Autonomous car- and ridesharing systems

Simulation-based analysis of potential impacts on the mobility market

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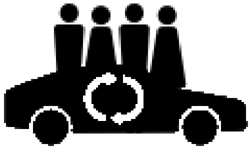
Agenda

Motivation

Motivation



- Introduction of autonomous vehicles within next years/decades
    - Privately owned vehicles
    - Autonomous Carsharing Systems (ACS)
    - Autonomous Ridesharing Systems (ARS)
- Different interests of different stakeholders
- Uncertainty in the acceptance by users
- This study: sketch planning with a grid-search approach to get estimates of potential impacts on the mobility market
    - Operator profit
    - System costs
    - Modal split, total mileage

Methodology

Travel demand generation for Germany in 2035

- Based on German NHTS data (MiD 2008)
  - 60k persons
  - 190k reported trips
  - 35k vehicles

- Trip generation: socio-demographic projection to 2035
  - # individuals per area type (urban, suburban, rural)
  - # individuals per age group and gender
  - # driver licenses (cohort effect)

- Diffusion of AVs into the private fleet (rates depend on vehicle class)
  - Mobilisation of new user groups (impaired, no drivers license, teenagers)
  - Reduction of VTTS in AVs (–25%)
  - Reduction of access and egress times

For details, see
Trommer et al. (2016)

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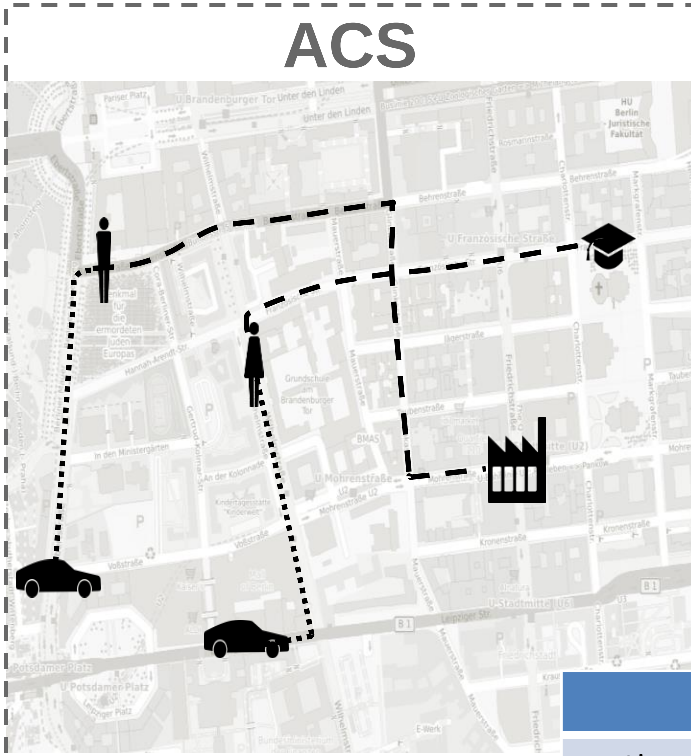
Destination and mode choice

- Generation of attributes for non-chosen modes
- Gravity model for distance class choice
- Multinomial logit model for mode choice
- No network loading → distance based, mode-specific travel times
- Result: reference scenario with private AVs
  - Up to 20% AVs in the fleet by 2035
  - Up to 10% increase in VKT
  - Modal shift mainly from PT

For details, see
Trommer et al. (2016)

New modes: Autonomous Car- or Ridesharing



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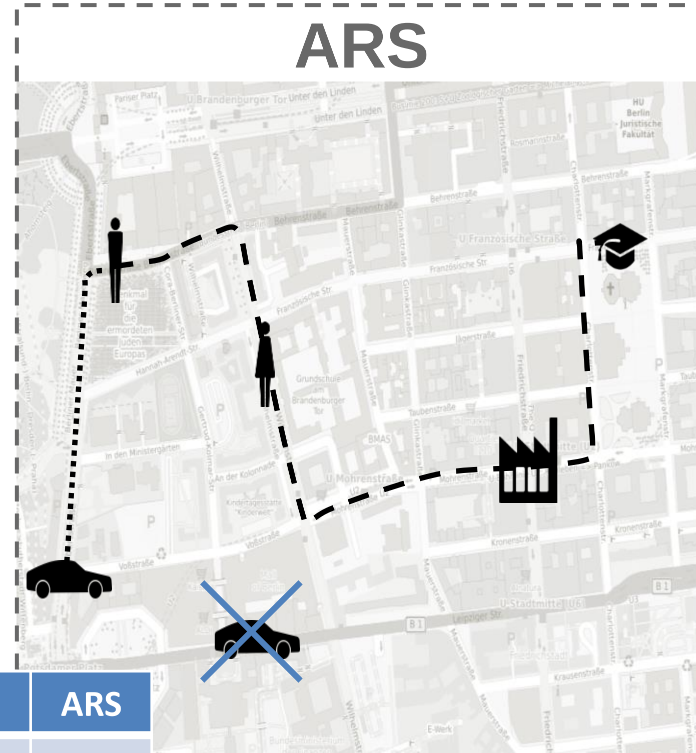

