Autonomous car- and ride-sharing systems: A simulation-based evaluation of various supply options for different regions

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Agenda

- Motivation
- Methodology
- Results
  - Reference scenario Autonomous Car Sharing
  - Sensitivity analyses for Autonomous Car Sharing
    - Alternative specific constant
    - Cost Structure
  - Comparison of Autonomous Car Sharing and Autonomous Ride Sharing
- Conclusion and Outlook

Motivation

Motivation

- Introduction of autonomous vehicles within next years / next decades
  - Privately owned vehicles
  - Autonomous car-sharing systems (ACS)
    and autonomous ride-sharing systems (ARS)

- Different interests of different stakeholders

- Uncertainty of the acceptance by the users

- Sketch planning to narrow down the extent of possible effects

Methodology

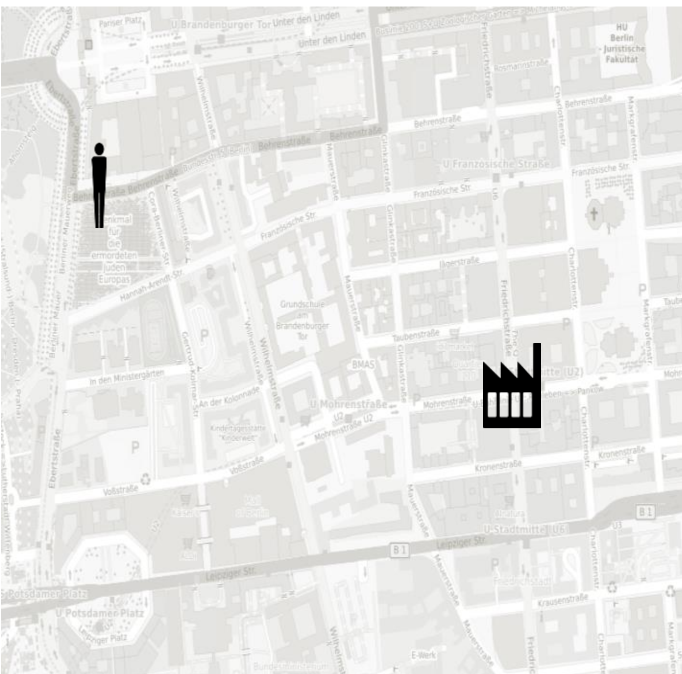
Simulation approach: Aspatial travel demand model

- based on MiD data (60k persons , 190k trips)
- generation of attributes of non-chosen mode alternatives (among them ACS/ARS)
- multinomial logit mode choice model (probability p_i for mode i)
  $p_i = \frac{e^{V_i}}{\sum_j e^{V_j}}$ for mode $i \in j$ with $j = \left\{walk, bike, car, pt, \frac{ACS}{ARS}\right\}$ with $V_i = ASC_i + \beta_{gc} * gc_i$
- no physical road network → no capacity restraint functions

For details see Trommer et al. (2016)

DLR

Autonomous Car Sharing (ACS)



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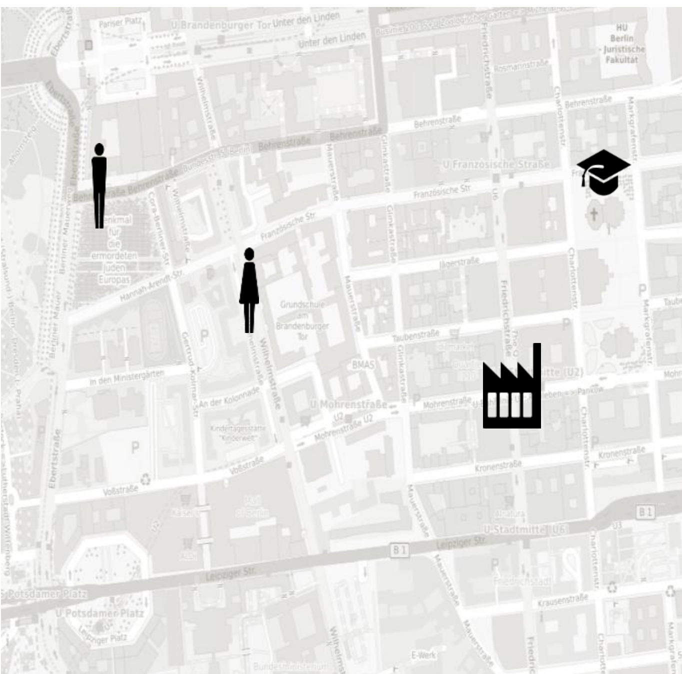

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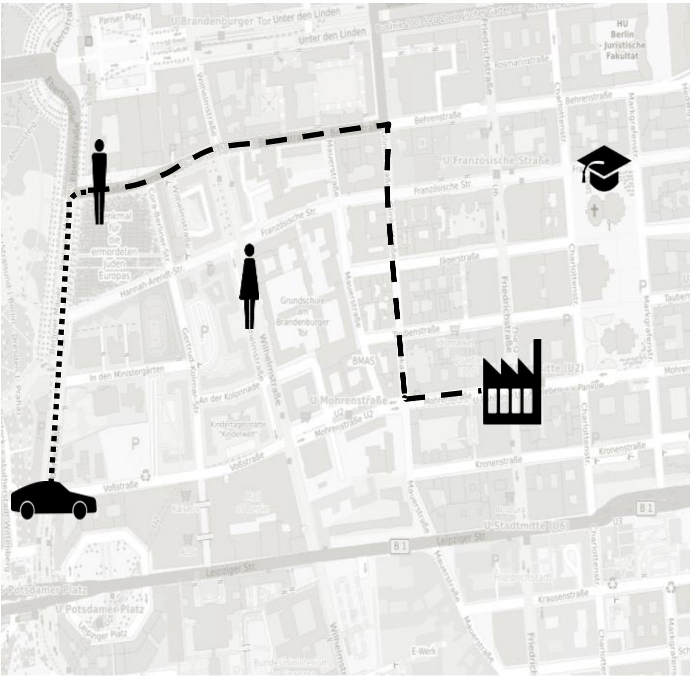

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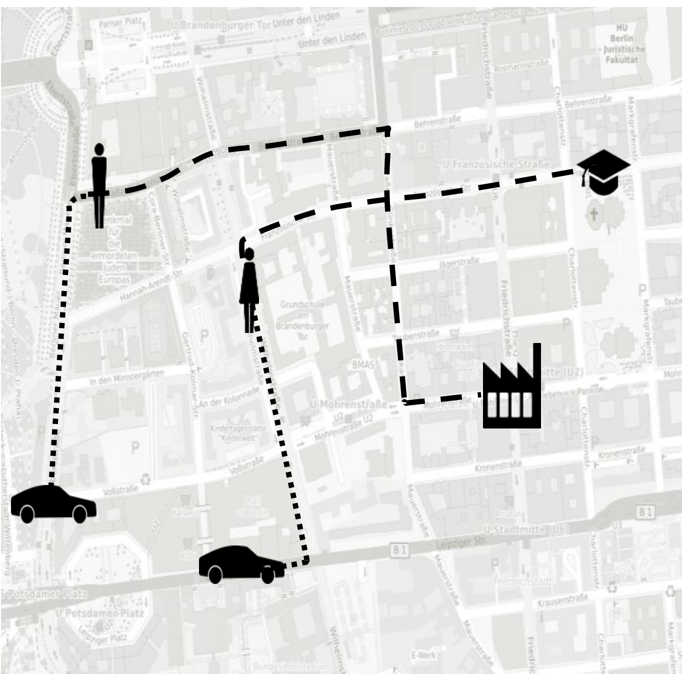

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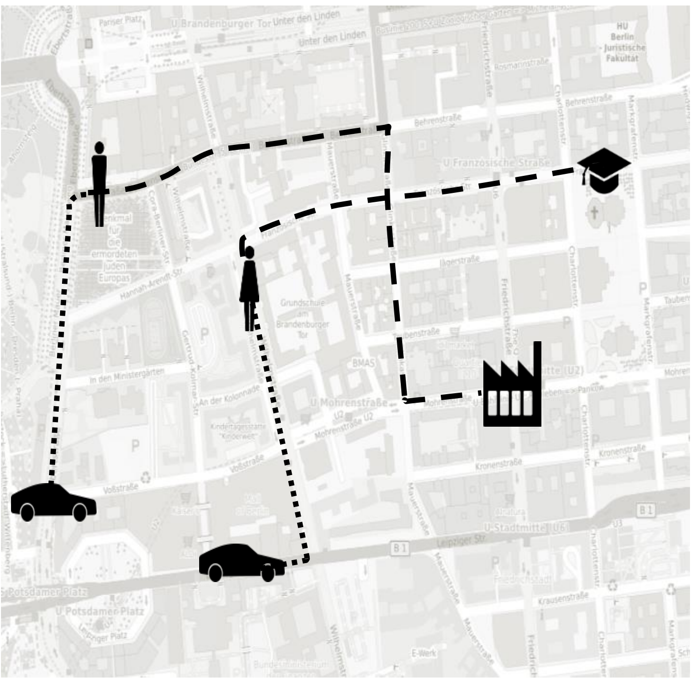

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	ACS	
Shared Vehicles	√	
Shared Rides		
Detours possible		
Empty rides possible	√	
Division of costs between users		

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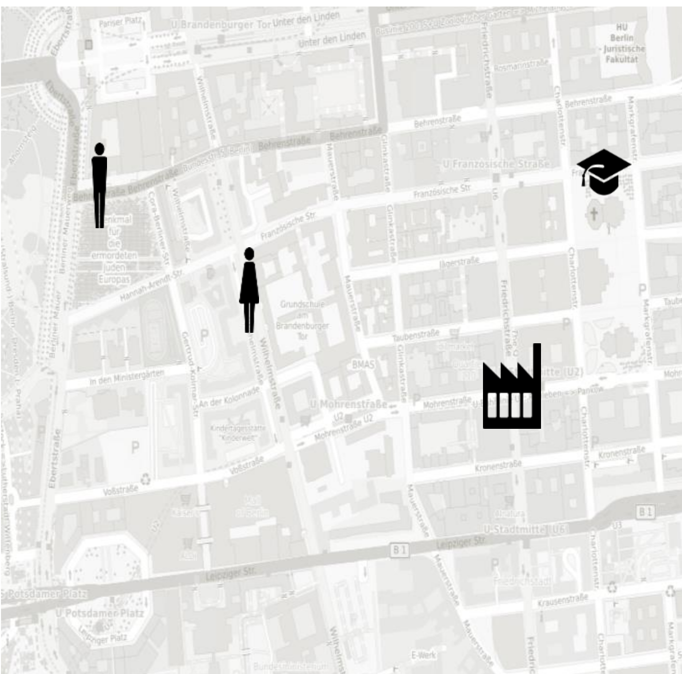

