ utils} \]
Deriving Damage Cost Estimates of Exhaust Emissions

1. Modeling emission levels
2. Modeling dispersion and deriving air quality
3. Modeling exposure of individuals to air pollutant concentration
4. Applying concentration-response functions [numbers of cases for mortality, life years lost, hospital admissions, premature mortality, minor restricted activity days, work loss days, etc.]
5. Assigning monetary values to each of these cases

How to determine the “correct” price level iteratively?
Approach
Modeling Emission Levels

Vehicle Type
- Engine Type
- Cubic Capacity
- European Emission Standard

Road Category
- Local Roads
- Collectors
- Arterials
- Freeways

Traffic State
- Freeflow
- Heavy
- Saturated
- Stop&Go

Activity time

Cold Emission Factors [g]
- Mass of Fuel
- CO₂
- PM

Warm Emission Factors [g/km]
- NOₓ
- CO
- SO₂
- NMHC
- HC
- …

HBEFA: Handbook on Emission Factors for Road Transport (see www.hbefa.net)
This is a non-exhaustive list of differentiations provided by HBEFA 3.1
Idea 1: Emission Toll (Independent of Exposure)

- Whenever a person leaves a road segment:
  - Calculate emissions (dependent on vehicle, traffic state, …)
  - Calculate emission costs (flat toll per [g])
  - Charge that person with the resulting individual toll

- Differentiated tolls are now part of the individual decision making process of every person
Idea 2: Exposure Toll (Dependent of Exposure)

$$c_{\text{actual}} = \text{average } t_{\text{average}}$$

Table:

<table>
<thead>
<tr>
<th>0.000 €</th>
<th>0.000 €</th>
<th>0.000 €</th>
<th>0.002 €</th>
<th>0.000 €</th>
<th>0.000 €</th>
<th>0.000 €</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.000 €</td>
<td>0.000 €</td>
<td>0.002 €</td>
<td>0.029 €</td>
<td>0.002 €</td>
<td>0.000 €</td>
<td>0.000 €</td>
</tr>
<tr>
<td>0.000 €</td>
<td>0.002 €</td>
<td>0.029 €</td>
<td>0.132 €</td>
<td>0.029 €</td>
<td>0.002 €</td>
<td>0.000 €</td>
</tr>
<tr>
<td>0.002 €</td>
<td>0.029 €</td>
<td>0.132 €</td>
<td>0.216 €</td>
<td>0.132 €</td>
<td>0.029 €</td>
<td>0.002 €</td>
</tr>
<tr>
<td>0.000 €</td>
<td>0.002 €</td>
<td>0.029 €</td>
<td>0.132 €</td>
<td>0.029 €</td>
<td>0.002 €</td>
<td>0.000 €</td>
</tr>
<tr>
<td>0.000 €</td>
<td>0.000 €</td>
<td>0.002 €</td>
<td>0.029 €</td>
<td>0.002 €</td>
<td>0.000 €</td>
<td>0.000 €</td>
</tr>
<tr>
<td>0.000 €</td>
<td>0.000 €</td>
<td>0.000 €</td>
<td>0.002 €</td>
<td>0.000 €</td>
<td>0.000 €</td>
<td>0.000 €</td>
</tr>
</tbody>
</table>
Results:

Munich Metropolitan Area
Subpopulations and Choice Dimensions

- Subpopulations:
  - Urban travelers
  - Commuters
  - Reverse Commuters
  - Freight

- Choice dimensions:
  - Route choice
  - Mode choice (car vs public transit; other modes fixed)
  - Freight: only route choice
Base Case: Absolute Emissions by Subpopulation

7.6% of total population
- Major part of total emissions
- PM and NOX over-proportionally high

68% of total population
- Relatively small part of total emissions
- NMHC over-proportionally high > cold starts!

14.6% and 9.8% of total population
- Commuters drive longer distances than rev. commuters…
- …and therefore emit more emissions
Changes in Relative Emissions by Subpopulation

- Similar impact on emission level
- Higher share of short trips with car (NMHC)

- Less emission reduction for commuters and rev. commuters

- Higher emission levels for freight
Absolute Changes in User Benefits by Subpopulation

Emission toll is implicitly a congestion toll

Higher toll payments for urban travelers

Lower toll payments for freight

Emission toll

Exposure toll

<table>
<thead>
<tr>
<th>SUBPOPULATION</th>
<th>User Benefits</th>
<th>Toll Payments</th>
<th>Sum</th>
</tr>
</thead>
<tbody>
<tr>
<td>URBAN</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>COMMUTER</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>REV_COMMUTER</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>FREIGHT</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Emission toll

Exposure toll

Lower toll payments for freight

Higher toll payments for urban travelers

Emission toll is implicitly a congestion toll

Emission toll

Exposure toll

Lower toll payments for freight

Higher toll payments for urban travelers

Emission toll is implicitly a congestion toll

Emission toll

Exposure toll

Lower toll payments for freight

Higher toll payments for urban travelers
Absolute Changes in Exposure Costs by Subpopulation

A flat toll per [g] yields a reduction of emission externalities below damage cost optimum

Even though freight produces more emissions, exposure costs drop
Toll Payments at Home Location

Emission toll

Exposure toll

Pricing local emission exposure of road traffic: An agent-based approach | B. Kickhöfer | mobil.TUM 2014
München, 19.05.2014
Page 16
Summary

• Exposure should be accounted for; bottleneck is the air pollution concentration model > simplified approach

• Calculation of vehicle-specific, time-dependent tolls is possible for large-scale real-world scenarios

• Both, emission toll and exposure toll can be used as benchmark for evaluating real-world policies