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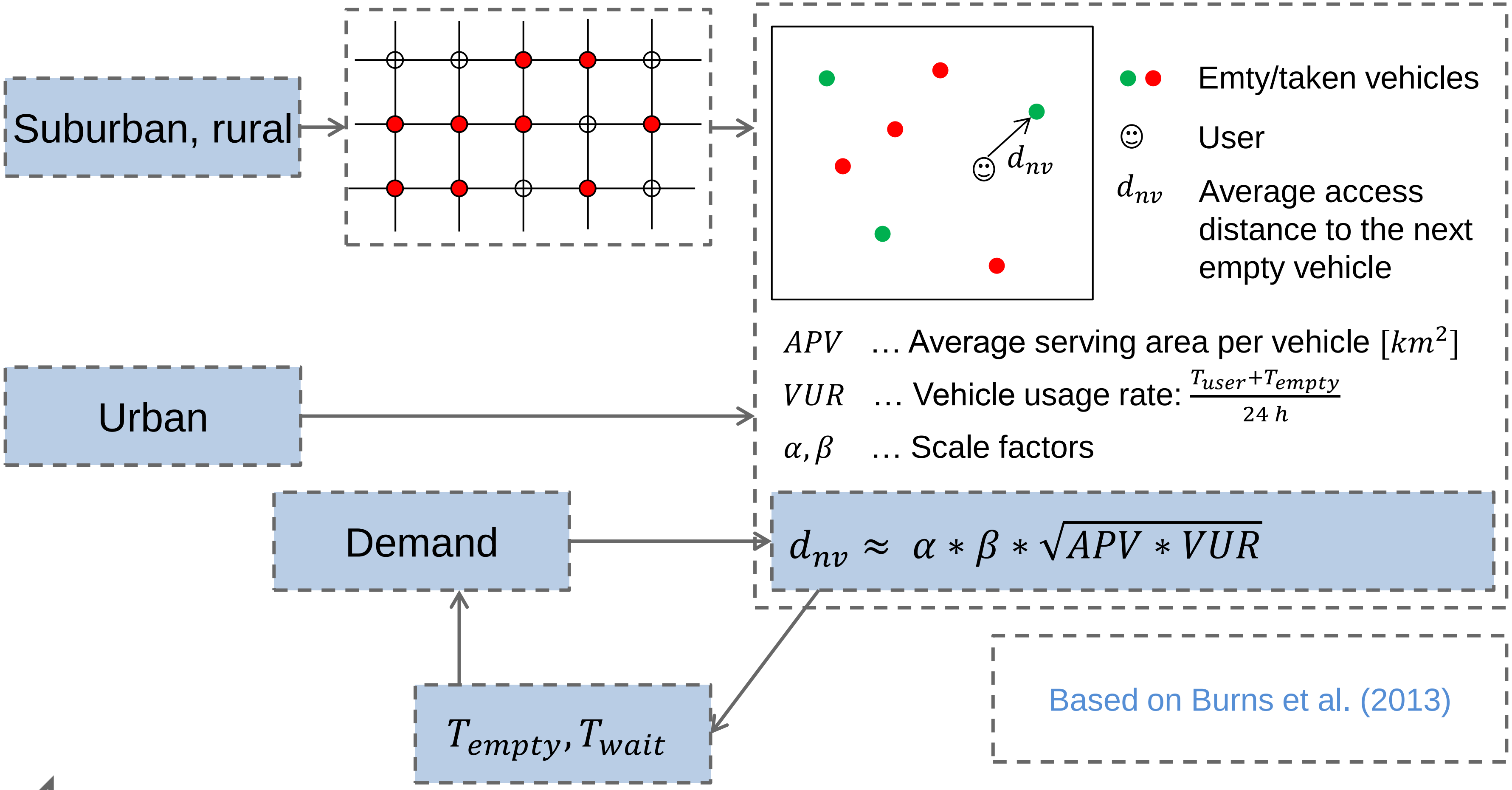
	ACS	ARS
Shared Vehicles	√	√
Shared Rides		√
Detours possible		√
Empty rides possible	√	√
Splitting of ride costs		√

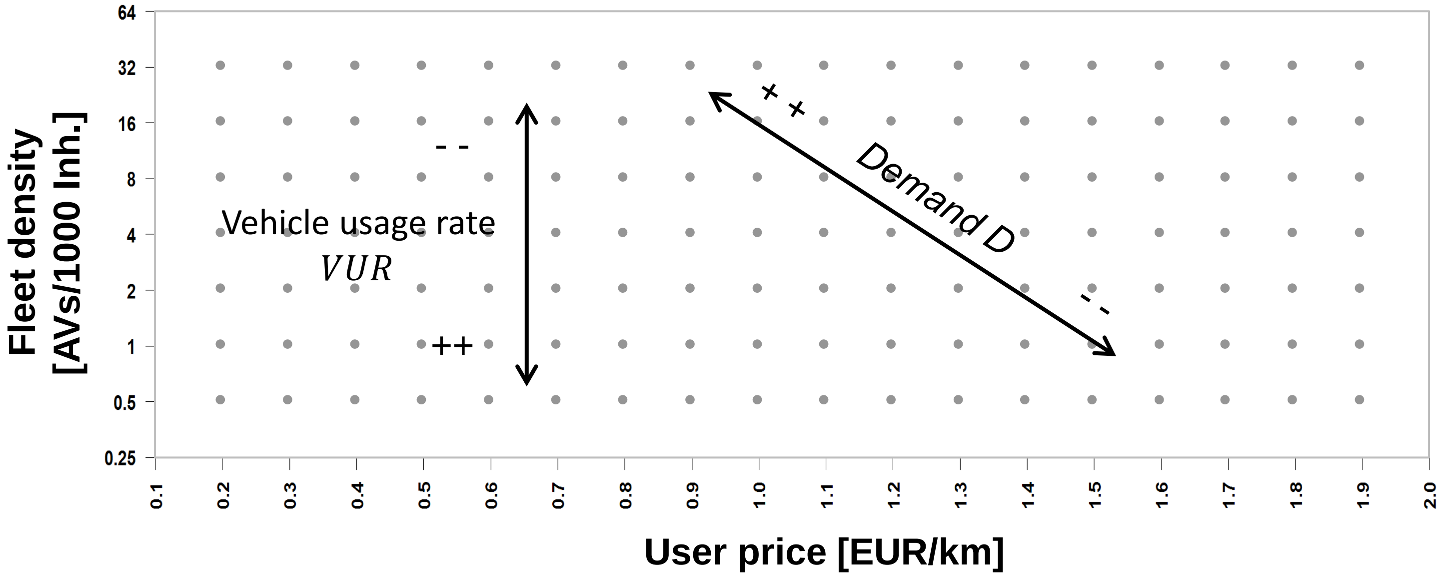
New modes: calculation of waiting times (in absence of a network)



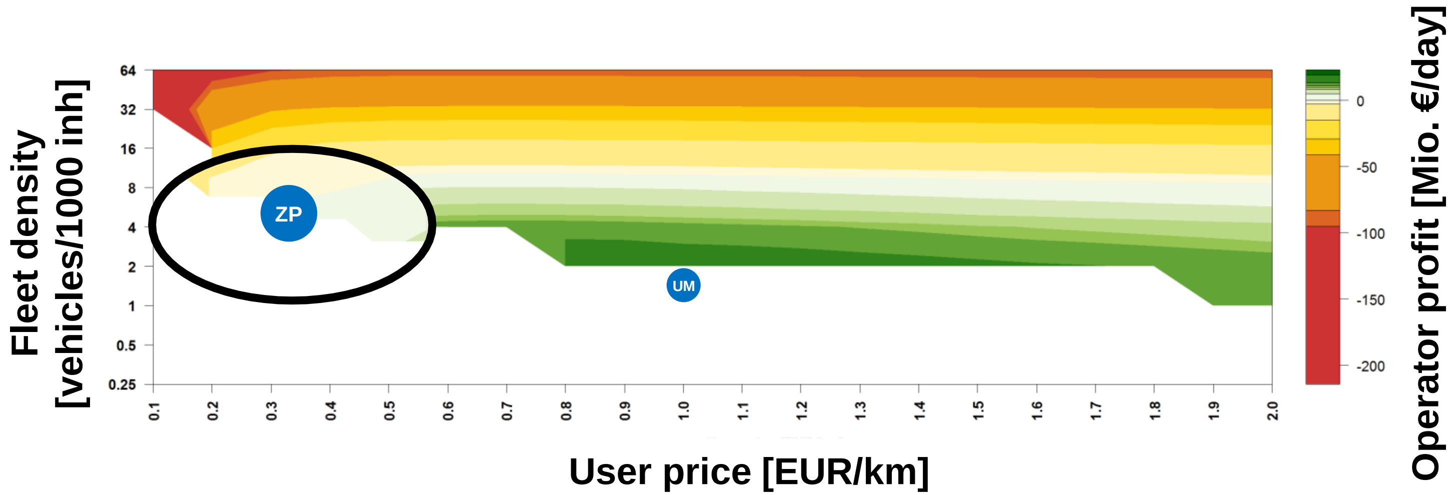
Based on Burns et al. (2013)