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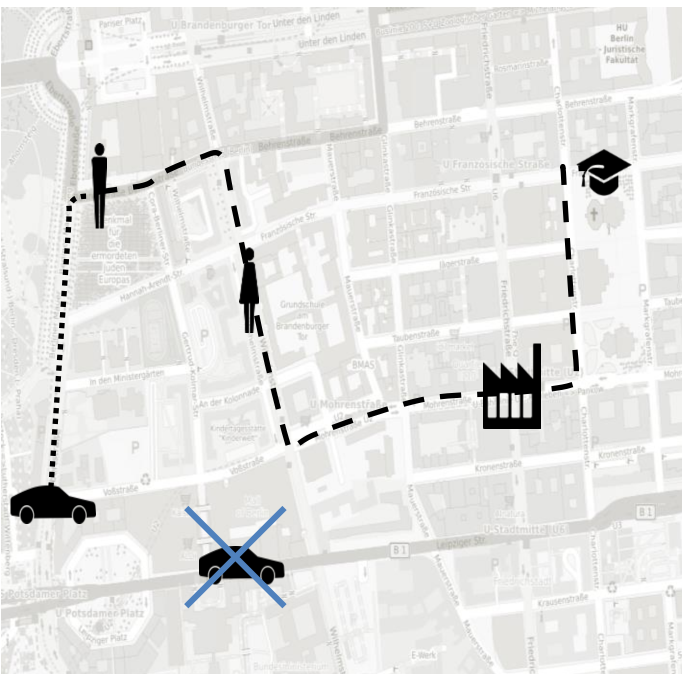

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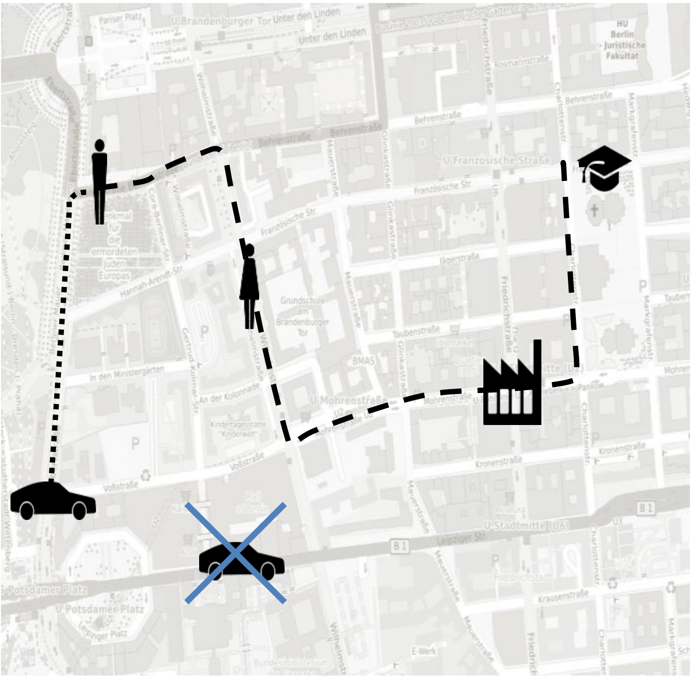

	ACS	ARS
Shared Vehicles	√	√
Shared Rides		√
Detours possible		√
Empty rides possible	√	√
Division of costs between users		√

Methodology: Grid search

- Grid search for different user price-fleet density-combinations
- Analysis of operator profit, mode shares, VKT, …

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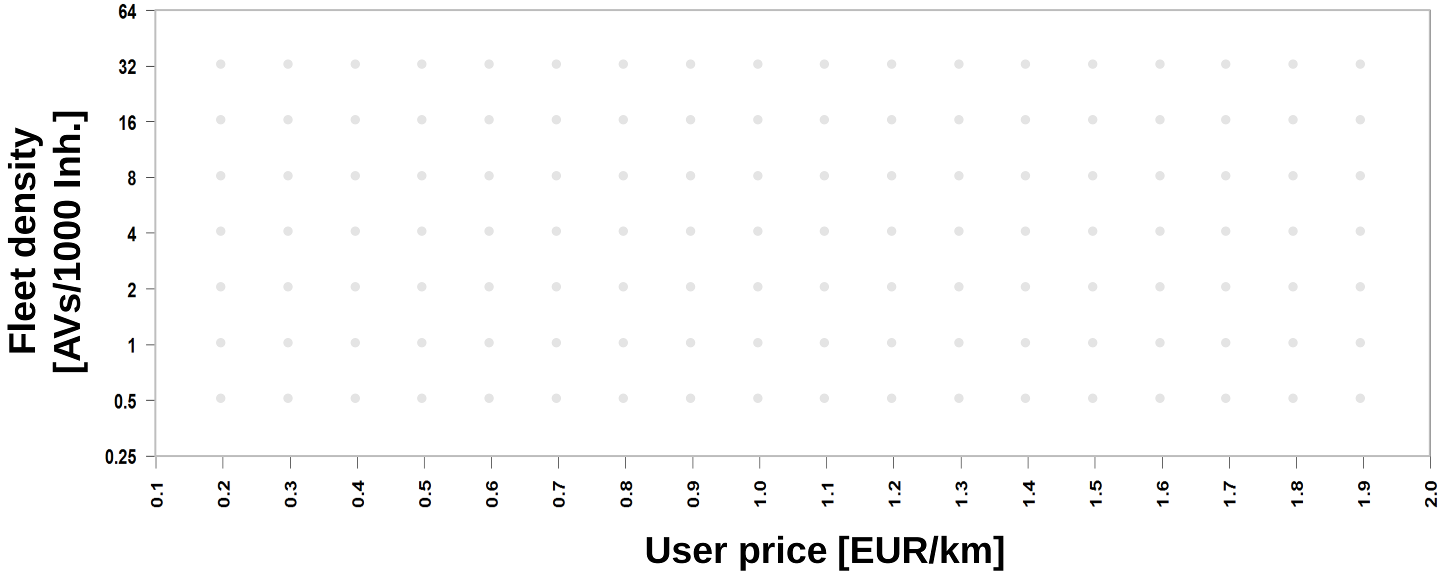
- Analysis of operator profit, mode shares, VKT, …

- Identification of two cases:
    1. **ZP: Zero-profit monopoly** → operator profit = 0
        - Breaking-even-point (comparable to an oligopoly-situation)
        - Min. user price (comparable to an oligopoly-situation)
    2. **UM: Unregulated monopoly** → max. profit
        - Max. Operator profit ($\Pi_{operator} = R_{operator} - C_{operator}$)

- Constraint: Vehicle usage rate < 50% (operationally feasible)

Methodology: Grid search



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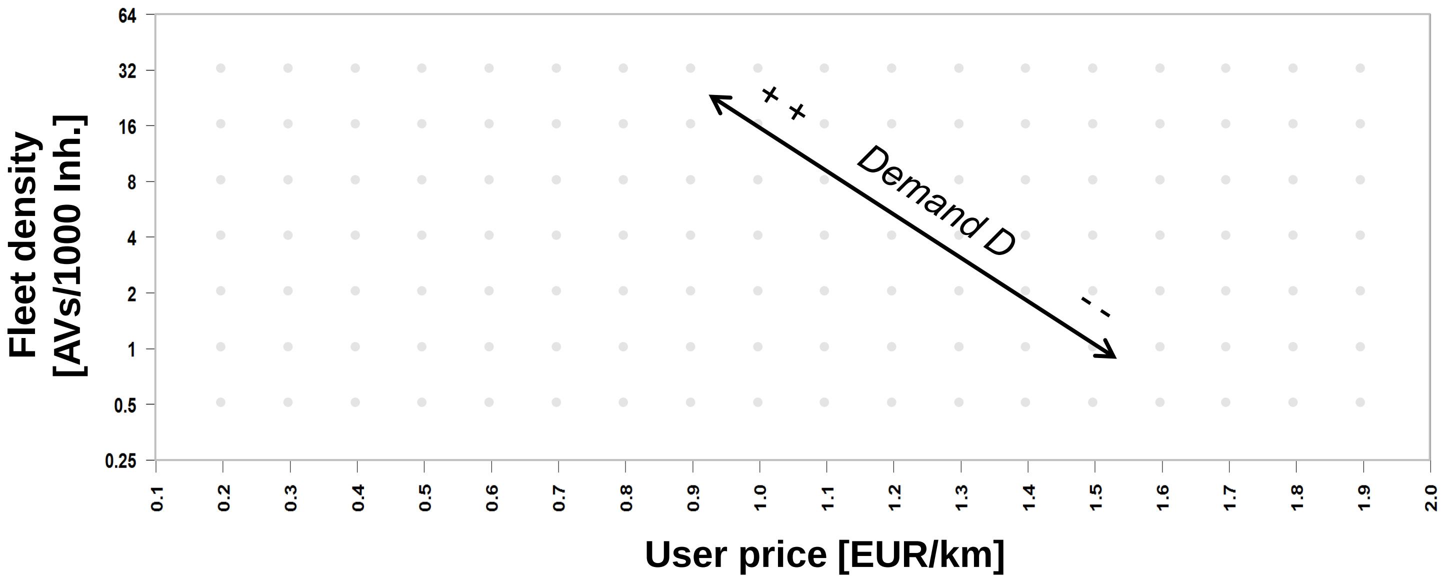

