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

The impact of route and mode choice

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Agenda

1. History of agent-based internalization studies with MATSim

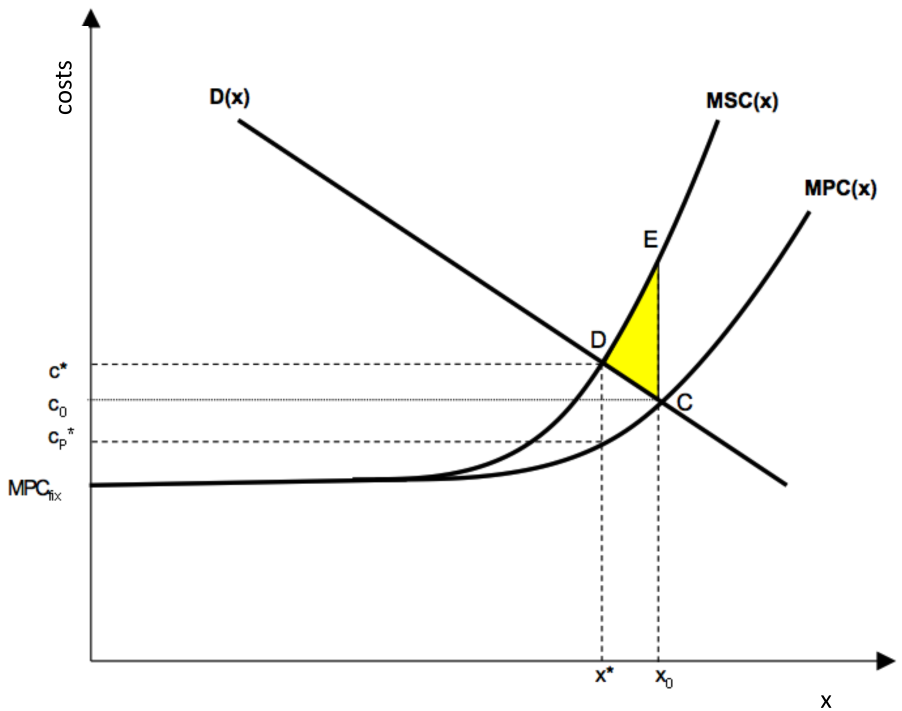
2. Case studies and results of CNA internalization approach

3. Summary and outlook

History of agent-based internalization studies with MATSim

What is internalization about?

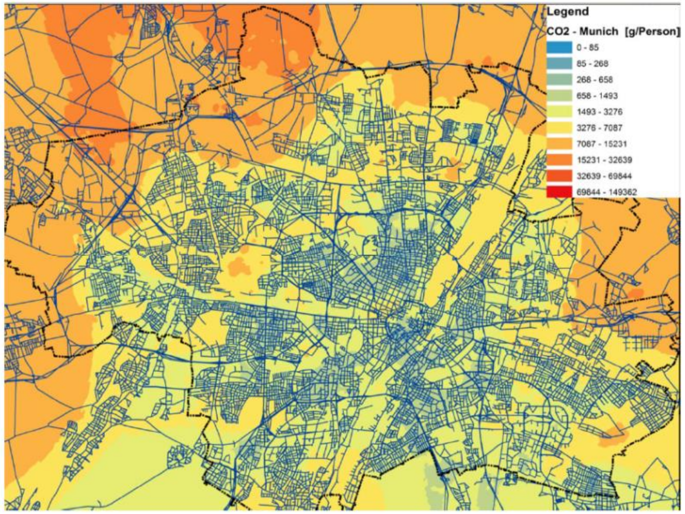
- **Starting point**: Transport-related negative externalities are bothersome
    - Congestion
    - Air pollution
    - Noise
    - Accidents
    - …
- **Reason**: People do not consider marginal social but only marginal private costs
- **Goal**: Improve system efficiency, i.e. maximize social welfare
- **Approach**: Pricing the externalities in order to evoke behavioral changes