• Emission toll (flat value per [g]) leads to only a small reduction in exposure costs

• Exposure toll will lead to less exposure costs, but can lead to more emissions [potential conflict: CO2 vs local pollutants]

• MATSim allows for in-depth analysis (e.g. identifying areas with “environmentally friendly” vs “polluting” life styles
Thank you.
Evaluating a Speed Limitation in the Inner City
Absolute Changes in NO2 Emissions

Zone 30

Exposure toll
Changes in Relative Emissions by Subpopulation

Mode choice effect: Emission levels below the economic optimum

Re-route effect: Emission levels above the economic optimum

Re-route effect: Emission level still below the economic optimum

Benchmark: Optimal change in emission levels
Absolute Changes in Benefits by Subpopulation

- Loss in user benefit for all subpopulations
- Net welfare gains: Emission toll is implicitly a congestion toll
- Exposure costs: Zone 30 is an effective strategy for urban travelers, ineffective for other subpopulations

Pricing local emission exposure of road traffic: An agent-based approach | B. Kickhöfer | mobil.TUM 2014
München, 19.05.2014
Page 22
Emission Modeling Tool: Warm Emission Events

- \( l_{\text{link}} = 500 \, \text{m} \); \( v_{\text{max}} = 30 \, \text{km/h} \)
- \( t_{\text{min}} = 60 \, \text{s} \);
- \( t_{\text{travel}} = 90 \, \text{s} \)

Traffic State

- Freeflow (60 s)
- Heavy
- Saturated
- Stop&Go (30 s)

\[
x_{\text{freeFlow}} = l_{\text{link}} - x_{\text{stopGo}}
\]

\[
x_{\text{stopGo}} = \frac{l_{\text{link}} \cdot v_{\text{stopGo}} \cdot (v_{\text{max}} - v_{\text{avg}})}{v_{\text{avg}} \cdot (v_{\text{max}} - v_{\text{stopGo}})}
\]
Emission Modeling Tool: Cold Emission Events

10:00:00 a.m. person enters link

10:00:01 a.m. person enters bar

11:00:01 a.m. person leaves bar

Emission Factors [g]

- Activity time
- Vehicle type
### Behavioral Parameters

Table 5.1.: Estimated and adjusted utility parameters; resulting VTTS.

**(a) Tirachini et al. (2014)**

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
<th>Unit</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\hat{\beta}_{tr, car}$</td>
<td>-0.96</td>
<td>$\text{util}_h$</td>
</tr>
<tr>
<td>$\hat{\beta}_{tr, pt}$</td>
<td>-1.14</td>
<td>$\text{util}_h$</td>
</tr>
<tr>
<td>$\hat{\beta}_c$</td>
<td>-0.062</td>
<td>$\text{AUD}_h$</td>
</tr>
<tr>
<td>$\hat{\beta}_{perf}$</td>
<td>N/A</td>
<td>$\text{util}_h$</td>
</tr>
<tr>
<td>VTTS$_{car}$</td>
<td>+15.48</td>
<td>$\text{AUD}_h$</td>
</tr>
<tr>
<td>VTTS$_{pt}$</td>
<td>+18.39</td>
<td>$\text{AUD}_h$</td>
</tr>
</tbody>
</table>

**(b) MATSim**

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
<th>Unit</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\beta_{tr, car}$</td>
<td>-0.00</td>
<td>$\text{util}_h$</td>
</tr>
<tr>
<td>$\beta_{tr, pt}$</td>
<td>-0.18</td>
<td>$\text{util}_h$</td>
</tr>
<tr>
<td>$\beta_c$</td>
<td>-0.07949</td>
<td>$\text{EUR}_h$</td>
</tr>
<tr>
<td>$\beta_{perf}$</td>
<td>+0.96</td>
<td>$\text{util}_h$</td>
</tr>
<tr>
<td>VTTS$_{car}$</td>
<td>+12.08</td>
<td>$\text{EUR}_h$</td>
</tr>
<tr>
<td>VTTS$_{pt}$</td>
<td>+14.34</td>
<td>$\text{EUR}_h$</td>
</tr>
</tbody>
</table>
## Emission Cost Factors

Table 5.2.: Emission cost factors by emission type. Source: Maibach et al. (2008).

<table>
<thead>
<tr>
<th>Emission type</th>
<th>Cost factor [EUR/ton]</th>
</tr>
</thead>
<tbody>
<tr>
<td>$CO_2$</td>
<td>70</td>
</tr>
<tr>
<td>NMHC</td>
<td>1'700</td>
</tr>
<tr>
<td>$NO_x$</td>
<td>9'600</td>
</tr>
<tr>
<td>PM</td>
<td>384'500</td>
</tr>
<tr>
<td>$SO_2$</td>
<td>11'000</td>
</tr>
</tbody>
</table>
Resulting Average Emission Cost Factors

<table>
<thead>
<tr>
<th>Subpopulation</th>
<th>incl. ( CO_2 )</th>
<th>excl. ( CO_2 )</th>
</tr>
</thead>
<tbody>
<tr>
<td>URBAN</td>
<td>2.71</td>
<td>1.20</td>
</tr>
<tr>
<td>COMMUTER</td>
<td>2.27</td>
<td>1.02</td>
</tr>
<tr>
<td>REV_COMMUTER</td>
<td>2.25</td>
<td>1.02</td>
</tr>
<tr>
<td>FREIGHT</td>
<td>14.51</td>
<td>10.29</td>
</tr>
</tbody>
</table>

For urban travelers, we find values close to those from the literature (e.g. Parry and Small, 2005: excl. CO2 approx. 1.23 EURct/km)

This needs to be investigated for Exposure Pricing!