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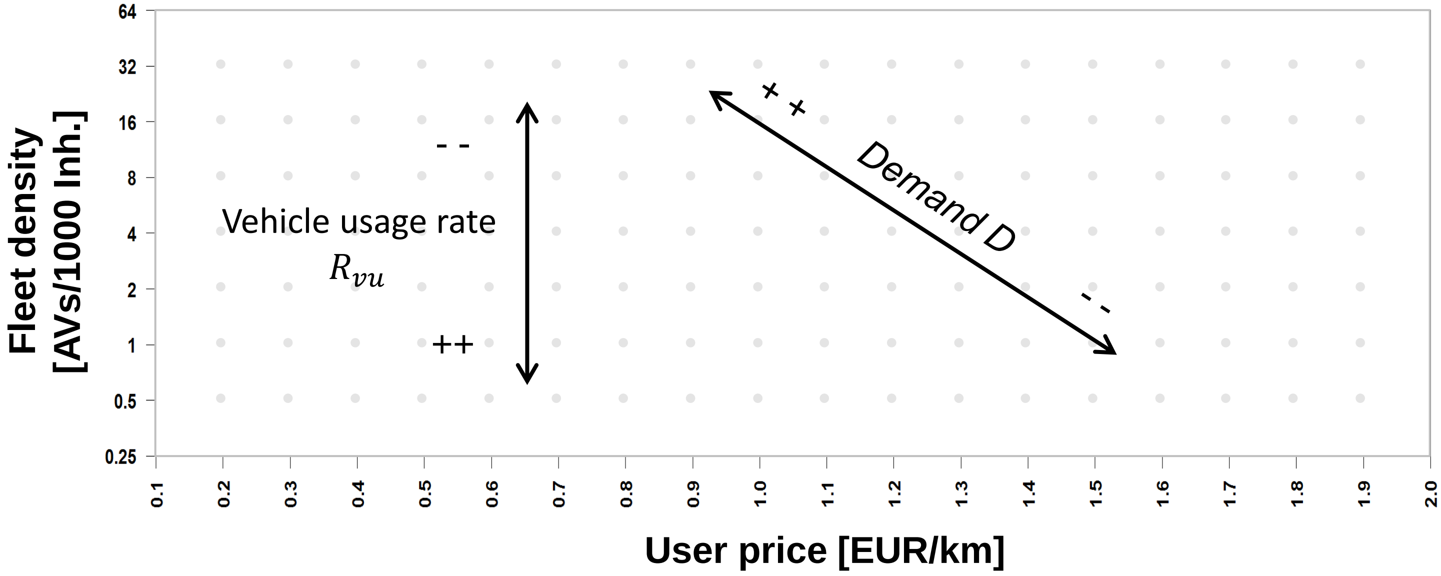
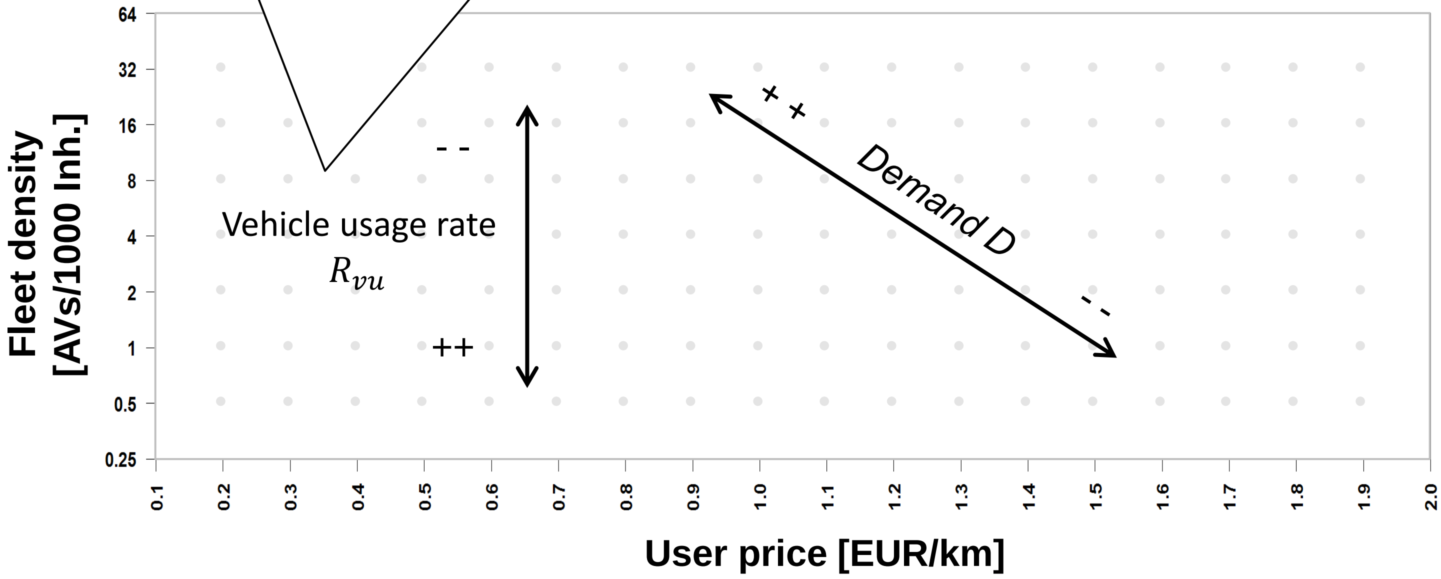


Methodology: Grid search

$$R_{vu} = \frac{(T_{empty} + T_{loaded})}{24\ h}$$

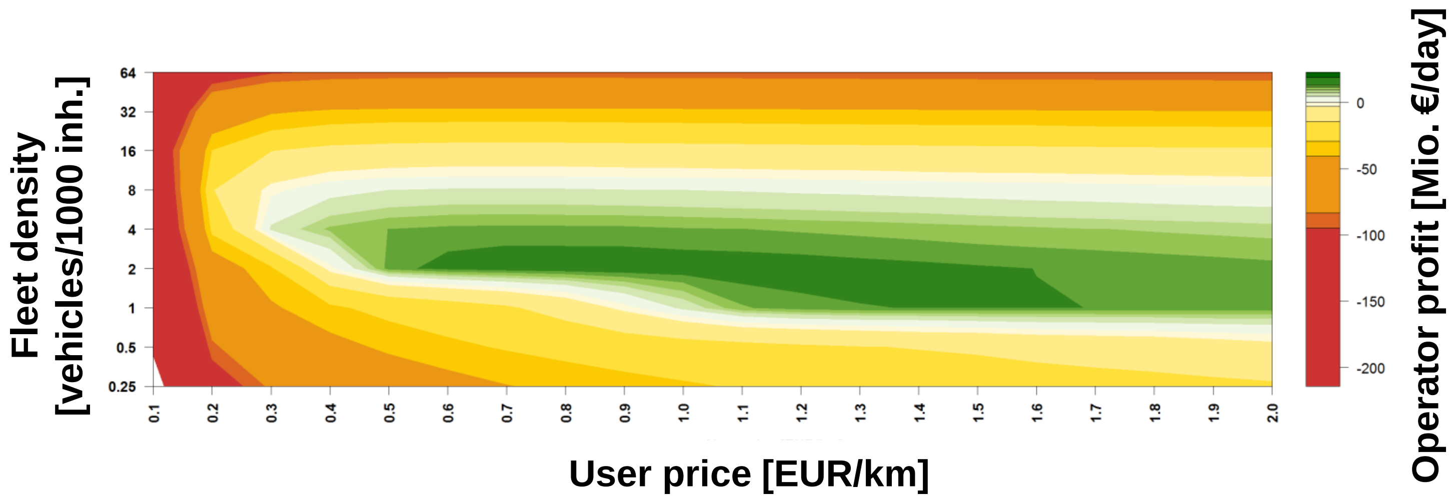
With: T_{empty} ... time for empty rides per day $[h]$

T_{loaded} ... time for loaded rides per day $[h]$



Reference scenario

ACS: Results reference scenario



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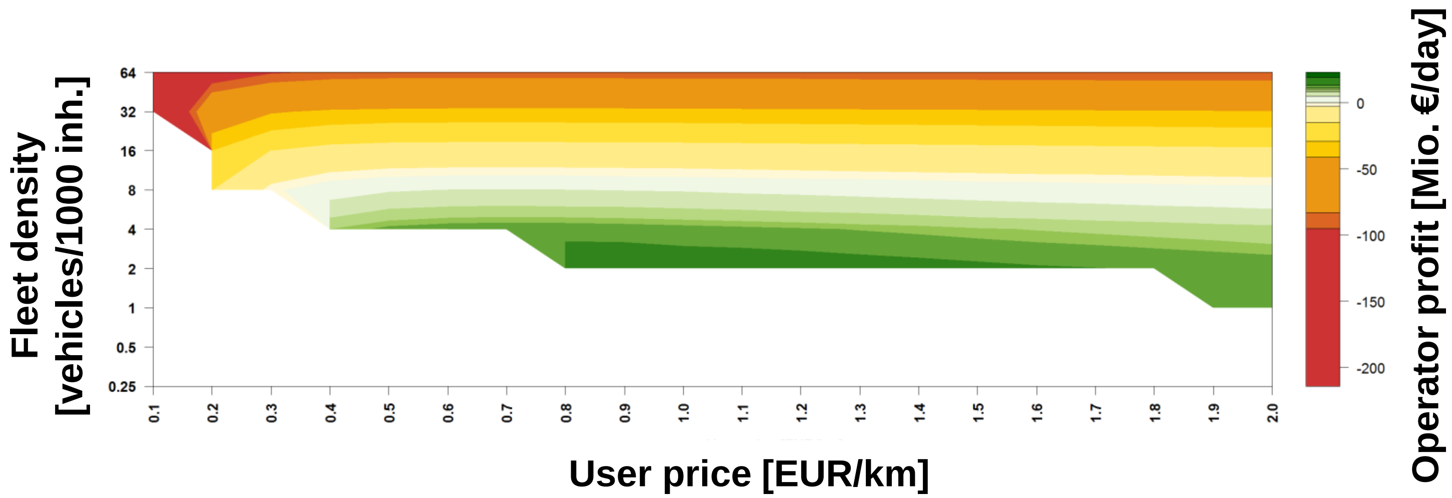