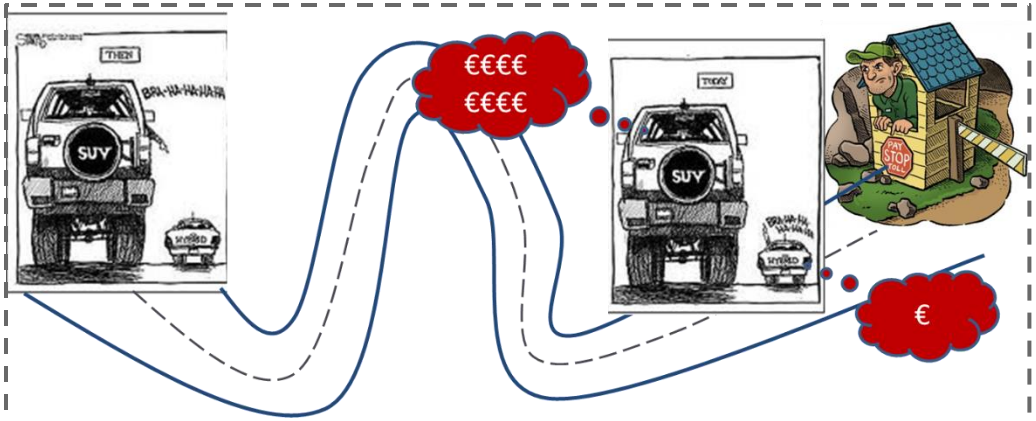


It all started in 2009 with air pollutant emissions,…

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)

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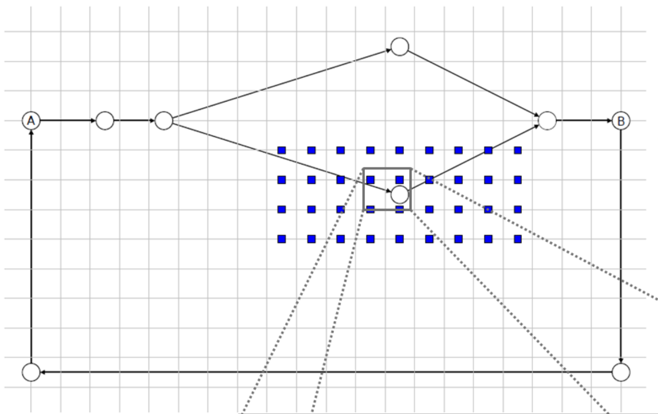
…continued with exposure cost internalization, …

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)



$$C_{ex} = \sum_{i=1}^{N} \frac{T_{act,i}}{T_{avg}} \cdot d_i \cdot C_{em}$$

0.000 €	0.000 €	0.000 €	0.002 €	0.000 €	0.000 €	0.000 €
0.000 €	0.000 €	0.002 €	0.029 €	0.002 €	0.000 €	0.000 €
0.000 €	0.002 €	0.029 €	0.132 €	0.029 €	0.002 €	0.000 €
0.002 €	0.029 €	0.132 €	0.216 €	0.132 €	0.029 €	0.002 €
0.000 €	0.002 €	0.029 €	0.132 €	0.029 €	0.002 €	0.000 €
0.000 €	0.000 €	0.002 €	0.029 €	0.002 €	0.000 €	0.000 €
0.000 €	0.000 €	0.000 €	0.002 €	0.000 €	0.000 €	0.000 €

…with congestion in public transport, …

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)

