How many cars are too many?

Recent results in the light of automated vehicles

Presentation

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How many cars are too many? Recent results in the light of automated vehicles

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M Menendez, NYU Abu Dhabi, previously ETH, for the MFD work
G Sarlas and R Fuhrer for the work on Swiss wages/productivity
FCL M8 for the SG MATSim model
S Hörl for the work on AV simulation
F Becker for the new mode choice and mobility tool models
P Bösch, F Becker and H Becker for the cost estimates

Basic issue

Transport is a

system of moving queues

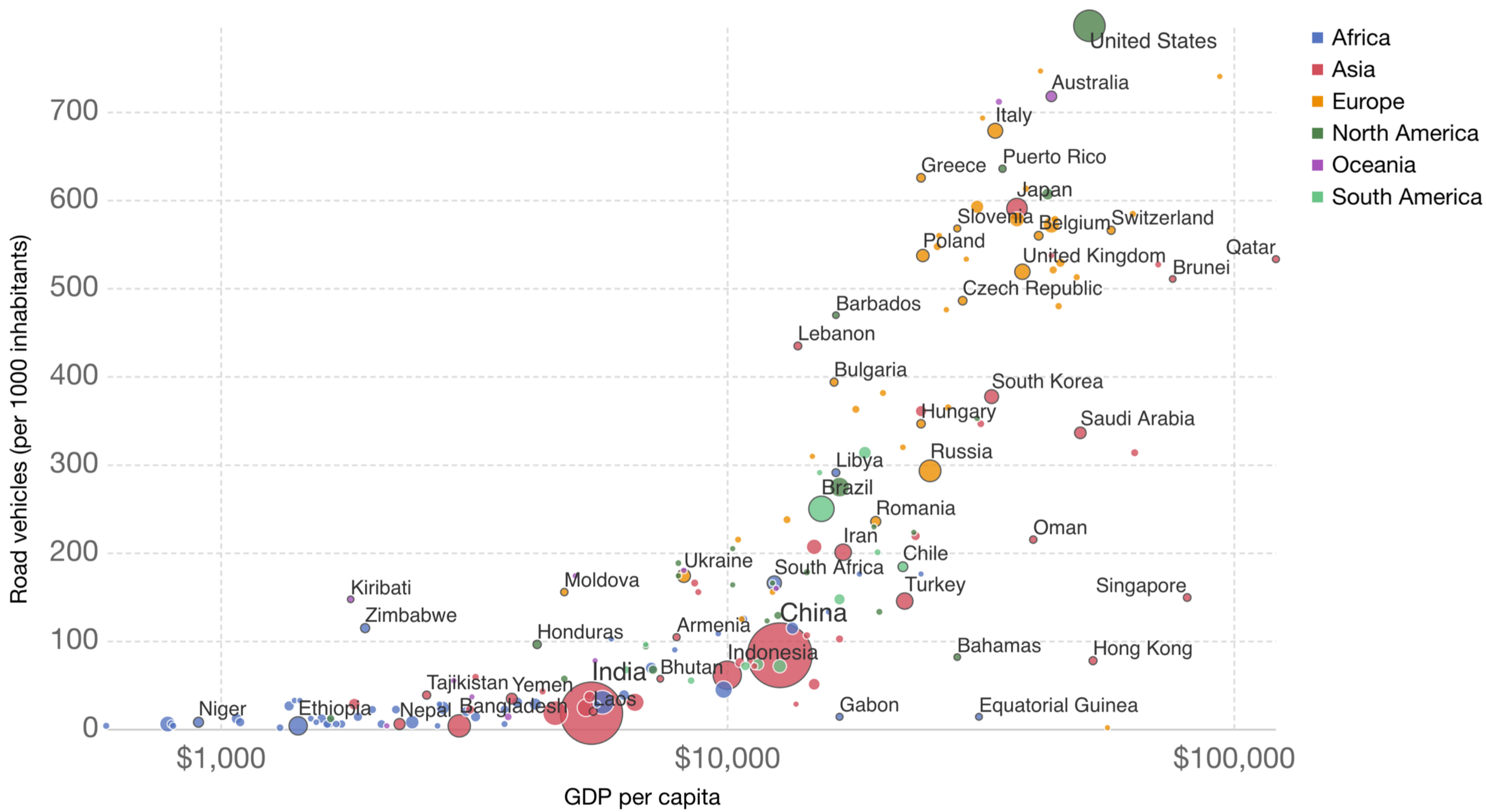
and

their servers

with

elastic demand

Motor vehicles (2014)