Results:
Autonomous Car Sharing (ACS)

Grid search

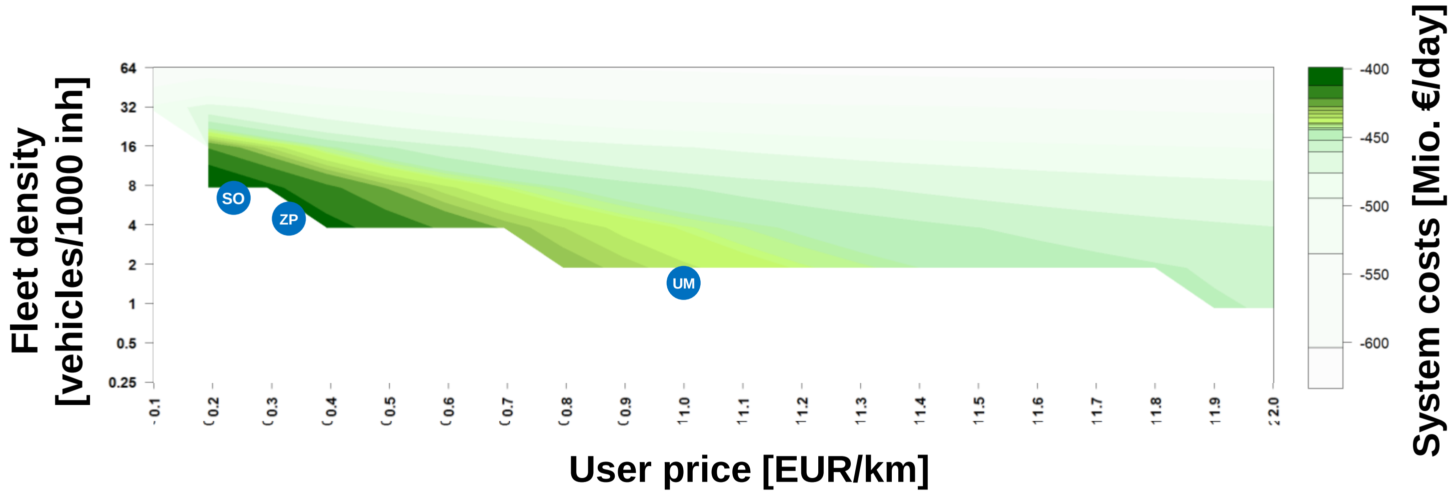

Fleet density [AVs/1000 Inh.]
64
32
16
8
4
2
1
0.5
0.25
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1.0
1.1
1.2
1.3
1.4
1.5
1.6
1.7
1.8
1.9
2.0
User price [EUR/km]
Vehicle usage rate
VUR
- -
++
+ +
Demand D
- -

ACS: operator profit landscape



- Zero Profit (ZP): 0.33 €/user-km ; 4.50 veh/1000 inh
- Unregulated Monopoly (UM): 1.00 €/user-km ; 1.55 veh/1000 inh
- System Optimum (SO): 0.23 €/user-km ; 6.50 veh/1000 inh

ACS: system costs (sum of operator profit and generalized user costs)



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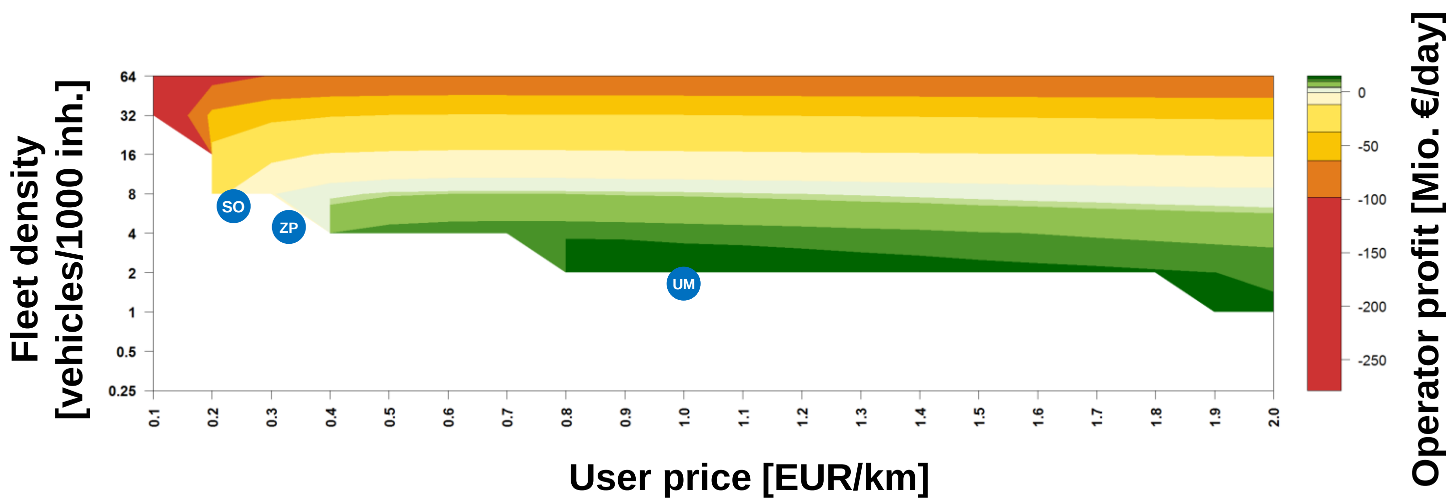
Results:
Sensitivity analysis
(ETHZ cost calculator)

Sensitivity analysis for ACS: cost structure

	DLR (Trommer et al. 2016)	ETHZ (based on Bösch et al. 2017)*
Depreciation, Capital Cost [€/veh-km]	0.12	0.092
Overhead, 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**