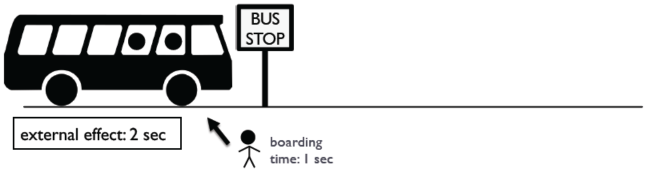


Figure 2: External effect 1

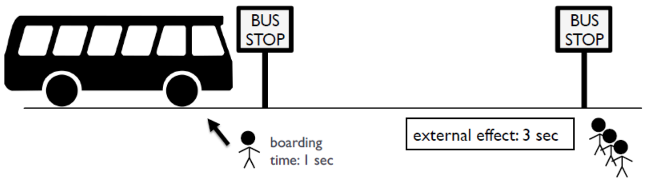


Figure 3: External effect 2

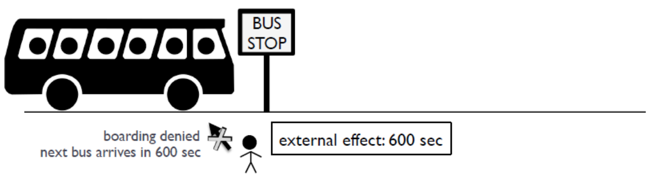
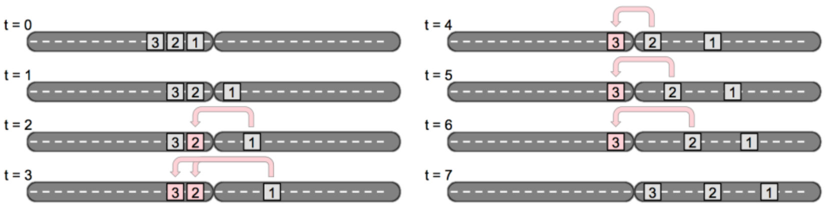


Figure 4: External effect 3

…congestion for private cars, …

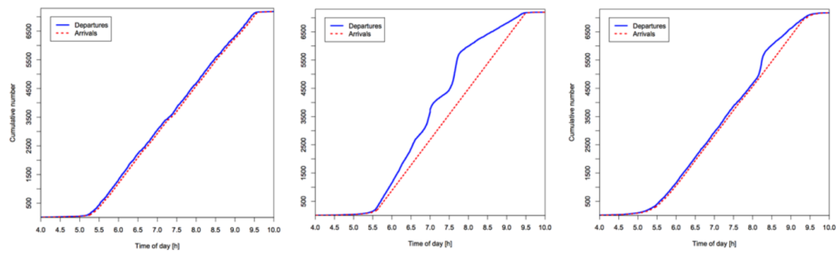
Calculating time losses of car users; identifying the responsible agent(s) and charging them accordingly

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)

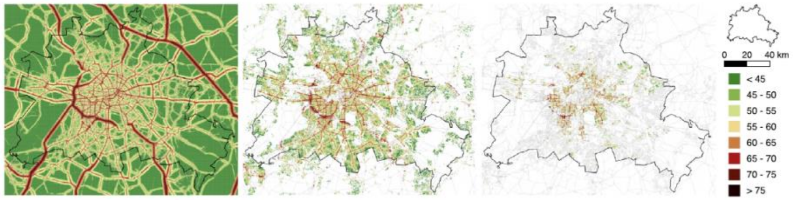


(b) LP, controller A; (similar for controller B)   (c) QCP, pre-existing approach   (d) QCP, approach = a/b

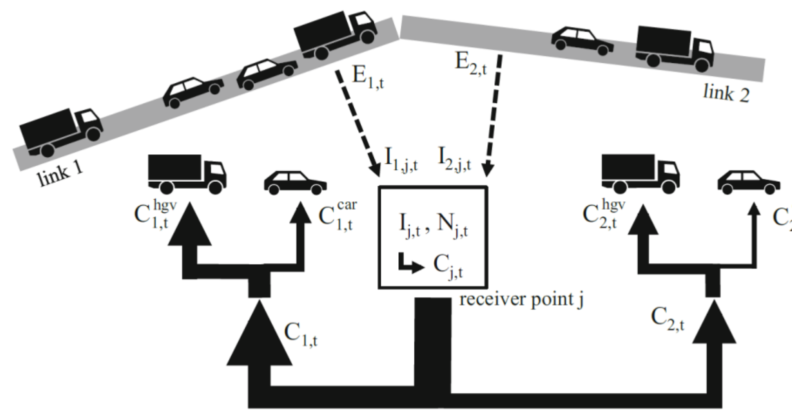
…noise damages, …

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

Kaddoura, Kröger and Nagel (2017a)



(a) all receiver points (b) > 0 affected agent units (c) > 50 affected agent units



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.