Source: NationMaster Database; World Bank - World Development Indicators (WDI)
OurWorldInData.org/technology-adoption/ • CC BY

Source: "our world in data", 5/12/2019

Car ownership (Jakarta 2014)

Source: globalindonesianvoices.com

Where to strike the balance

Between

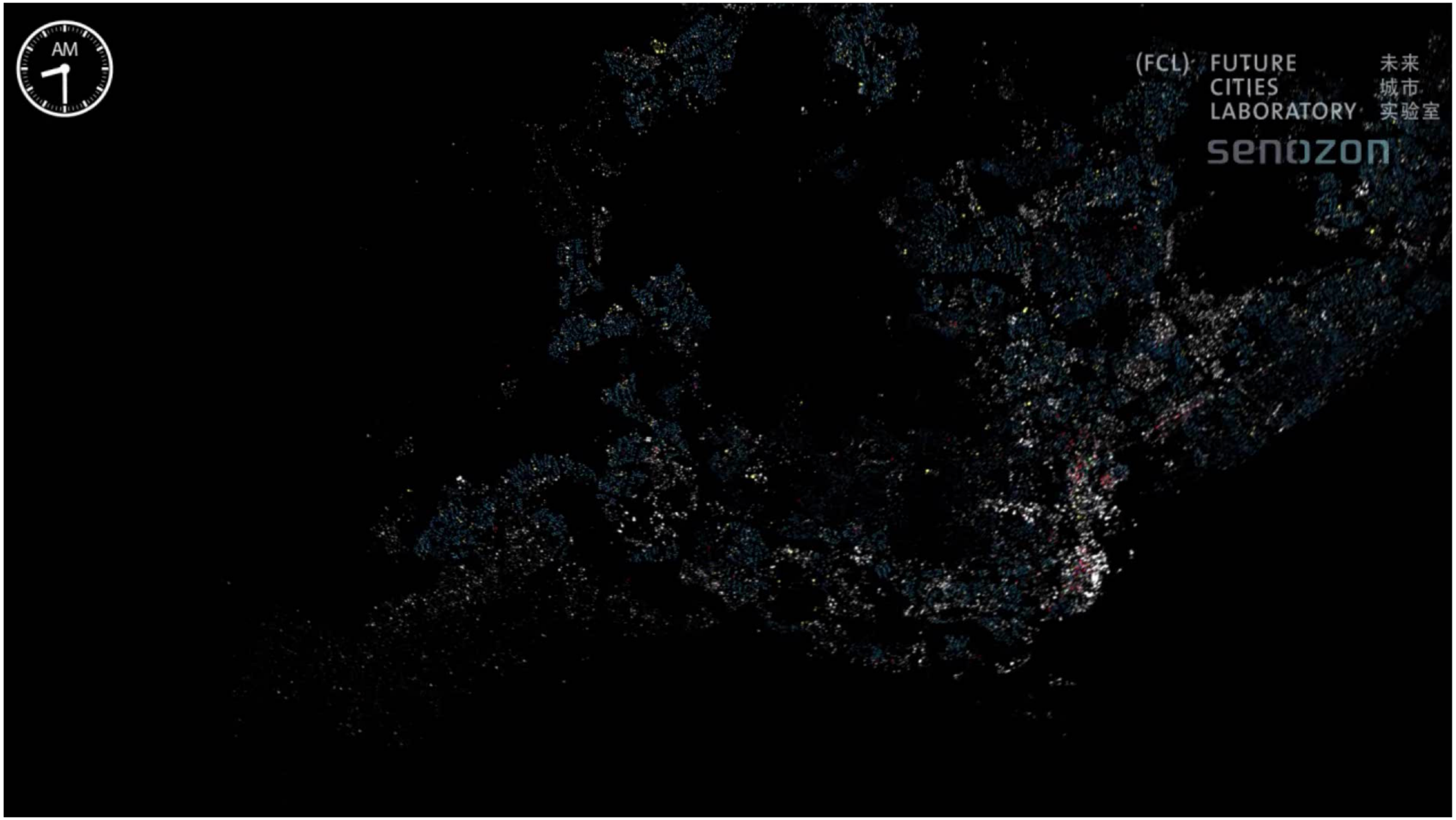
- Accessibility (speed, population/employment density)
- Productivity (speed)
- Cars
- Public transport
- Slow modes ?