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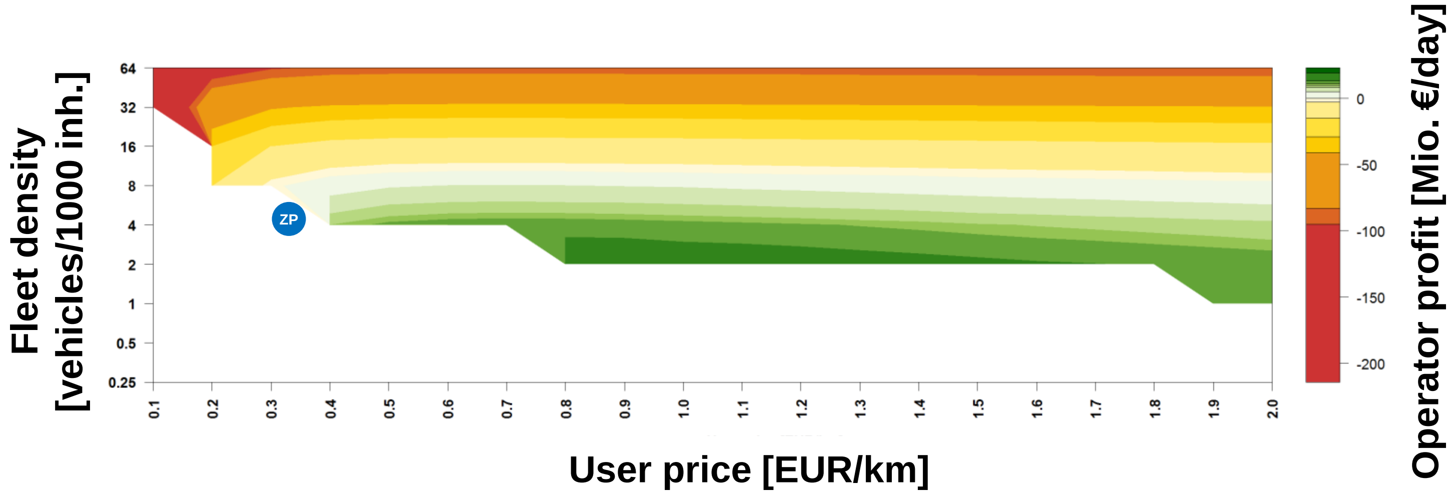

- ZP: 0.33 €/user-km / 4.50 vehicles/1000 inhabitants

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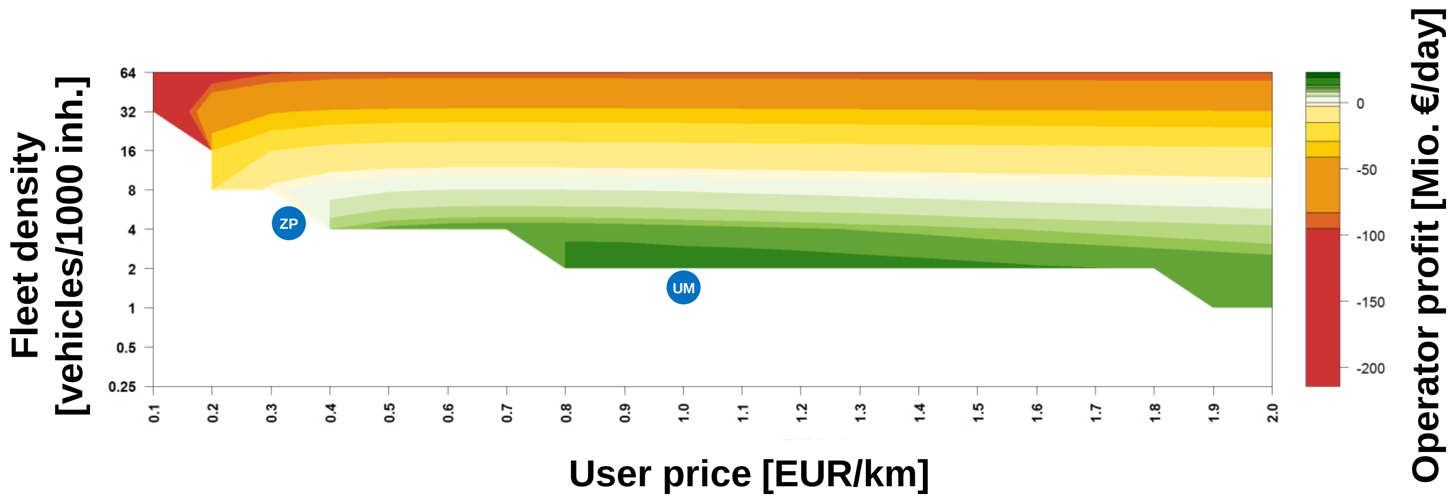

- ZP: 0.33 €/user-km / 4.50 vehicles/1000 inhabitants
- UM: 1.00 €/user-km / 1.55 vehicles/1000 inhabitants

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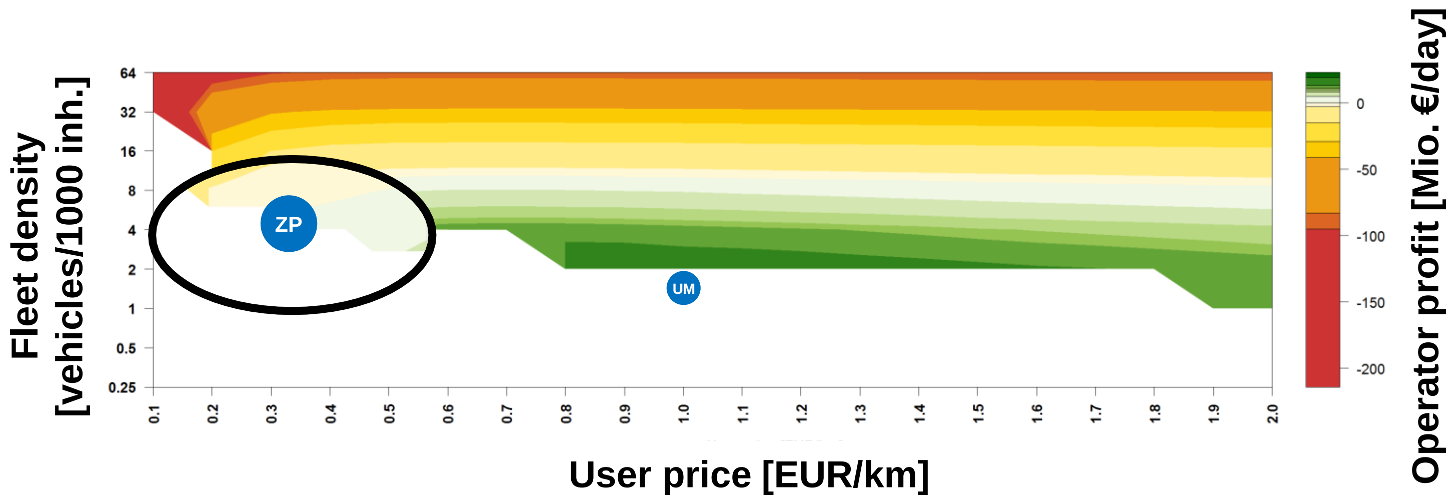

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Sensitivity analyses for ACS

Sensitivity analyses for ACS: Alternative specific constant

- Mode choice model takes into account for valuation of mode alternatives:
  - Travel time and access & egress times (based on fleet density)
  - Travel costs (based on user price)
  - Mode specific constant (alternative specific constant – ASC)

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→Variation of ASC (in relation to car- and pt-ASC)

- Higher ASC: $ASC_{ACS} = ASC_{pt} + 0.75 * (ASC_{car} - ASC_{pt})$
- Reference scenario: $ASC_{ACS} = ASC_{pt} + 0.50 * (ASC_{car} - ASC_{pt})$
- Lower ASC: $ASC_{ACS} = ASC_{pt} + 0.25 * (ASC_{car} - ASC_{pt})$

DLR

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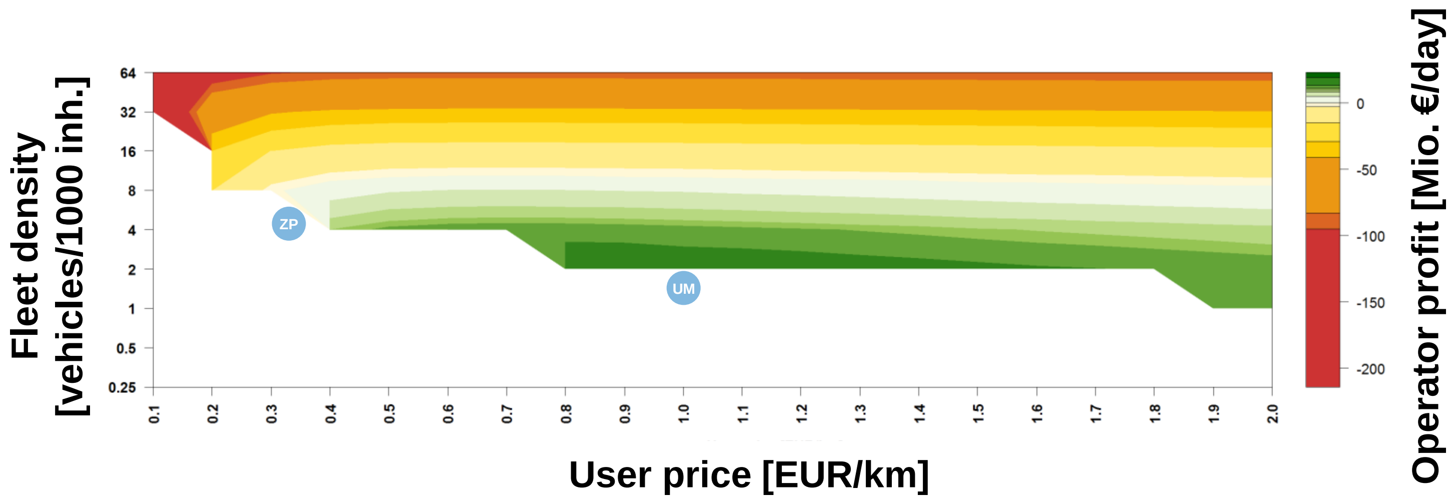
Sensitivity analyses for ACS: Alternative specific constant

→Which effects can be observed?