Study	Car congestion	PT congestion	Air pollution Flat	Air pollution Exposure	Noise	Accidents
Agarwal and Kickhöfer (2014, 2015, 2016)	x		x	--		
Kaddoura and Nagel (2017b)	x				x	
This study (paper #21)	x		--	x	x	

Follow
https://www.researchgate.net/project/Investigating-the-use-of-simulated-dynamic-pricing-to-optimize-transport-systems
to find references and updates.

Case studies and results of CNA internalization approach

Real-world case studies

Greater Berlin Area

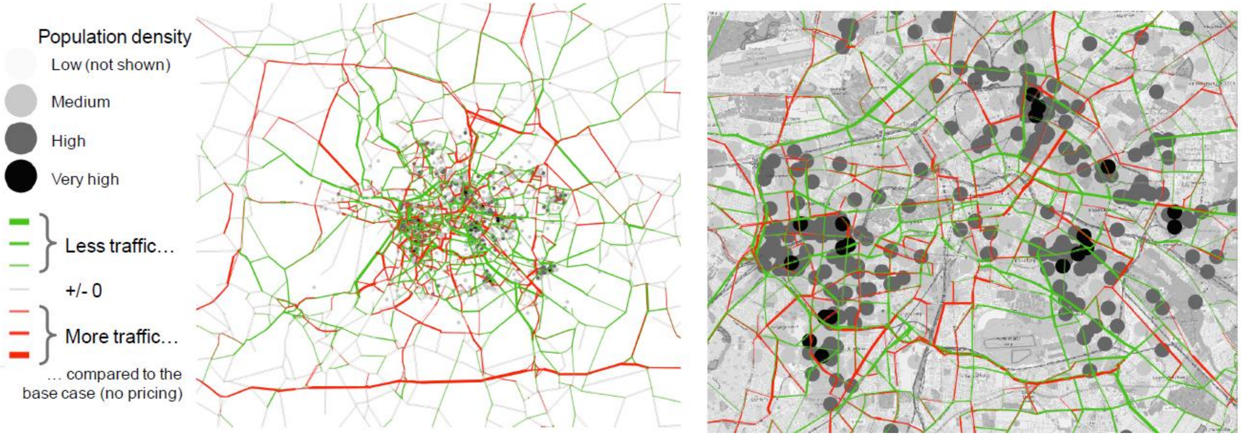
- Transport network: major roads
- Travel demand (1% sample):
  - Synthesized with CEMDAP based on Census 2011 data, commuters as O-D from German Federal Employment Office, and calibrated with Cadyts; validated against SrV 2008
  - No freight traffic
- Open data scenario, available through https://svn.vsp.tu-berlin.de/repos/public-svn/matsim/scenarios/countries/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