And why the dilemma?

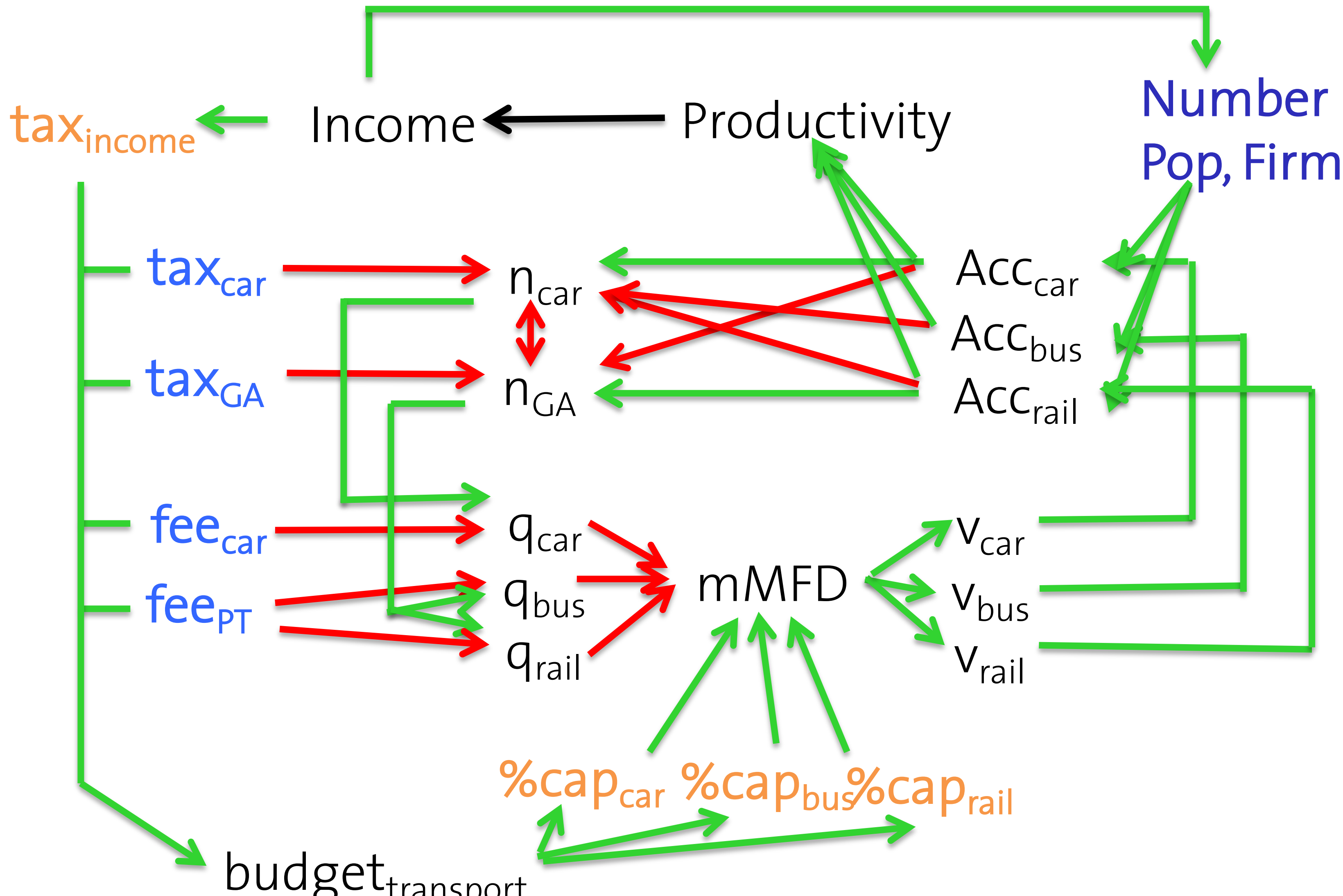
- Accessibility ~ Productivity ~ Welfare
- Car-accessibility ~ Car ownership ~ 1/transit season ticket ownership
- Accessibility ~ PKm ~ CO_2 production (with today's fleet)
- Accessibility ~ Urban sprawl ~ PKm