- Operator profit
- ZP and UM move
- Mode shares
- Total VKT on road

Sensitivity analyses for ACS: Alternative specific constant (higher value)



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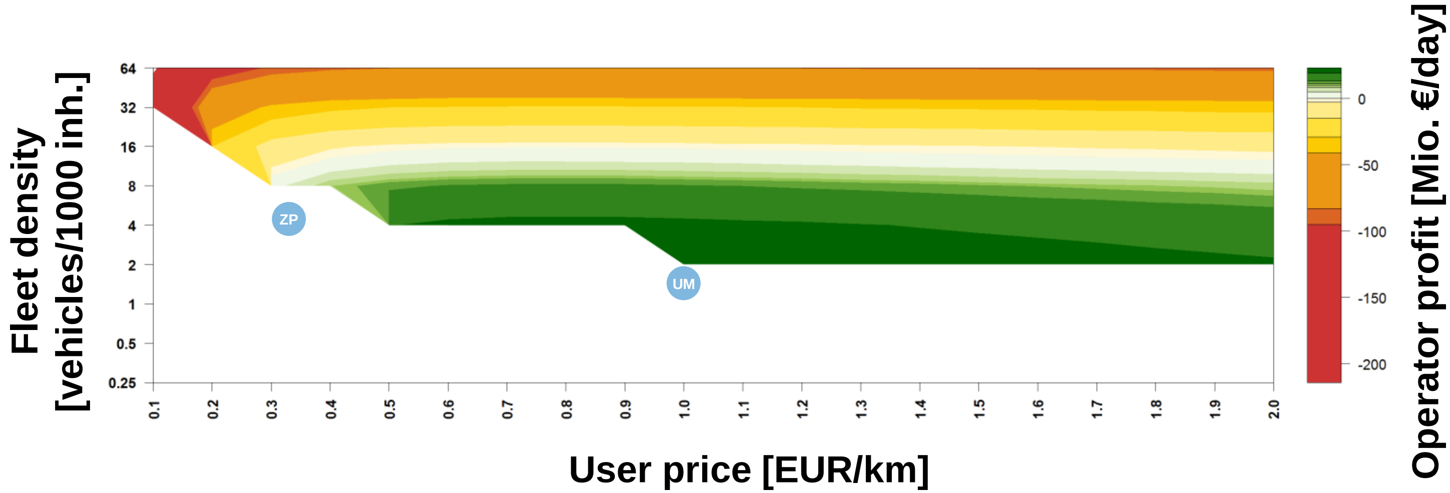

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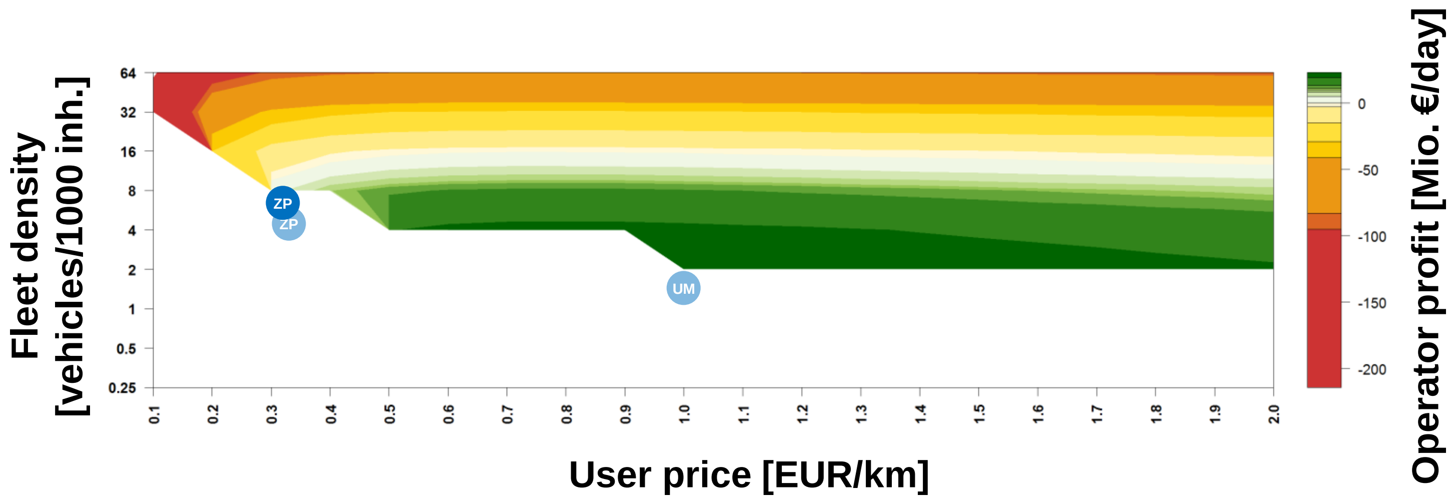

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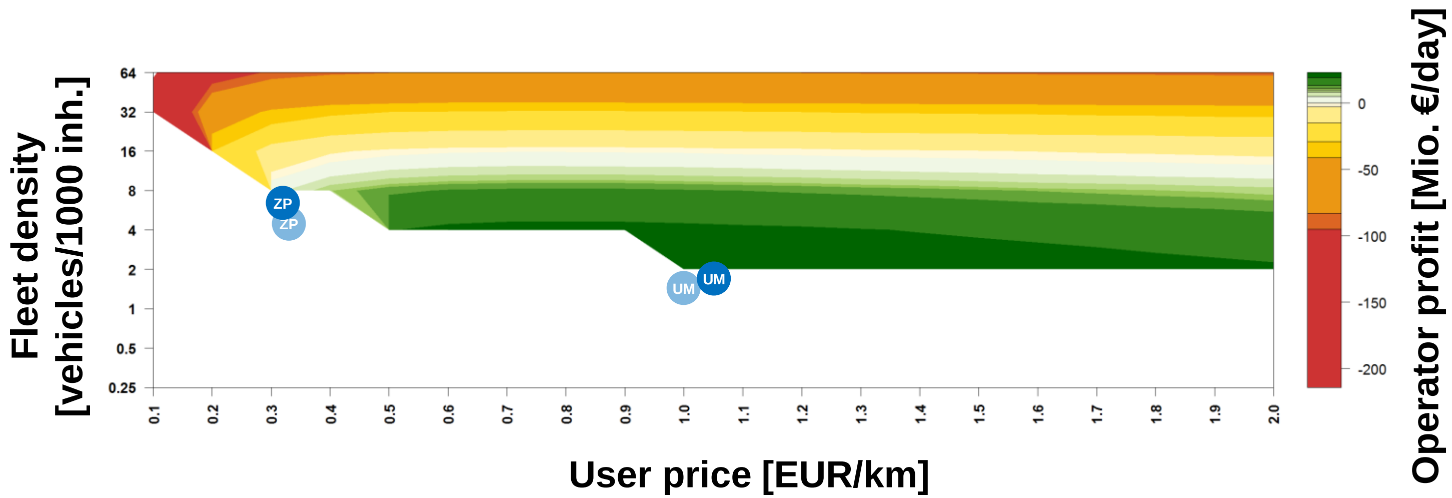
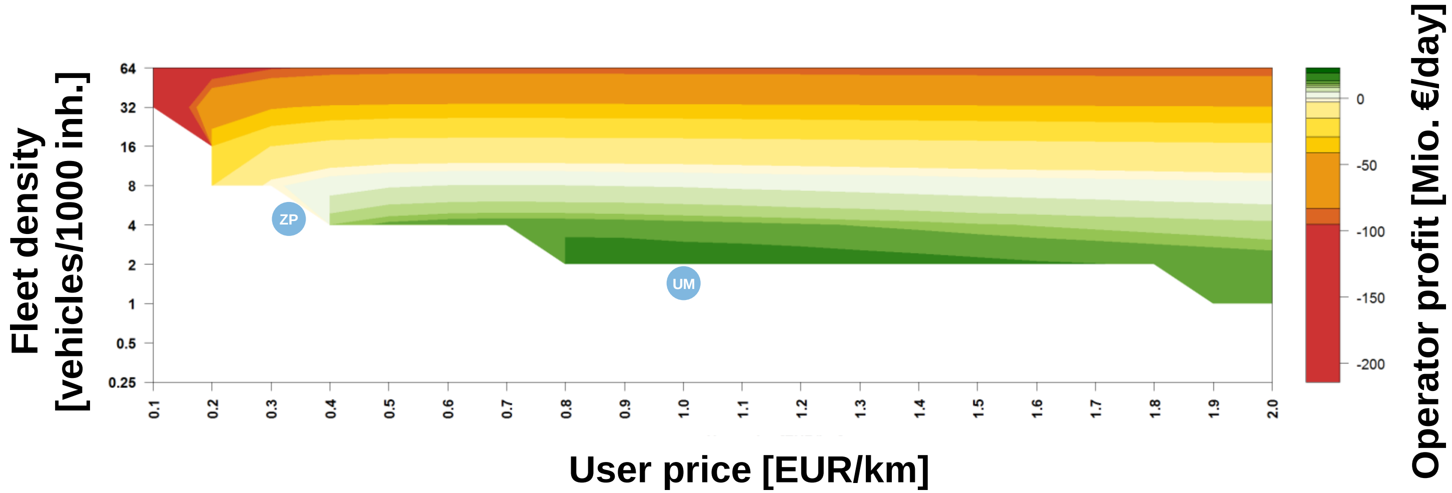


- ZP: 0.32 €/user-km / 6.00 vehicles/1000 inhabitants
- UM: 1.05 €/user-km / 1.75 vehicles/1000 inhabitants

Sensitivity analyses for ACS: Alternative specific constant (lower value)