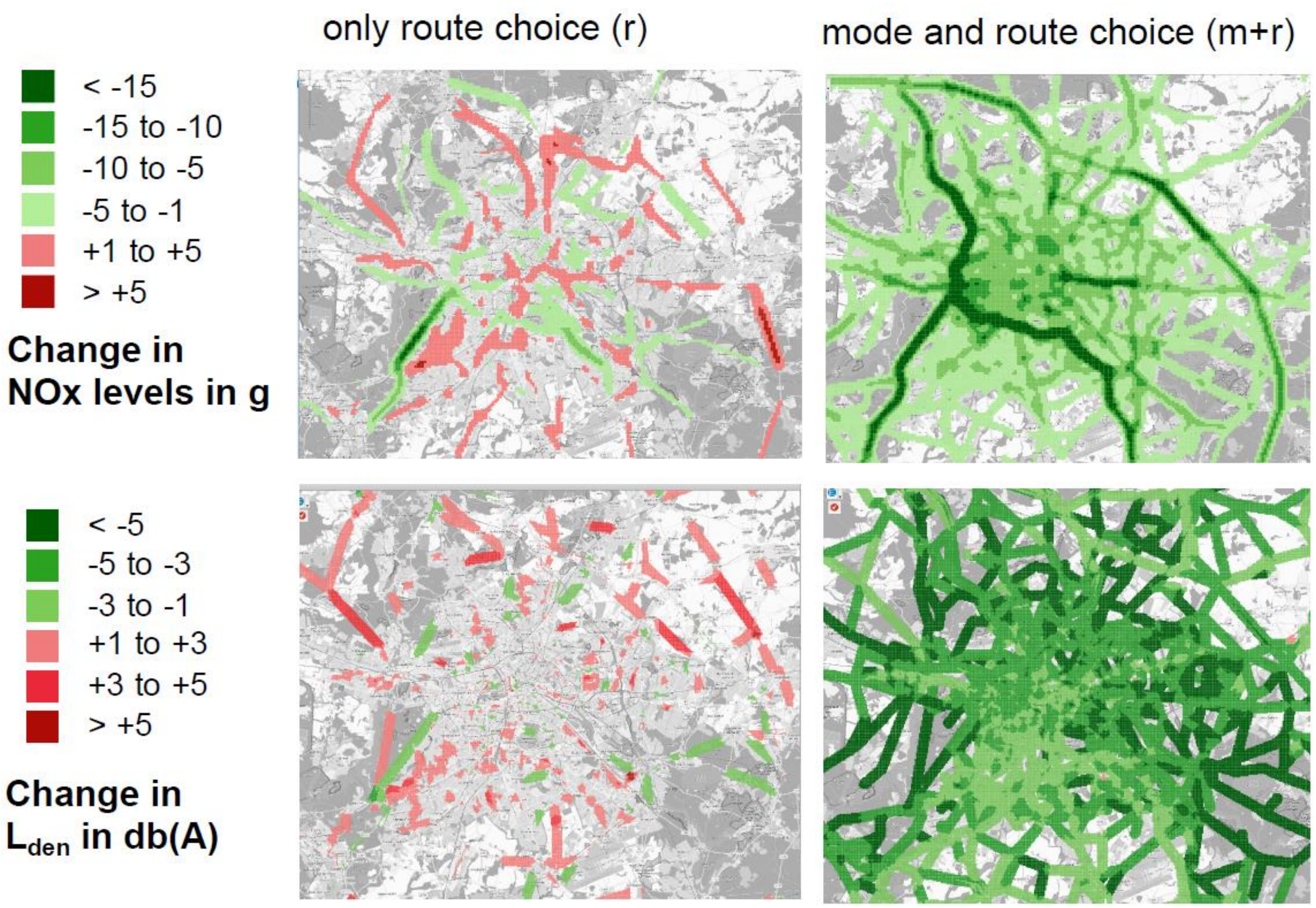
Results CNA: Exposure minimization through new routes

Berlin



Munich

Results CNA: Change in externalities for Berlin



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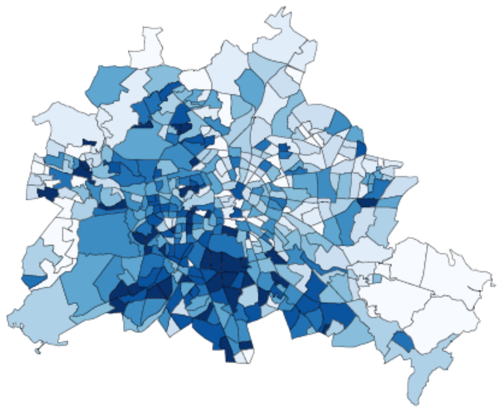
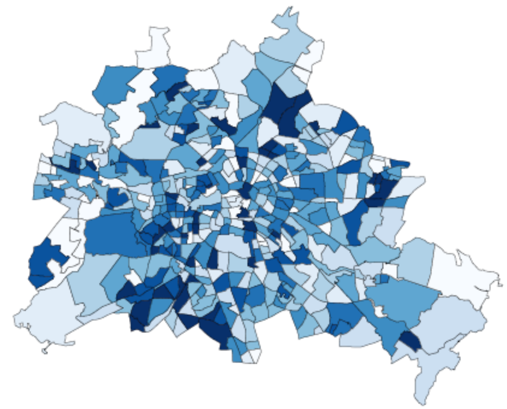
Results CNA: Who are the bad guys in Berlin?