Where to strike the balance, but based on what ?

A model of Singapore‘s travel demand and traffic

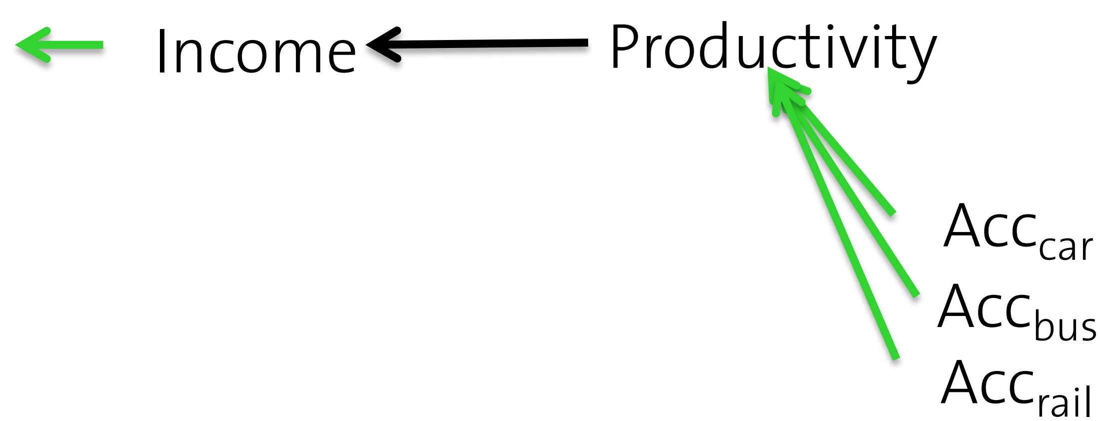


Would this be enough ?



What do we know ?

Access and productivity: Switzerland



Access and productivity: Literature

Different streams

- Aggregate (region)
  - e.g. Aschauer (1989)
- Disaggregate (firm, person)
  - e.g. Graham (2007)

Issues

- Measurement of accessibility
- Endogeneity of the network and productivity
- Role of instruments or proxies
- Spatial correlation