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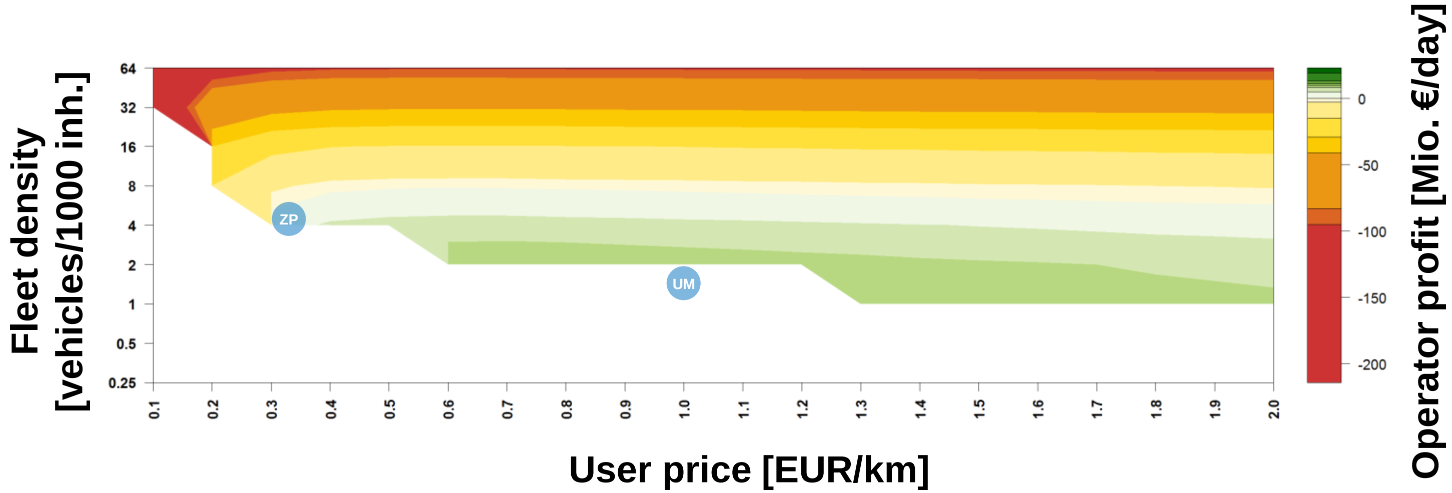

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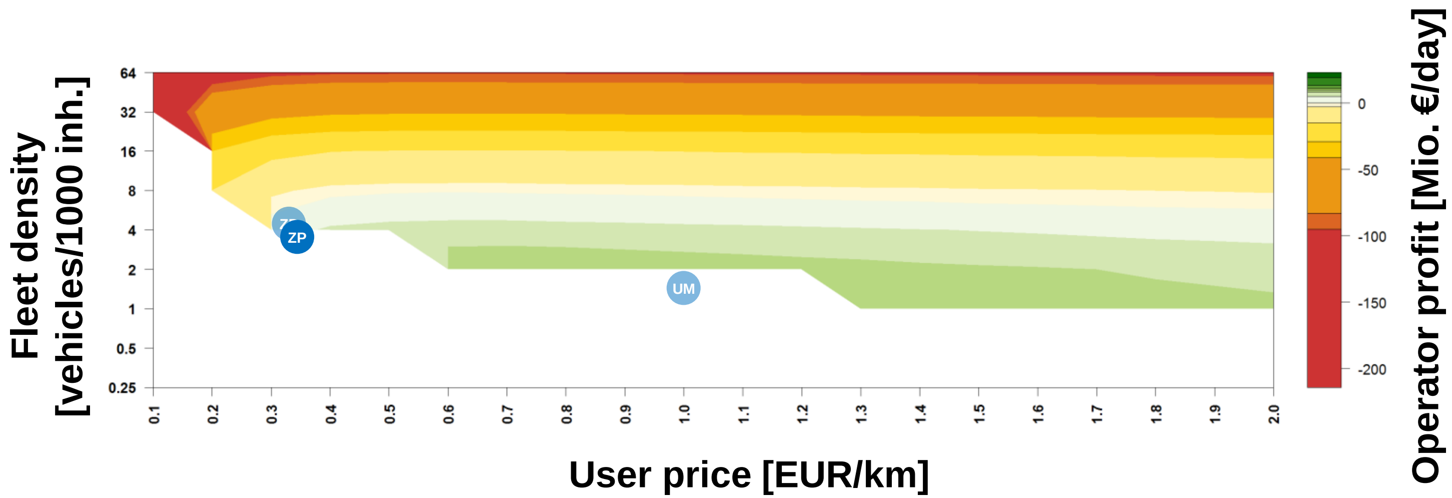

- ZP: 0.34 €/user-km / 3.50 vehicles/1000 inhabitants

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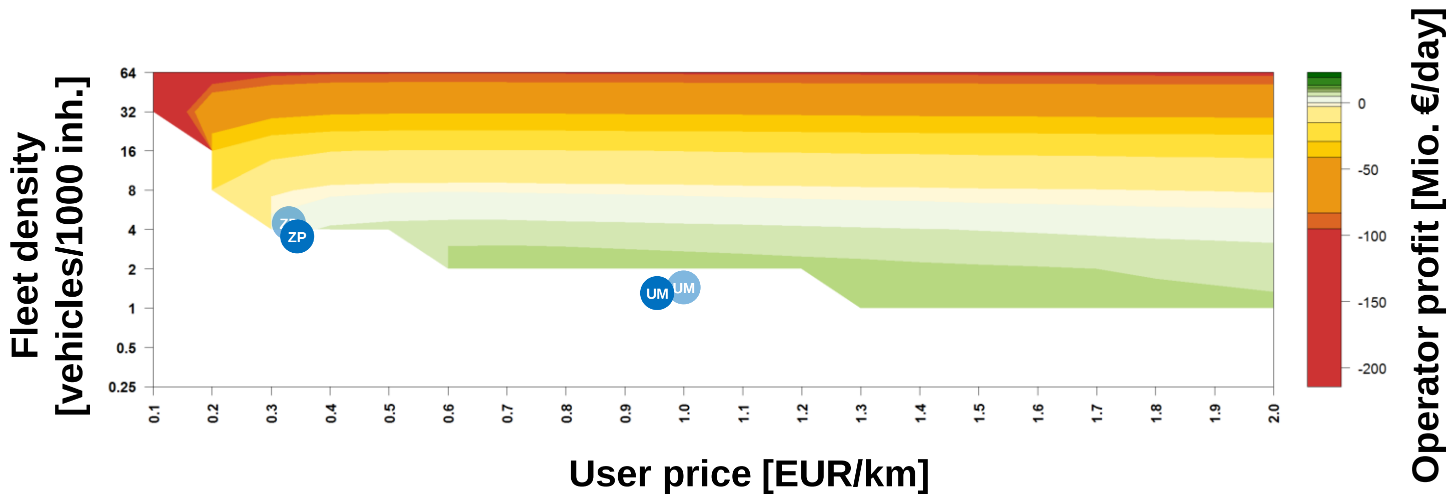

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Sensitivity analyses for ACS: Alternative specific constant

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Scenario	User price [€/km]	Fleet density [veh / 1000 inh.]	Operator profit Π p.d. [Mio. €]	ACS mode share	Change of VKT (relative to no-ACS case)
Higher ASC	0.32	6.00	~0	14.7 %	+ 4.8 %
Reference scenario	0.33	4.50	~0	10.6 %	+ 3.7 %
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Scenario	User price [€/km]	Fleet density [veh / 1000 inh.]	Operator profit Π p.d. [Mio. €]	ACS mode share	Change of VKT (relative to no-ACS case)
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DLR

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Depreciation & Interest [€/veh-km]	0.12	0.092
HR, Vehicle Operations etc. [€/veh-km]	0.035	0.12
Cleaning, Maintenance, Insurance, Vehicle Tax, Parking [€/veh-km]	0.05	0.155
Fuel/Electricity [€/veh-km]	0.075	0.066
Profit Margin & VAT [€/veh-km]	0.00	0.044
Total Cost [€/veh-km]	**0.28**	**0.48**

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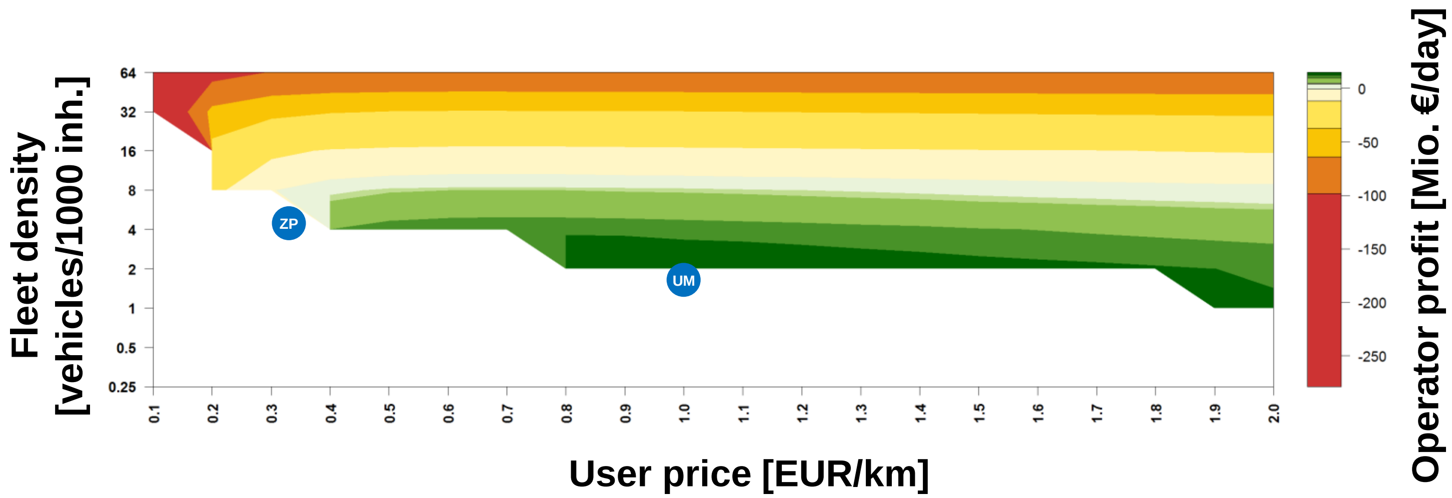
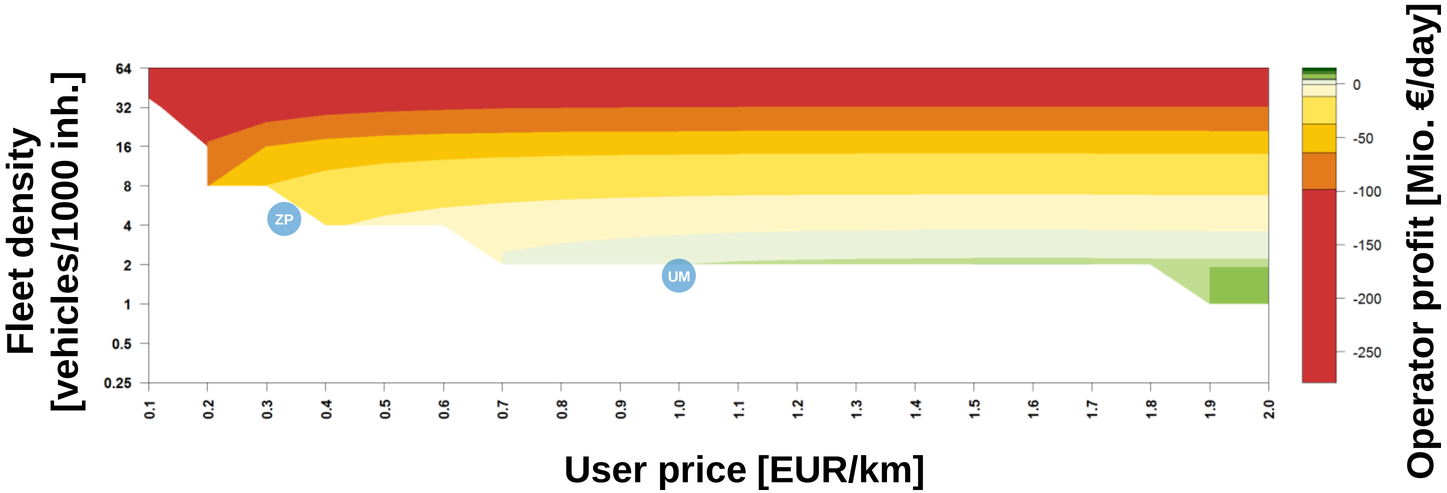