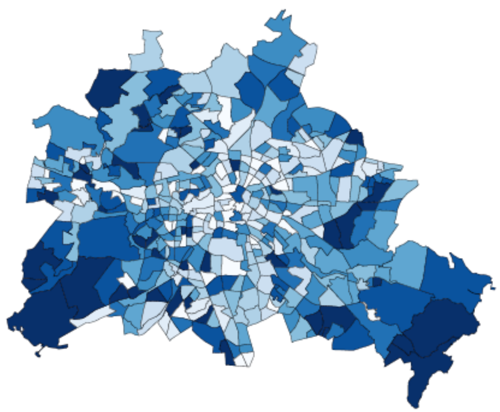
Route choice



(a) Congestion toll payments



(b) Noise toll payments

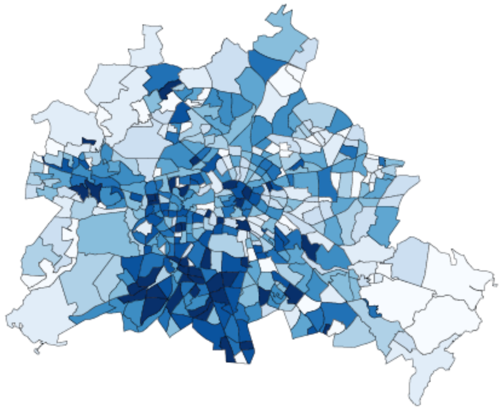


(c) Air pollution toll payments

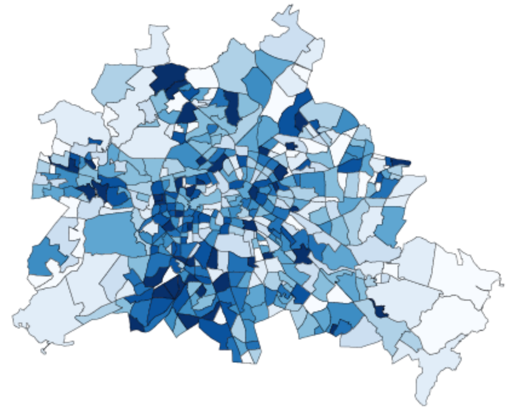
- 1st decile
- 2nd decile
- 3rd decile
- 4th decile
- 5th decile
- 6th decile
- 7th decile
- 8th decile
- 9th decile
- 10th decile

Results CNA: Who are the bad guys in Berlin?