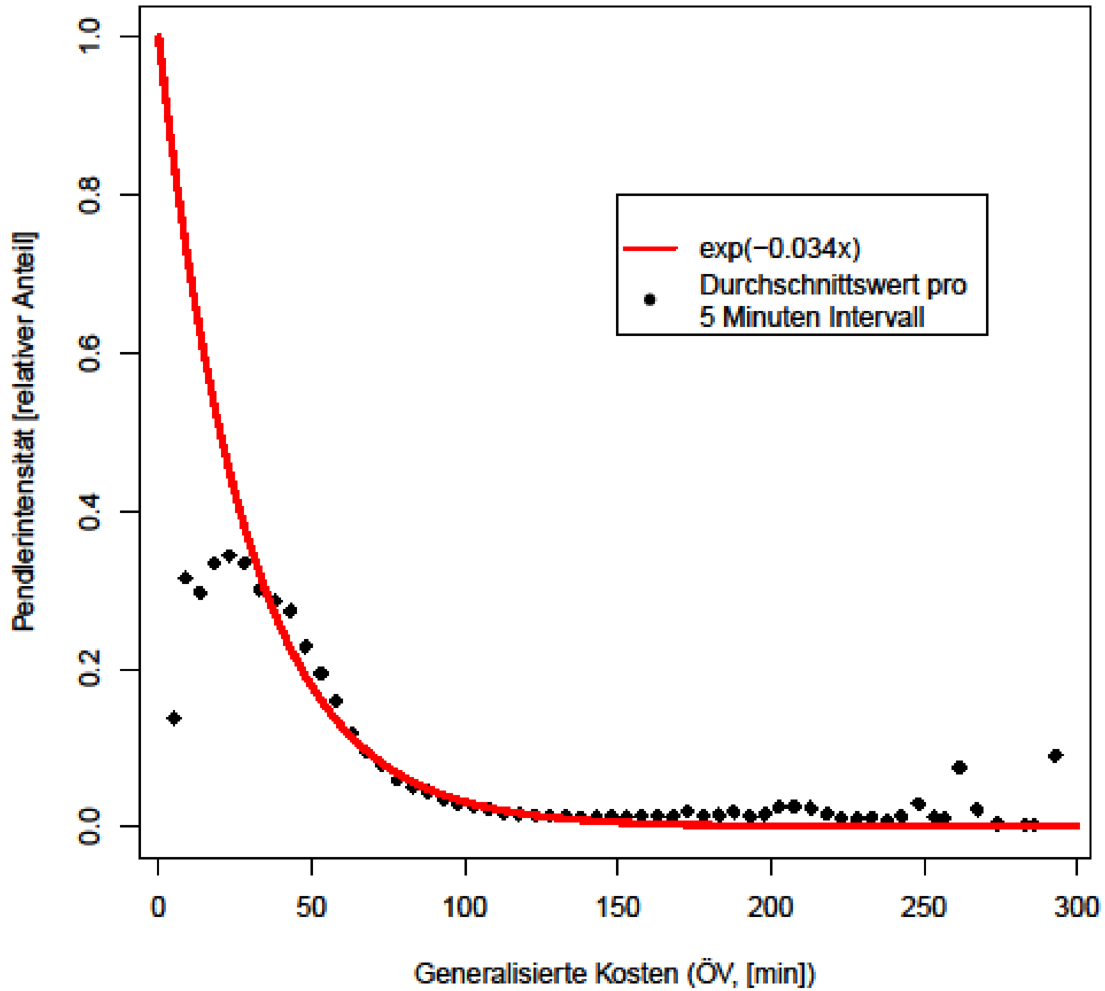
Accessibility, i.e. logsum of destination choice model

$$E_i = \ln\left(\sum_j E_{ij}\right) = \ln\left(\sum_j^{c_{ij} \leq \max c_{ij}} A_j \cdot f(c_{ij})\right)$$