- ZP: 0.33 €/user-km / 4.50 vehicles/1000 inhabitants
- UM: 1.00 €/user-km / 1.55 vehicles/1000 inhabitants
- Low density areas: break-even user price amounts to ~0.40 €/km

Sensitivity analyses for ACS: Cost Structure (ETHZ)



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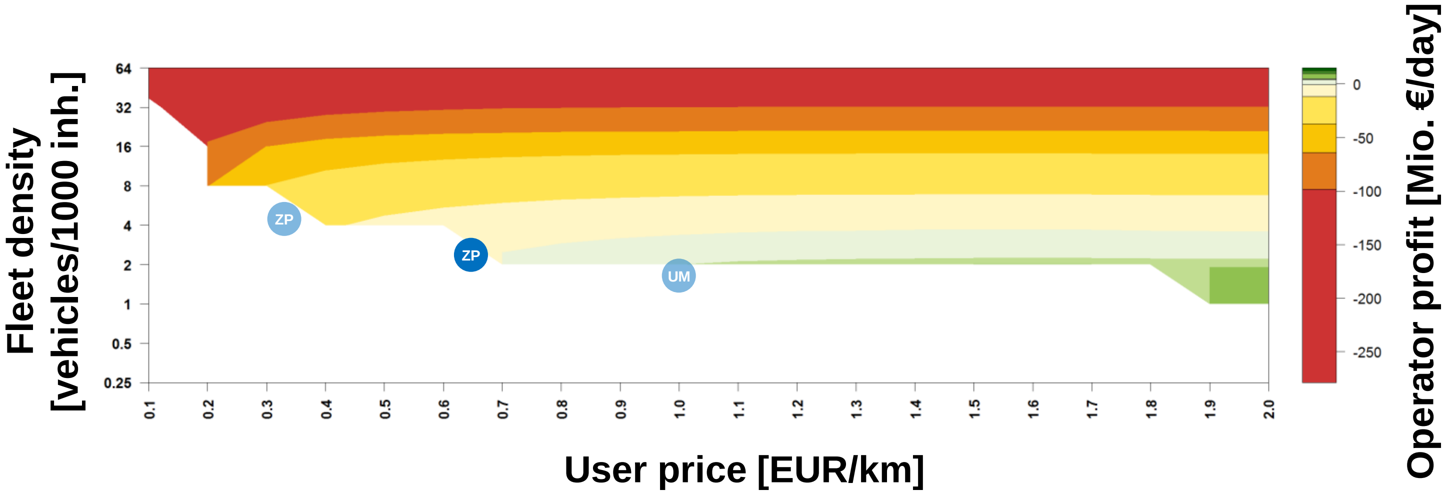
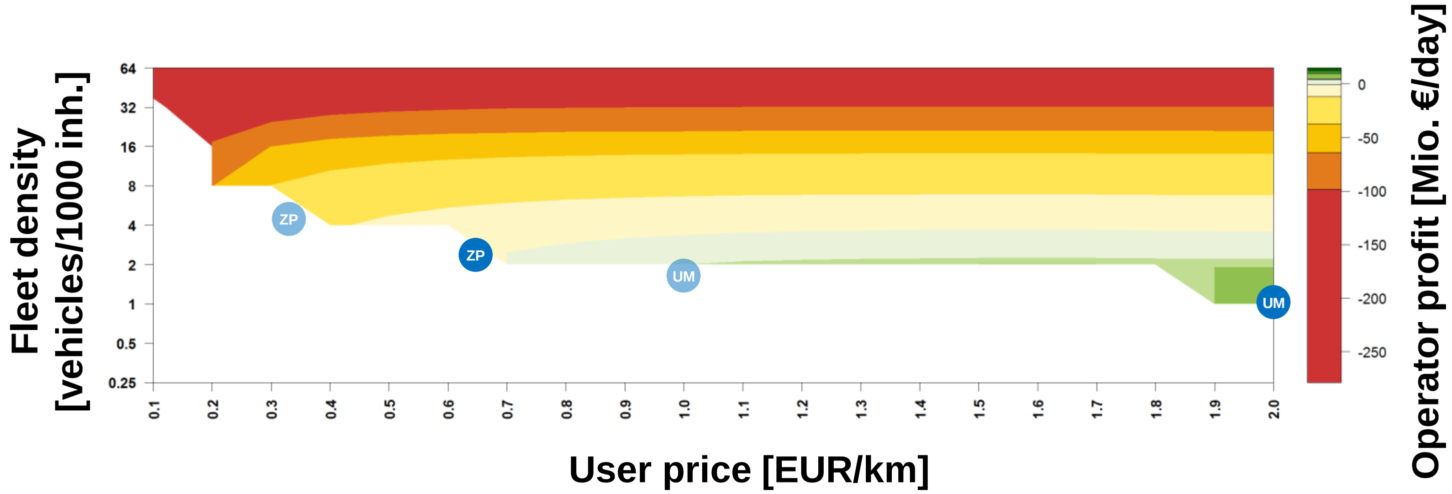


- ZP: 0.64 €/user-km / 2.25 vehicles/1000 inhabitants
- Low density areas: break-even user price amounts to ~1.50 €/km +

Sensitivity analyses for ACS: Cost Structure (ETHZ)



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DLR cost scenario	0.33	4.50	~0	10.6 %	+ 3.7 %
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ETH cost scenario	2.00	1.00	6.8	3.4 %	+ 0.9 %

DLR

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- Average trip length decreases when increasing the user price

DLR

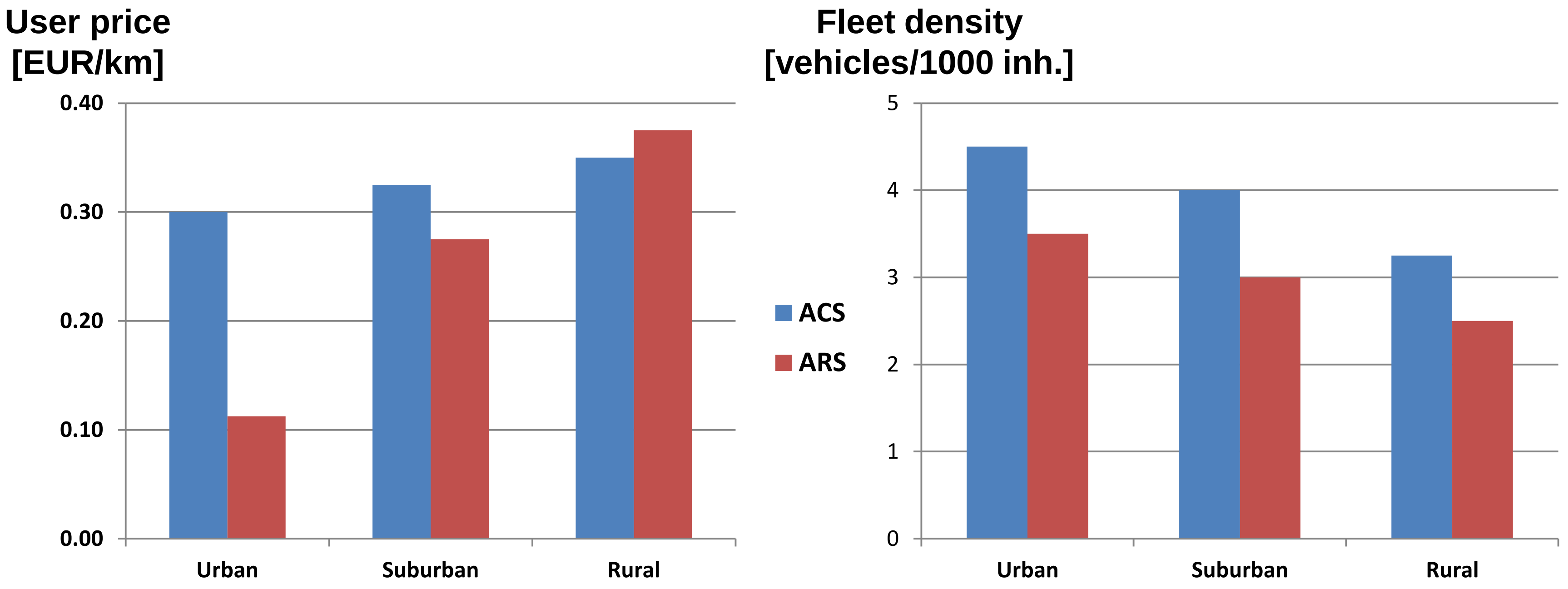
Comparison of ACS and ARS

Comparison of ACS and ARS

- User acceptance may be higher for ACS mode
- User prices may be lower for ARS mode
- Waiting times may be higher for ARS mode
- Travel time may be higher for ARS mode (detour factors)

→What are the user price/fleet size combinations in
(1) Zero-profit monopoly and
(2) Unregulated monopoly ?