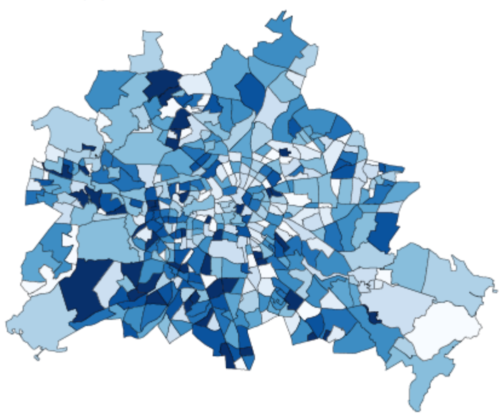
Mode and route choice



(a) Congestion toll payments



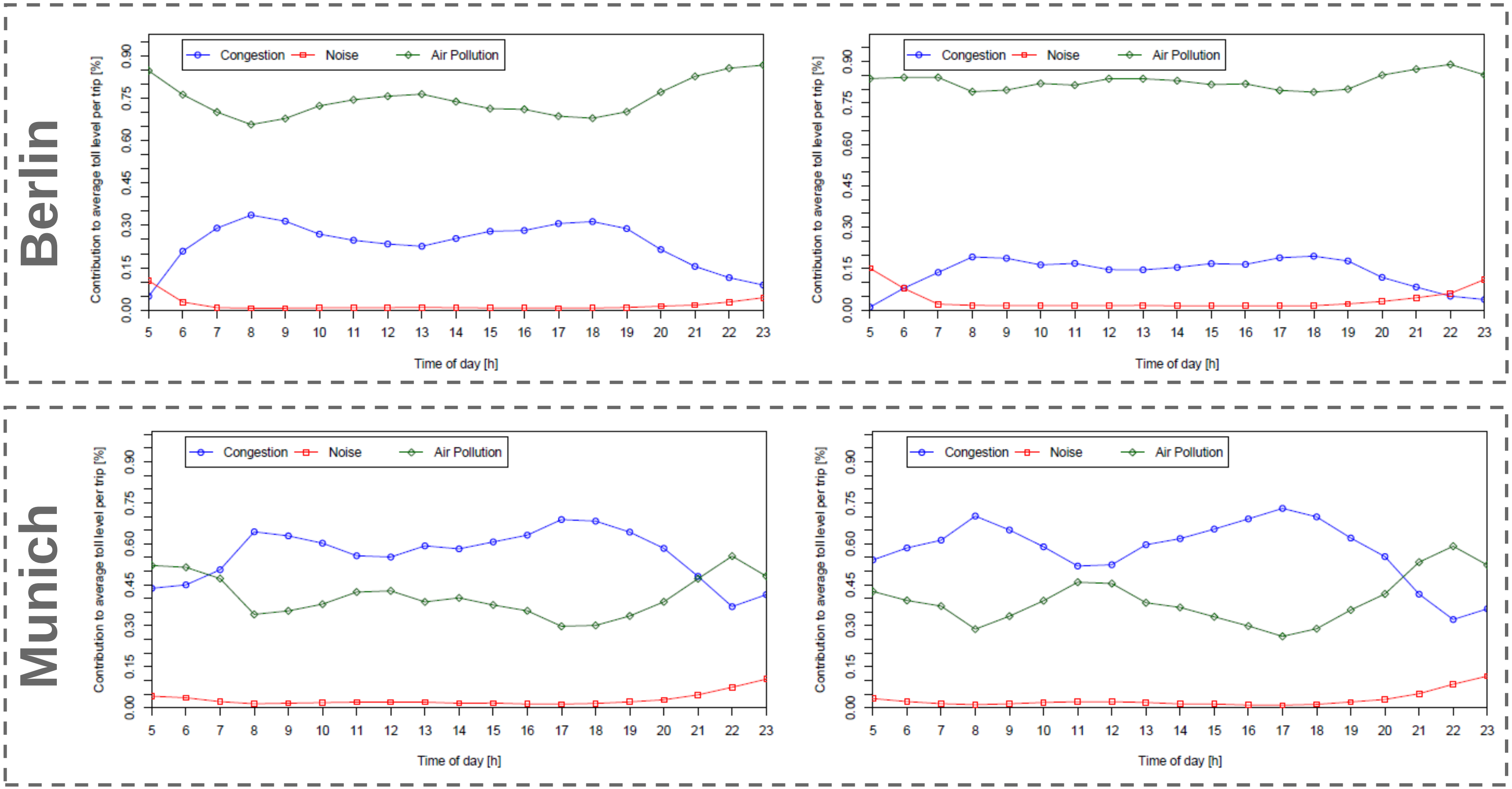
(b) Noise toll payments



(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: 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

Change in…	C	N	A	CNA
delay [h]	-44,225	7,336	32,246	-18,455
noise costs [EUR]	153	-2,257	769	-532
air pollution costs [EUR]	449,879	451,934	-1,081,635	-1,107,170
toll revenues [EUR]	5,879,058	254,470	16,757,374	23,112,233
system welfare [EUR]	-103,843	-907,807	-28,071	909,422

Route and mode choice

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

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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

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Thank you.

Backup

Results: mode switchers

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

		Contribution of each external effect			
	Considered users	Congestion	Noise	Air pollution	$\sum$
Average toll per trip	Car retainers	0.57	0.02	1.45	2.05
Average toll per trip	Car to non-car switchers	1.40	0.06	3.96	5.42

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

		Contribution of each external effect			
	Considered users	Congestion	Noise	Air pollution	$\sum$
Average toll per trip	Car retainers	2.11	0.06	1.33	3.50
Average toll per trip	Car to non-car switchers	2.89	0.12	1.55	4.55

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)