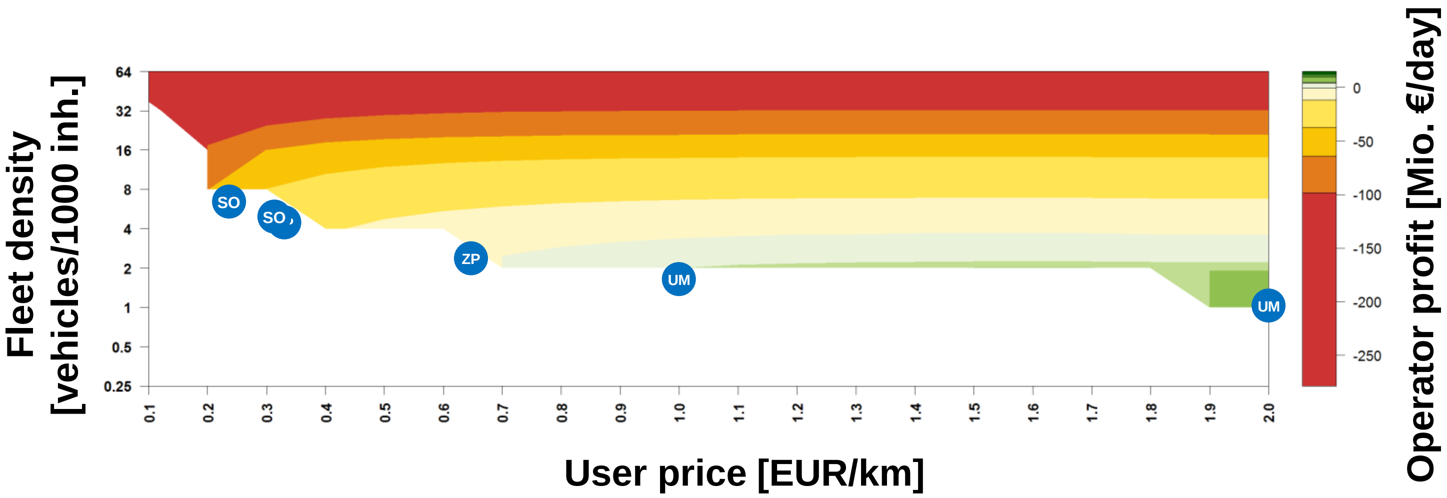
* 1 EUR = 1.07 CHF

Sensitivity analysis for ACS: cost structure (DLR)



- Zero Profit (ZP): 0.33 €/user-km ; 4.50 veh/1000 inh
- Unregulated Monopoly (UM): 1.00 €/user-km ; 1.55 veh/1000 inh
- System Optimum (SO): 0.23 €/user-km ; 6.50 veh/1000 inh
- Rural areas break-even at ~0.40 €/km

Sensitivity analysis for ACS: cost structure (ETHZ)



- Zero Profit (ZP): 0.64 €/user-km ; 2.25 veh/1000 inh
- Unregulated Monopoly (UM): 2.00 €/user-km ; 1.00 veh/1000 inh
- System Optimum (SO): 0.32 €/user-km ; 4.60 veh/1000 inh
- Rural areas break-even at ~1.50 €/km

Sensitivity analysis for ACS: cost structure

Scenario	User price [€/km]	Fleet density [veh/1000 inh]	Operator profit [Mio. € p.d.]	ACS mode share	Change of VKT (w.r.t. ref. case)	System costs [Mio. € p.d.]
ZP: DLR cost	0.33	4.50	~0	10.6 %	+ 3.7 %	-402.9
ZP: ETHZ cost	0.64	2.25	~0	7.3 %	+ 2.0 %	-432.8
UM: DLR cost	1.00	1.55	13.0	5.4 %	+ 1.5 %	-434.3
UM: ETHZ cost	2.00	1.00	6.8	3.4 %	+ 0.9 %	-457.6
SO: DLR cost	0.23	6.50	-14.1	12.7 %	+ 5.5 %	-397.6
SO: ETHZ cost	0.32	4.60	-22.3	10.8 %	+ 3.9 %	-424.8

- Zero profit: most likely case in competitive situation
- System optimum: subsidies needed > likely to change if external effects are considered (see change in VKT!)
- Unregulated monopoly: regulation needed to avoid over-pricing

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Results: Comparison of ACS and ARS

Comparison of ACS and ARS

- **ARS:**
  - Simplistic pooling strategy based on demand (per 1x1km raster, 10 min time bins and rough direction).
  - Less attractive than ACS (vehicle waits for 10 min for other passengers).
  - However, splitting costs is possible and makes it cheaper than ACS.

- **So far**:
  - User price and fleet density fixed for all area types (urban, suburban, rural).
  - That is, urban areas subsidize rural areas.

- **Now**:
  - User price and fleet density varies for every area type.
  - Still: one operator can materialize economies of scale.

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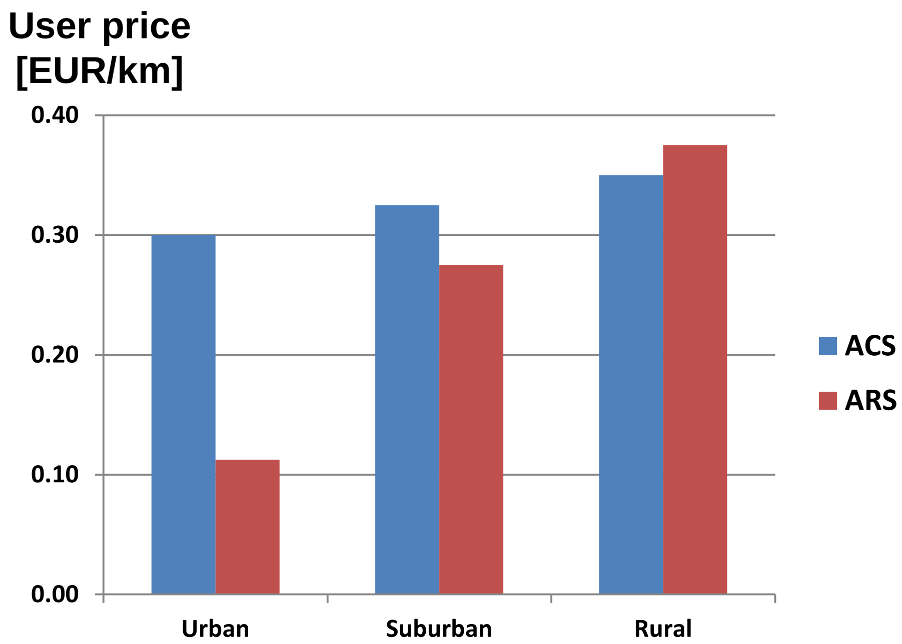
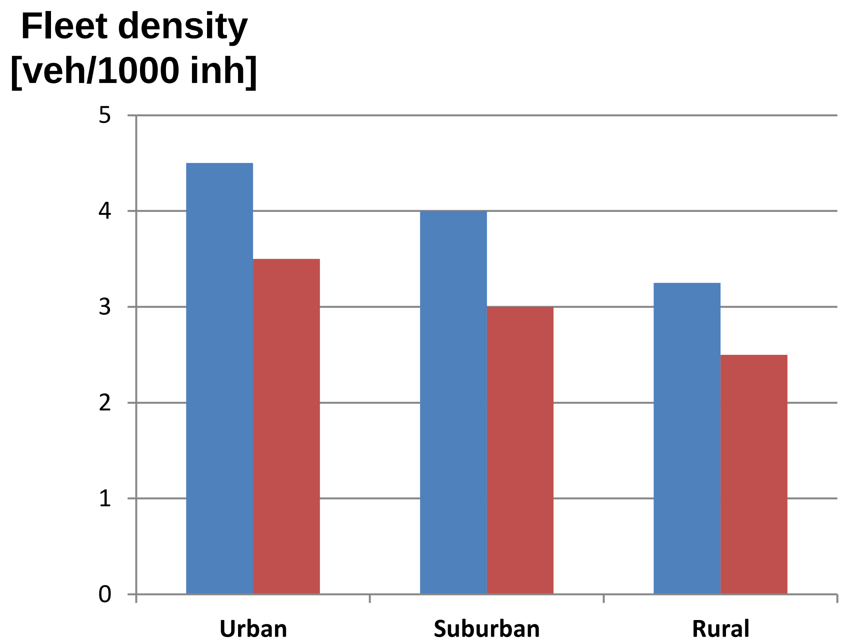
Zero profit supply parameters for different area types