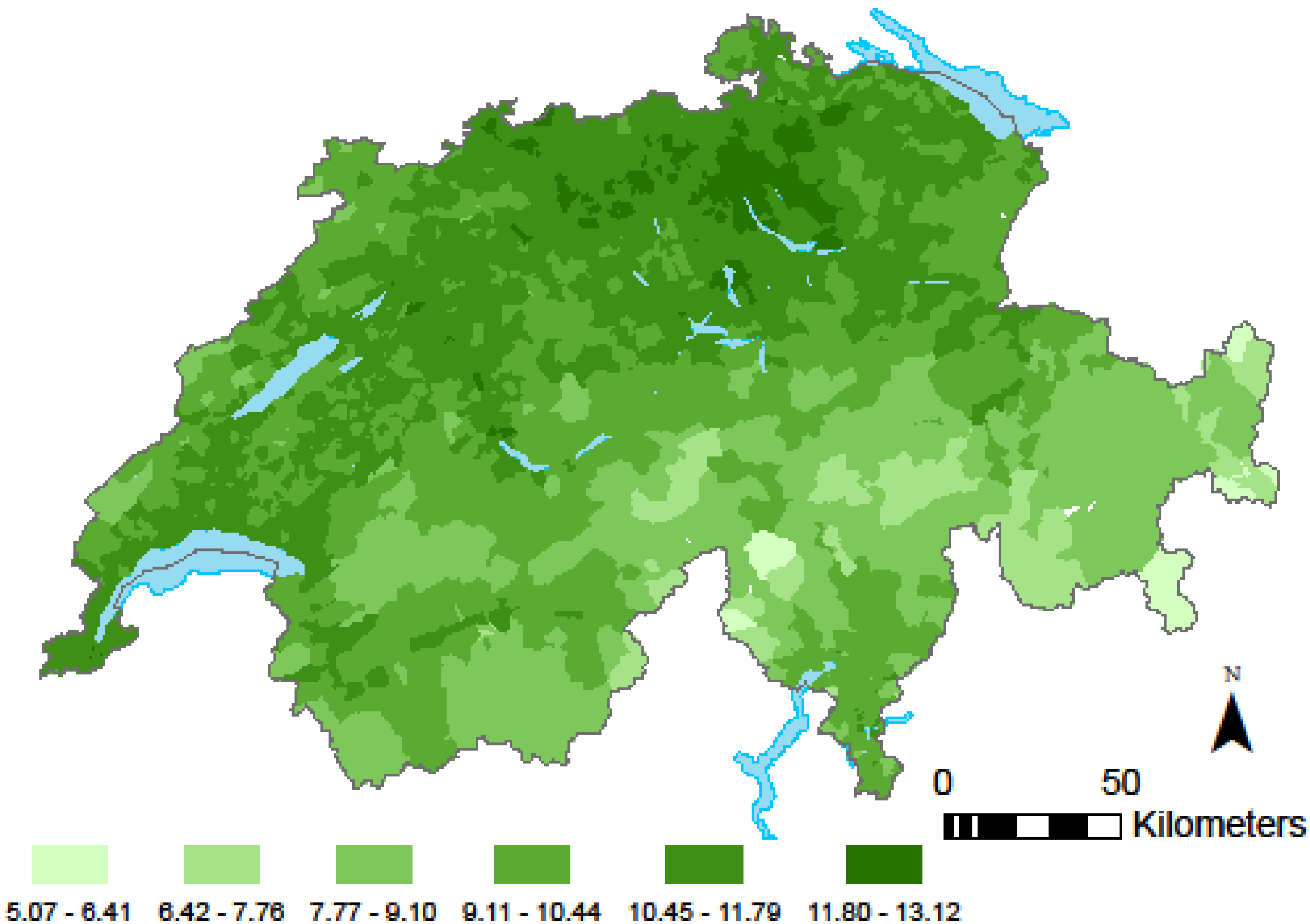
with	E_i:	Accessibility at location *i* (Potential)
	c_{ij} :	Generalised costs between *i* und *j* with upper range
	A_j:	Number of opportunities at *j*
	$f(c_{ij})$:	Weighting function $f(c_{ij}) = e^{-c_{ij}}$

The case of Switzerland (2000-2010)