Zero profit over different area types



- Spatial differences of user prices are higher for ARS than for ACS
- Reason: high potential of pooling in urban regions at very low user prices

DLR

Zero profit vs unregulated monopoly

1. Zero-profit monopoly → operator profit = 0

Scenario	User price [€/km]	Fleet density [veh / 1000 inh.]	Operator profit Π [Mio. €]	ACS/ARS mode share	Change of VKT (relative to no-ACS case)
ACS Scenario	0.30 – 0.35	3.0 – 5.0	~0	8.2 – 12.5 %	+ 3.0 to +5.7 %
ARS Scenario	0.12 – 0.38	2.5 – 3.5	~0	4.4 – 11.1 %	- 1.5 to 2.7 %

2. Unregulated Monopoly → max. operator profit

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Conclusion and Outlook

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- Profit regions for ACS operations are highly dependent on user acceptance (utility function) and operator cost function:
  - Lower bound to break even (Germany): 0.33 – 0.64 €/km
  - Lower bound to break even (low density areas only): 0.40 – 1.50 €/km (!)

- Price to break even approximately 3 times lower than in unregulated monopoly

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Outlook

- Detailed analysis of modal shifts
- Analysis of social welfare
- Differentiation of price schemes

Thank you for your attention!

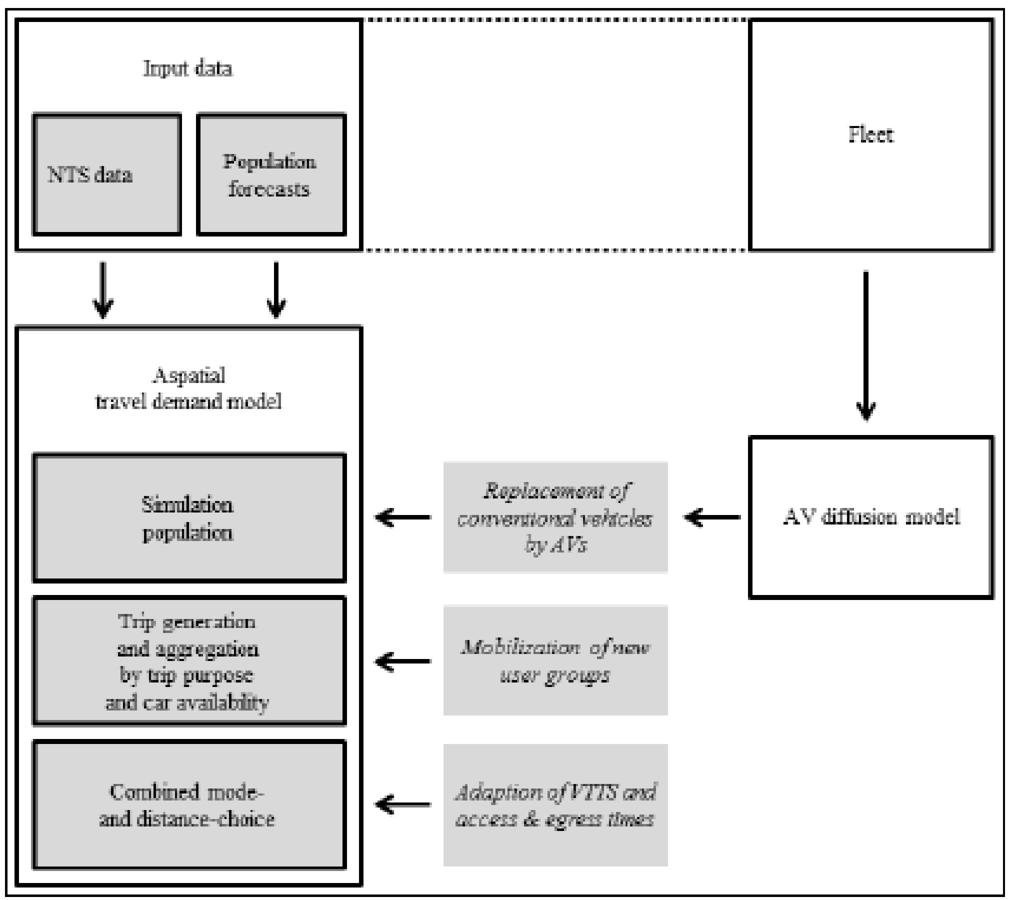
Autonomous car- and ride-sharing systems: A simulation-based evaluation of various supply options for different regions

Lars Kröger
in collaboration with Benjamin Kickhöfer
German Aerospace Center (DLR) – Institute of Transport Research, Berlin

22 June 2017

Backup

Model scheme: Aspatial Travel demand model



Methodology

- Operator profit as difference between operator revenues and operator costs

$$\Pi_{operator} = R_{operator} - C_{operator}$$

With: $\pi_{operator}$ … Operator profit [€]

$R_{operator}$ … Operator revenue [€]

$C_{operator}$ … Operator costs [€]

- Welfare as difference of operator profit and generalised user costs

$$W = \Pi_{operator} - GC_{user}$$

With: W … Welfare (as defined here, ignoring e.g. external costs) [€]

GC_{user} … generalised user costs [€]

DLR

Methodology

- Operator revenue as product of user price per km and sum of vehicle-km in use

$$R_{operator} = p_{user.km} * km_{user}$$

With: $p_{user.km}$ … price per user km [€/*km*]
km_{user} … vehicle-km (loaded) [*km*]

- Operator costs as sum of fixed operator costs per vehicle and product of variable operator costs per km and sum of vehicle-km (empty and loaded)

$$C_{operator} = p_{fix.operator.veh} * veh + p_{var.operator.km} * (km_{empty} + km_{user})$$

With: $p_{fix.operator.veh}$ … fix operator costs per vehicle [€/*vehicle per year*]
$p_{var.operator.km}$ … variable operator costs per vehicle-km [€/*km*]
veh … number of vehicles
km_{empty} … vehicle-km (empty) [*km*]

Spatial classification

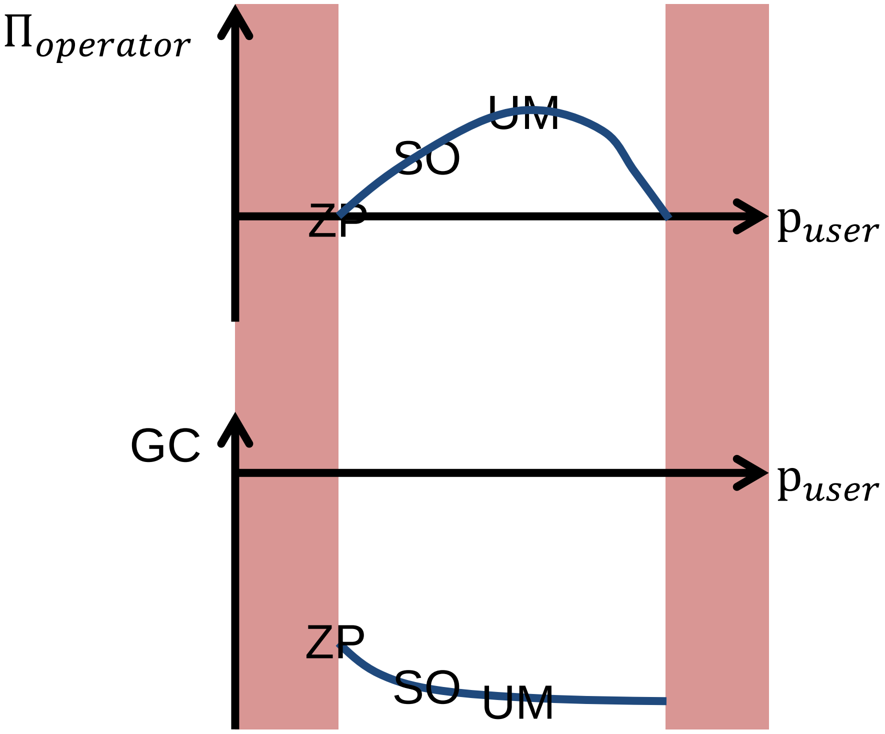
BIK	BIK-category	Population size	Core region
1	Rural	< 2 k	-
2	Rural	2 - 5 k	-
3	Rural	5 - 20 k	-
4	Rural	20 - 50 k	-
5	Suburban	50 - 100 k	-
6	Urban	50 - 100 k	Core region
7	Suburban	100 - 500 k	-
8	Urban	100 - 500 k	Core region
9	Suburban	>= 500 k	-
10	urban	>= 500 k	Core region

Parameter values

trip purpose	car availability	mode	intercept	beta_gc
1	0	walk	0	-0.670665
1	0	cycle	-1.0872081	-0.670665
1	0	car	-4.3769592	-0.670665
1	0	pt	0.387225	-0.670665
1	0	ACS	0.4047568	-0.670665
1	1	walk	0	-0.5458953
1	1	cycle	-0.8393514	-0.5458953
1	1	car	-0.2790663	-0.5458953
1	1	pt	-0.3491937	-0.5458953
1	1	ACS	-0.31413	-0.5458953
1	2	walk	0	-0.5458953
1	2	cycle	-0.8393514	-0.5458953
1	2	car	1.0584506	-0.5458953
1	2	pt	-0.3491937	-0.5458953
1	2	ACS	-0.31413	-0.5458953
2	0	walk	0	-0.2753231
2	0	cycle	-1.2532791	-0.2753231
2	0	car	-3.3000337	-0.2753231
2	0	pt	-1.3390296	-0.2753231
2	0	ACS	-0.8218296	-0.2753231
2	1	walk	0	-0.3396498
2	1	cycle	-1.6771383	-0.3396498
2	1	car	-0.4223544	-0.3396498
2	1	pt	-2.4911545	-0.3396498
2	1	ACS	-1.4567544	-0.3396498
2	2	walk	0	-0.3396498
2	2	cycle	-1.6771383	-0.3396498
2	2	car	0.1148534	-0.3396498
2	2	pt	-2.4911545	-0.3396498
2	2	ACS	-1.4567544	-0.3396498

Social Optimum (Schematic View)

- Comparing different user prices (optimal fleet density is assumed → 50% vehicle usage rate as defined here)



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