- ARS can reach price levels comparable to PT in urban areas
- Spatial differences of prices are higher for ARS than for ACS
- Reason: high potential of pooling in urban areas yielding very low user prices

Zero Profit (ZP) vs Unregulated Monopoly (UM)

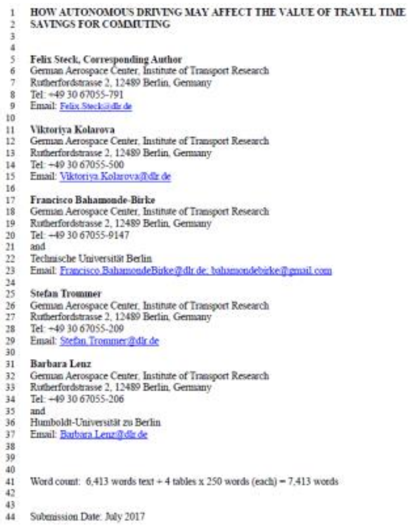
Scenario	User price [€/km]	Fleet density [veh/1000 inh]	Operator profit [Mio. € p.d.]	Mode share	Change of VKT (w.r.t. ref. case)
ZP: ACS	0.30 – 0.35	3.0 – 5.0	~0	8.2 – 12.5 %	+3.0 to +5.7 %
ZP: ARS	0.12 – 0.38	2.5 – 3.5	~0	4.4 – 11.1 %	–1.5 to +2.7 %
UM: ACS	0.95 – 1.05	1.4 - 1.6	13.2	4.2 – 6.2 %	+1.2 to +1.6 %
UM: ARS	0.45 – 0.80	1.3 – 1.5	6.2	2.5 – 6.0 %	+1.1 to +1.8 %

- UM: High prices lower pooling probabilities > higher VKT
- ZP: Lower prices increase pooling probabilities in urban areas > lower VKT
- Regulatory measures needed!

Conclusion and outlook

Conclusion and outlook

- Sketch planning tool allows to get first estimates of country-wide/area type impacts on the mobility market through ACS/ARS
- Results are highly dependent on utility functions, vehicle operations, and operator cost structure > good test: under which circumstances exists a business case?
- Results hint towards regulatory measures (for the monopoly case) or even subsidies of ACS, ARS (for the system optimal case); however, externalities need to be considered/modeled
- Only ARS is able to reduce VKT in urban areas;
  all other schemes increase VKT
- Future research:
  - Use behavioral parameters by Steck et al. (2017 forthcoming)
  - Differentiation by time
  - Consideration of externalities
  - Implications on car ownership?



HOW AUTONOMOUS DRIVING MAY AFFECT THE VALUE OF TRAVEL TIME SAVINGS FOR COMMUTING

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Thank you.

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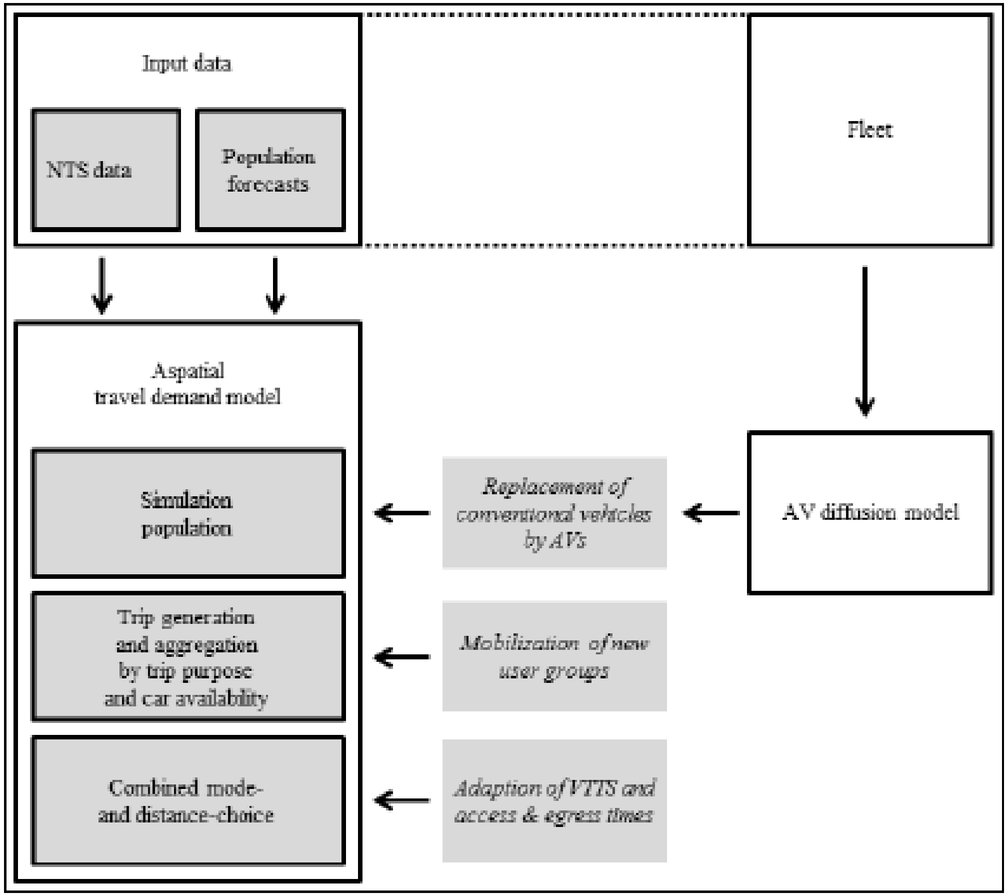
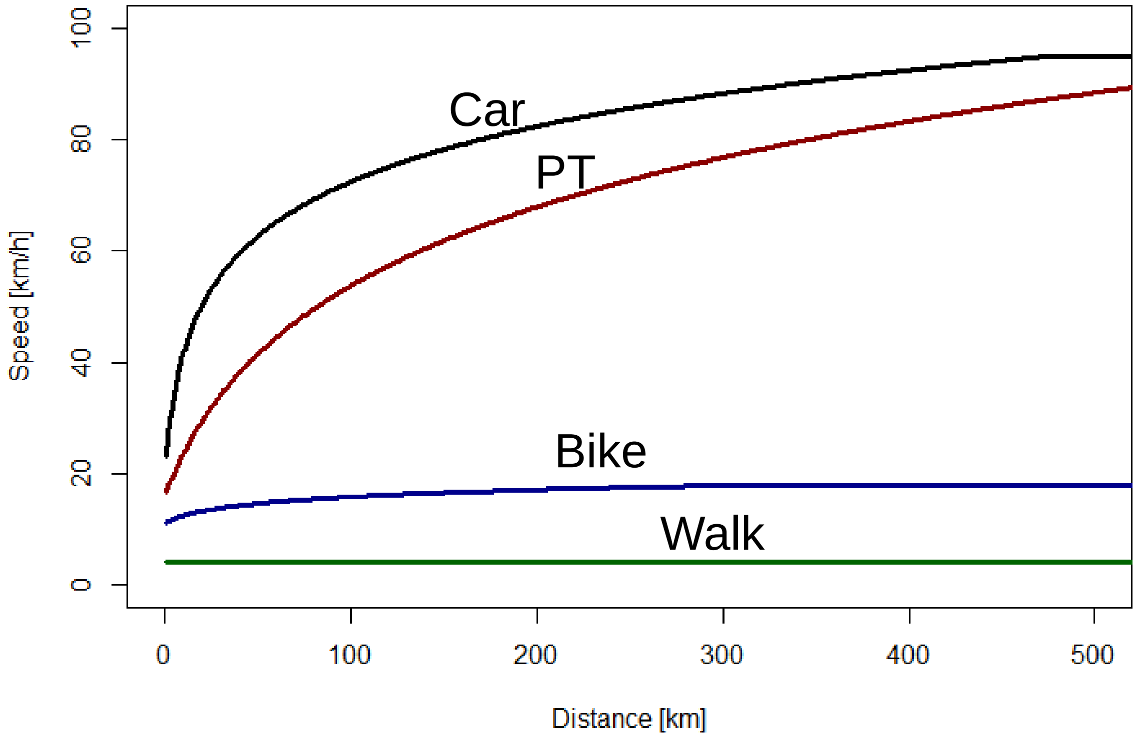
2. Bösch, P. M., Becker, F., Becker, H., and Axhausen, K. W. (2017). „Cost-based analysis of autonomous mobility services“. WP 1225, ETHZ.
3. Burns, L. D., Jordan, W. C., and Scarborough, B. A. (2013). „Transforming personal mobility“. WP, The Earth Institute Columbia University.

Backup methodology

Aspatial travel demand model



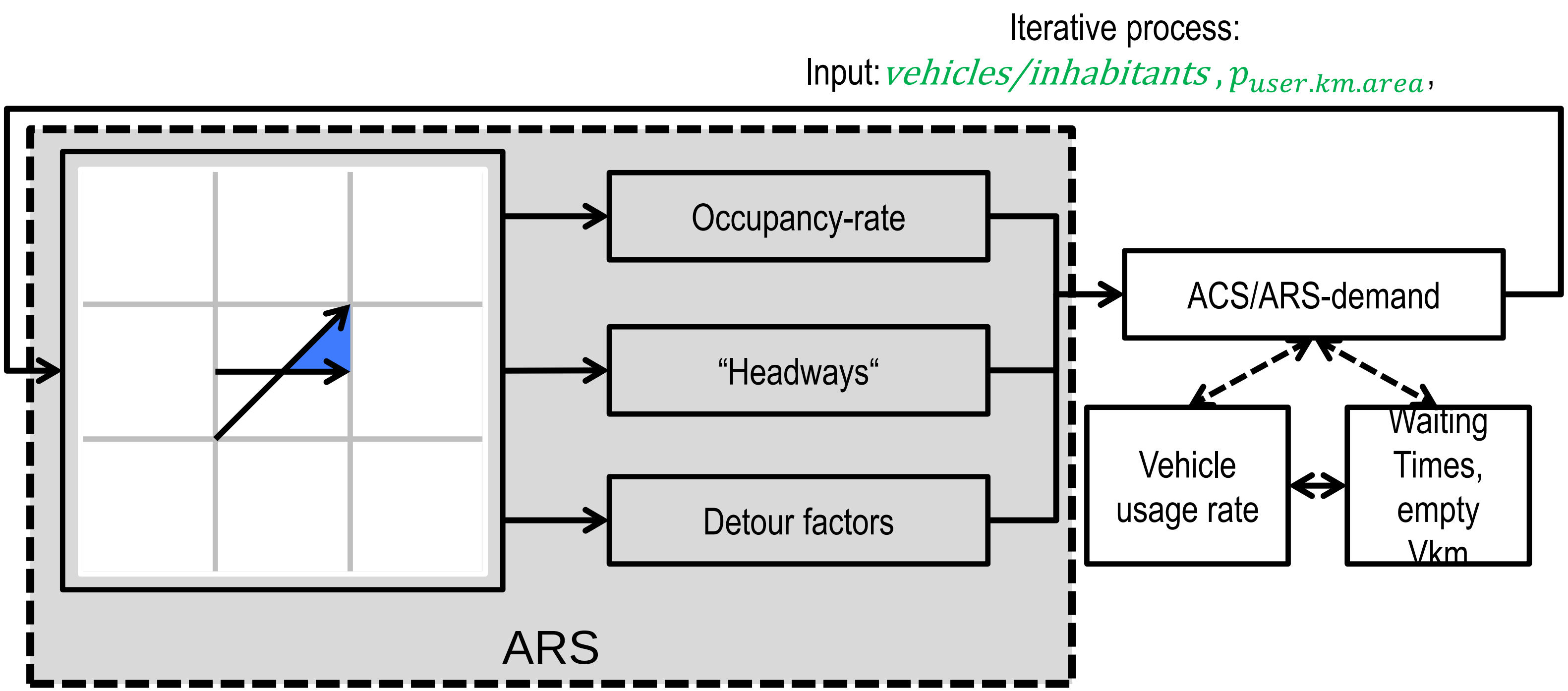
Distance based, mode-specific travel speed



Utility functions for ACS, ARS

Constant	Price	Travel time
Set in relation to car and PT mode	$p_{user} = p_{user.km.area} * km_{user}$	$TT_{ACS} = \min(T_{access}, WT_{ACS}(distance\ to\ the\ next\ empty\ vehicle)) + DT_{ACS}(distance) + T_{egress}$ $TT_{ARS} = \min\left(T_{access}, WT_{ARS}\left(\begin{matrix} distance\ to\ the\ next\ empty\ vehicle, \\ occupancy\ rate, maximum\ headway \end{matrix}\right)\right) + DT_{ACS}(distance, detour\ factor) + T_{egress}$ $distance\ to\ the\ next\ empty\ vehicle_{ACS/ARS} = f(vehicles/inhabitants, area\ type, vehicle\ usage\ rate)$ $detour\ factor_{ARS} = f(occupancy\ rate, modal\ split_{ARS})$

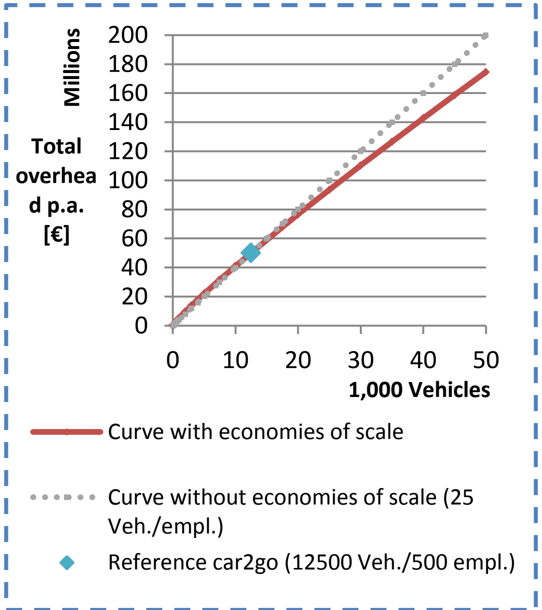
Pooling strategy ARS

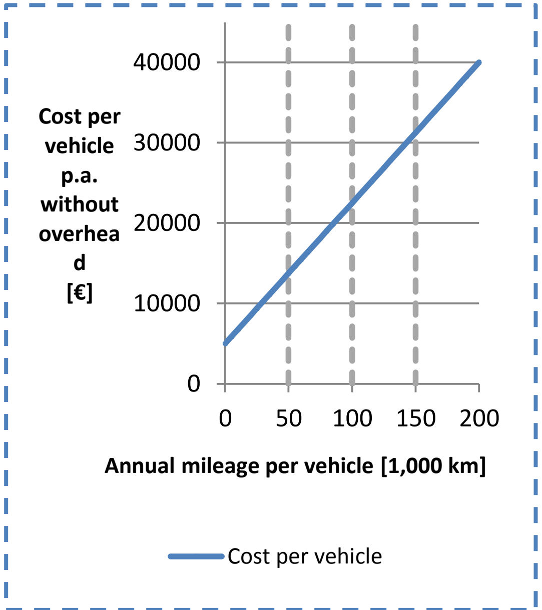


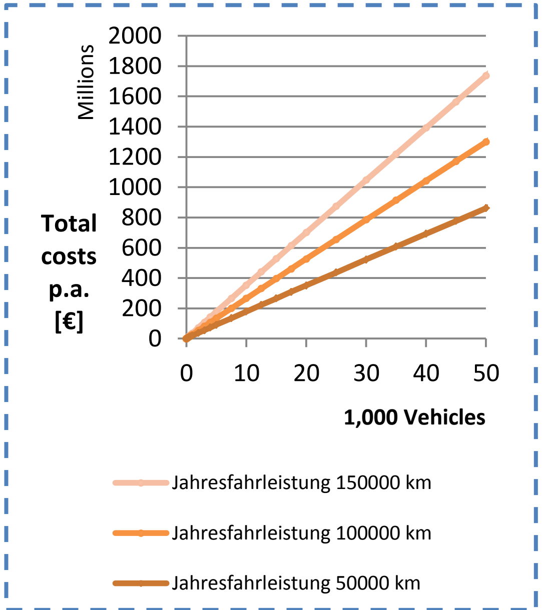
Operator cost structure

$$C_{operator} = C_{fix,operator}(fleet\ size) + C_{var,operator}(KM_{empty}, KM_{loaded})$$

$$R_{operator} = \sum_{area\ type} (p_{user.km,area\ type} * KM_{user,area\ type})$$







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Operator revenue and costs

- 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*]

Operator profit and social costs

- 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 [€]

- Social costs as difference between operator profit and generalized user costs

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

With: SC … Social costs (omitting external costs) [€]

GC_{user} … generalized user costs [€]

Area type classification

BIK	BIK-category	Population size of the associated central location	Core region
1	Rural	< 2 k	X
2	Rural	2 - 5 k	X
3	Rural	5 - 20 k	X
4	Rural	20 - 50 k	X
5	Suburban	50 - 100 k	X
6	Urban	50 - 100 k	√
7	Suburban	100 - 500 k	X
8	Urban	100 - 500 k	√
9	Suburban	>= 500 k	X
10	Urban	>= 500 k	√

Estimated 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

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Backup results

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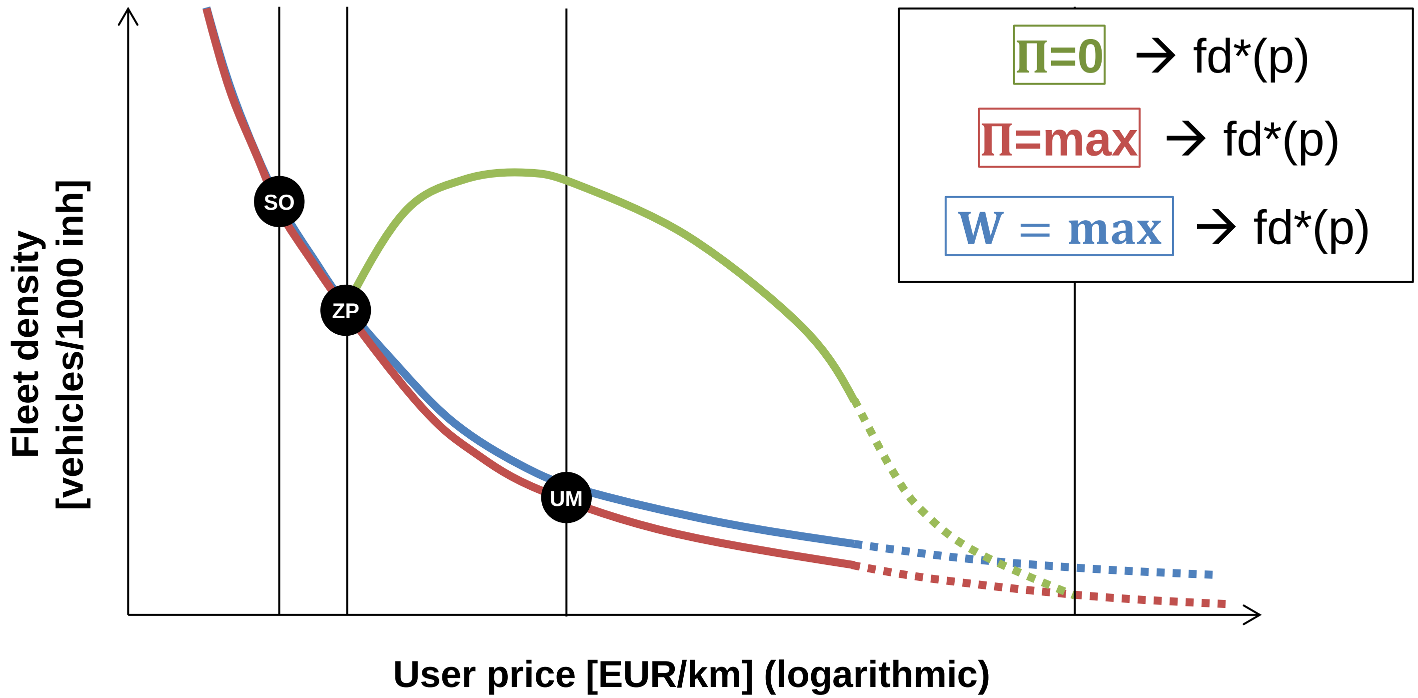
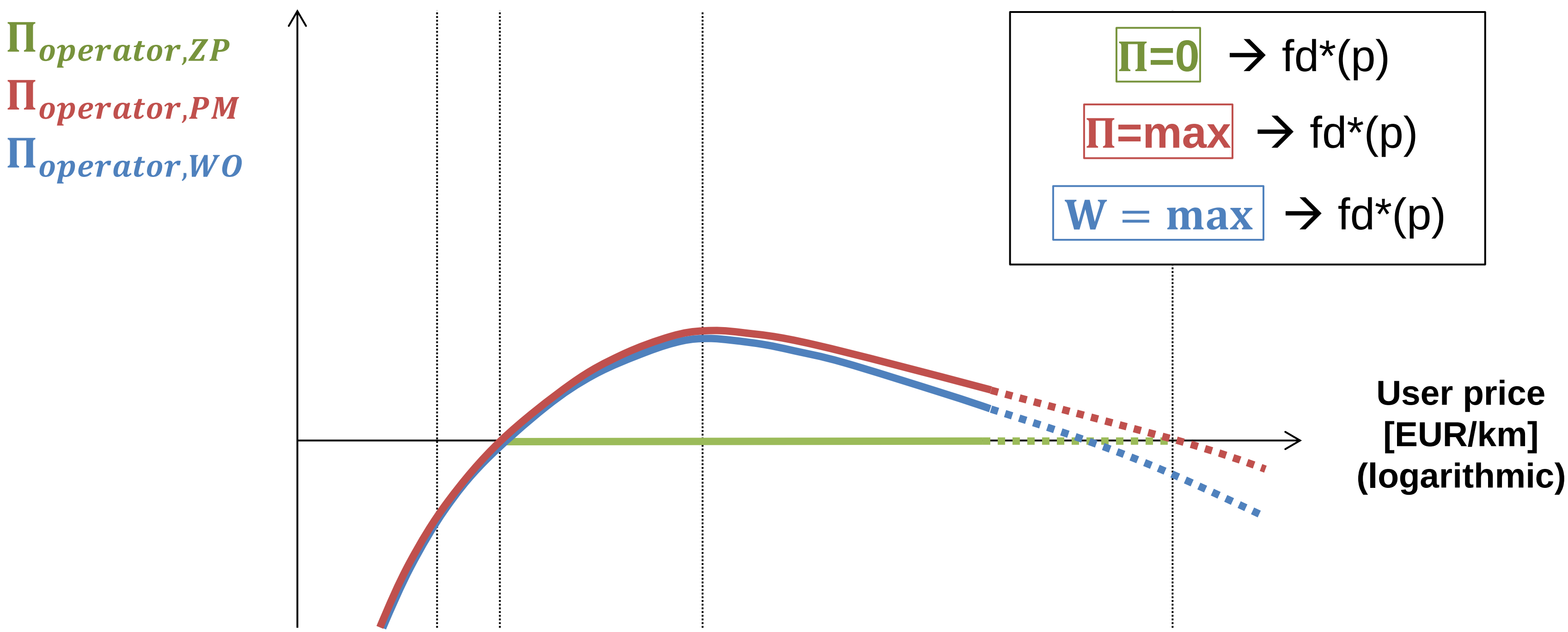
Methodology: Assumptions on the setting of fleet-density/user-price-combinations



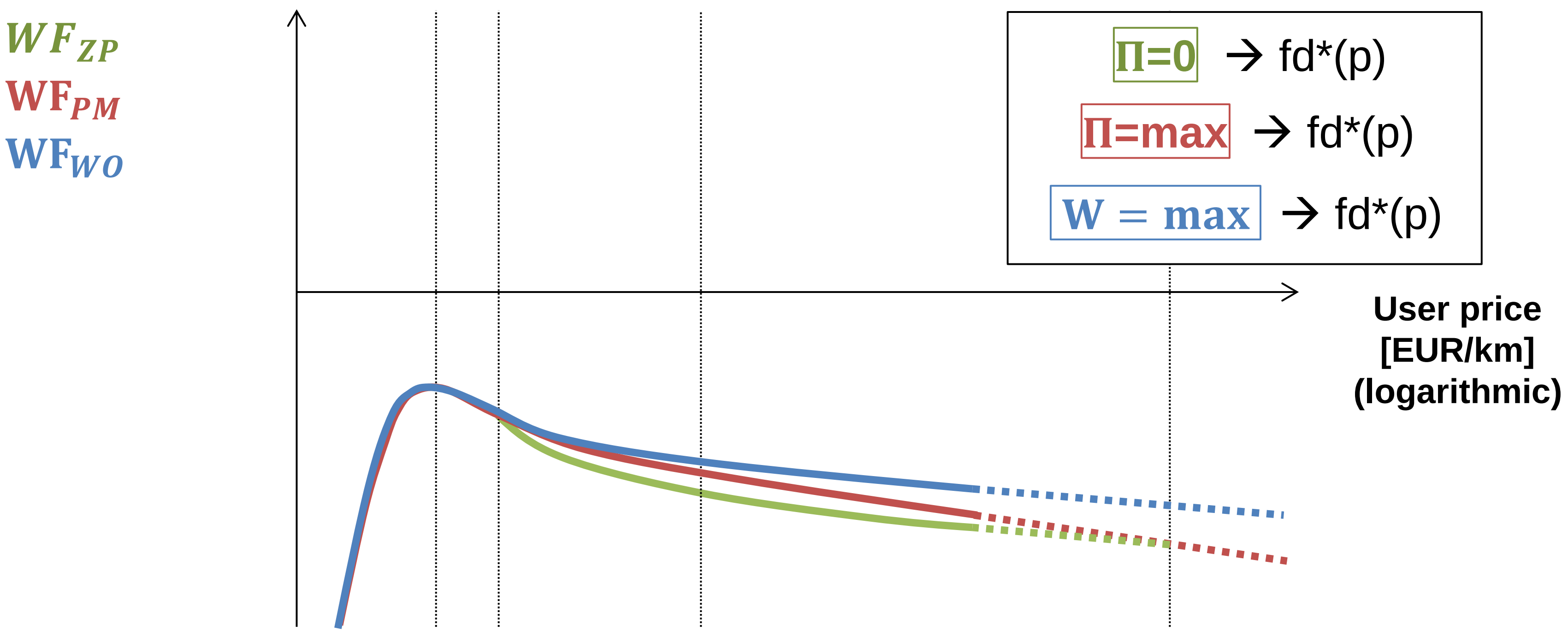
- Different fleet densities at a given user price for the assumptions of a zero-profit-case, a max-profit-case and a social-optimum-case

Methodology: Assumptions on the setting of fleet-density/user-price-combinations



- Oerator profit in the social-optimum-case is less or equal to that one in the max-profit-case for all user prices
- Bigger differences when fleet density decreaes (at a higher user price level)

Methodology: Assumptions on the setting of fleet-density/user-price-combinations



- Social welfare in the social-optimum-case is greter than or equal to that one in the max-profit-case for all user prices
- Bigger differences when fleet density decreaes (at a higher user price level)

Methodology: Operator profit, generalized user costs and social welfare