Accessibility, new weighting function

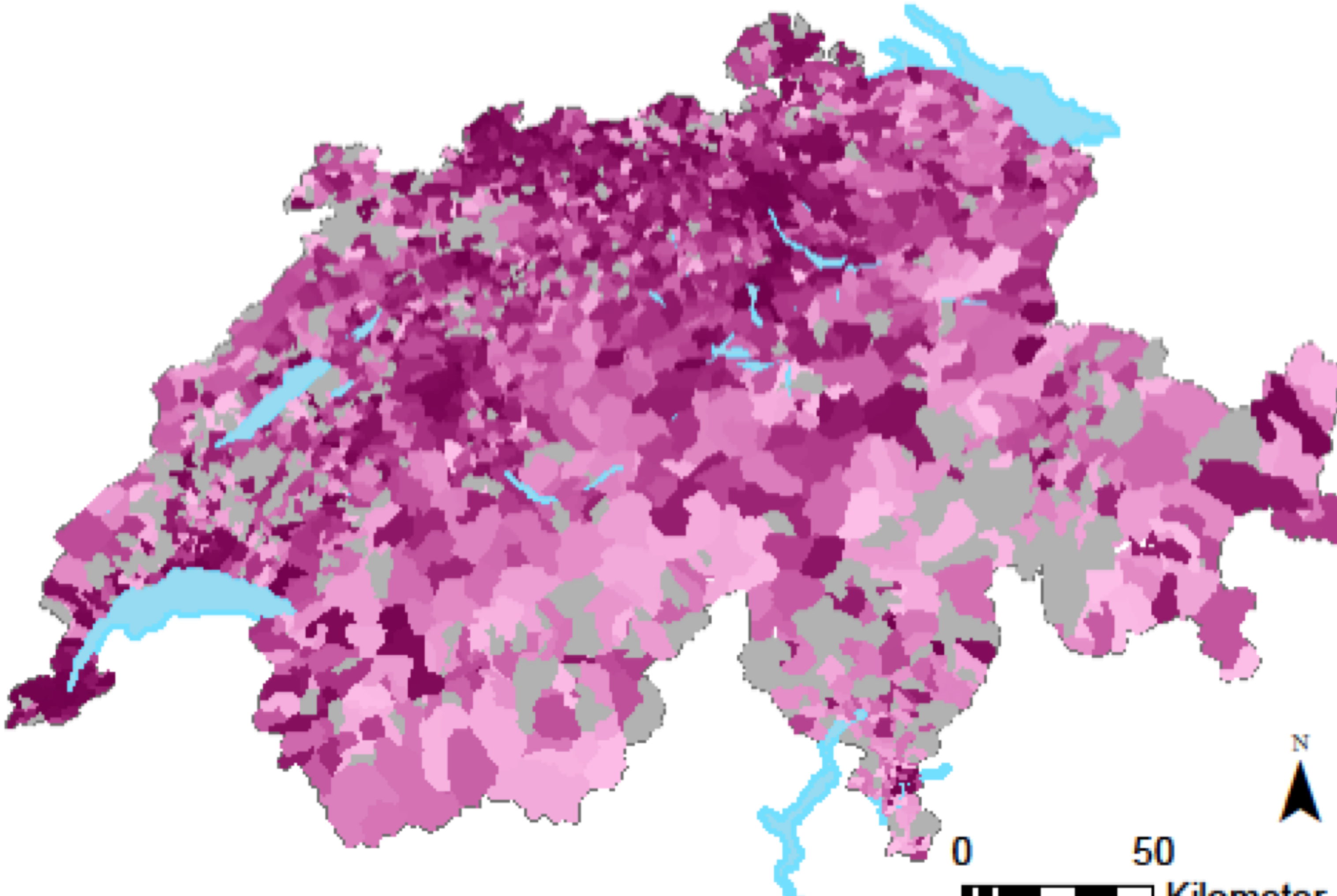


Population accessibility by public transport: 2010



Axhausen et al., 2015

Income levels: 2010



Grey: less then 20 observations
Pink to purple: Low to high wages

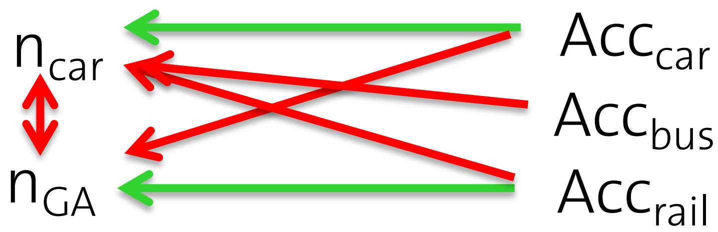
Axhausen et al., 2015

Spatial error model: Part 1

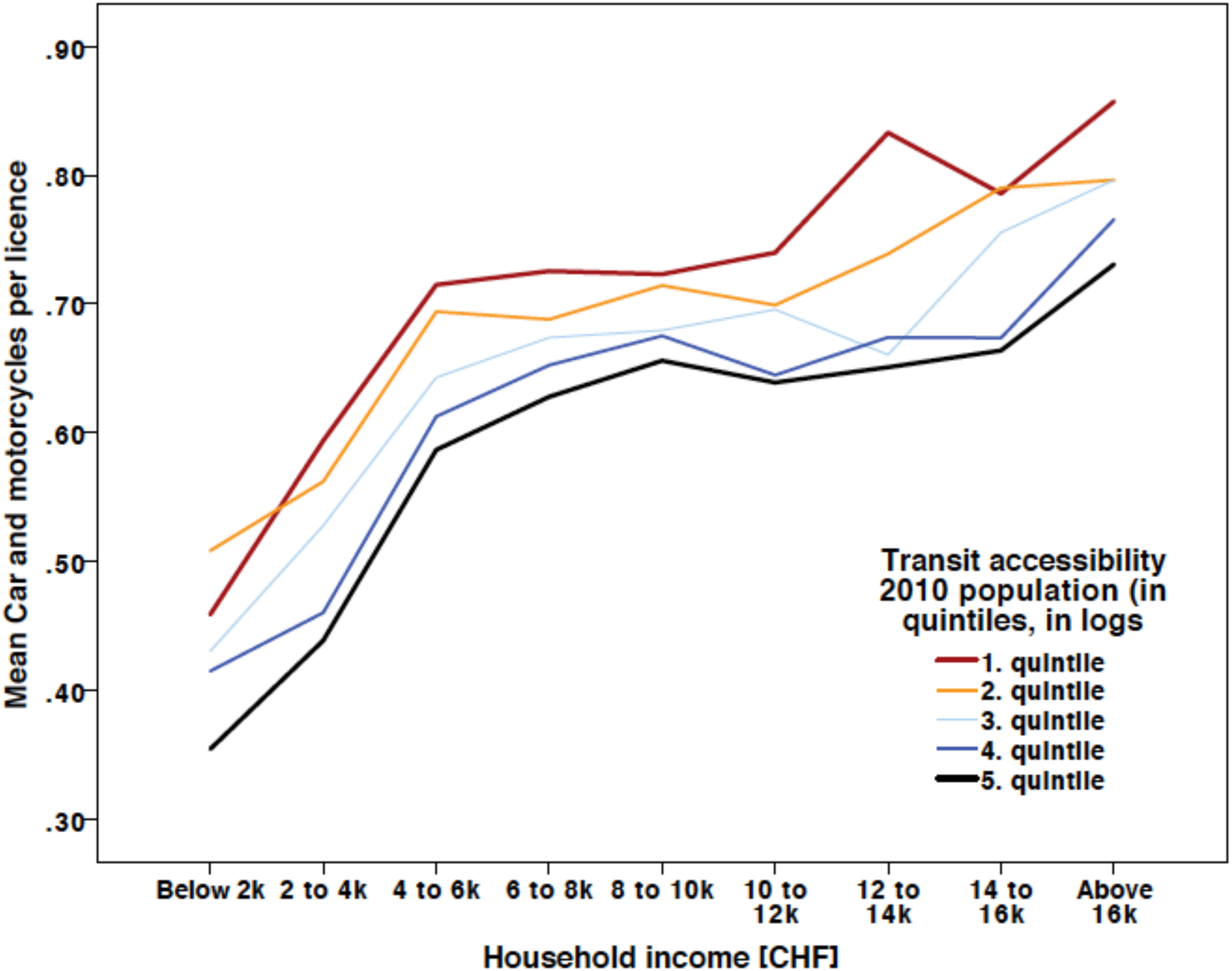
	2000		2005		2010	
Y: Ln mean salary	Estimate	Sig.	Estimate	Sig.	Estimate	Sig.
Intercept	6.43	***	7.07	***	6.89	***
Ln car accessibility	**0.01**	**	**0.02**	***	**0.01**	**
Ln public transport accessibility	**0.01**	**	**0.01**	***	**0.01**	*
Ln number of local employed	**0.02**	***	**0.01**	***	**0.01**	***
From outside Switzerland	-0.11	***	-0.09	***	-0.09	***
Short residence permit	-0.24	***	-0.13	***	-0.23	***
Average duration in-post	0.00	*	0.01	***	0.01	***
Ln average age	0.36	***	0.24	***	0.32	***
lamda parameter	**0.33**	***	**0.41**	***	**0.40**	***
Nagelkerke pseudo-R-squared	0.69		0.67		0.62	
Residuals' spatial autocorrelation	**-0.009**		**-0.009**		**-0.007**	
# observations	1448		2298		2229	

Axhausen et al., 2015

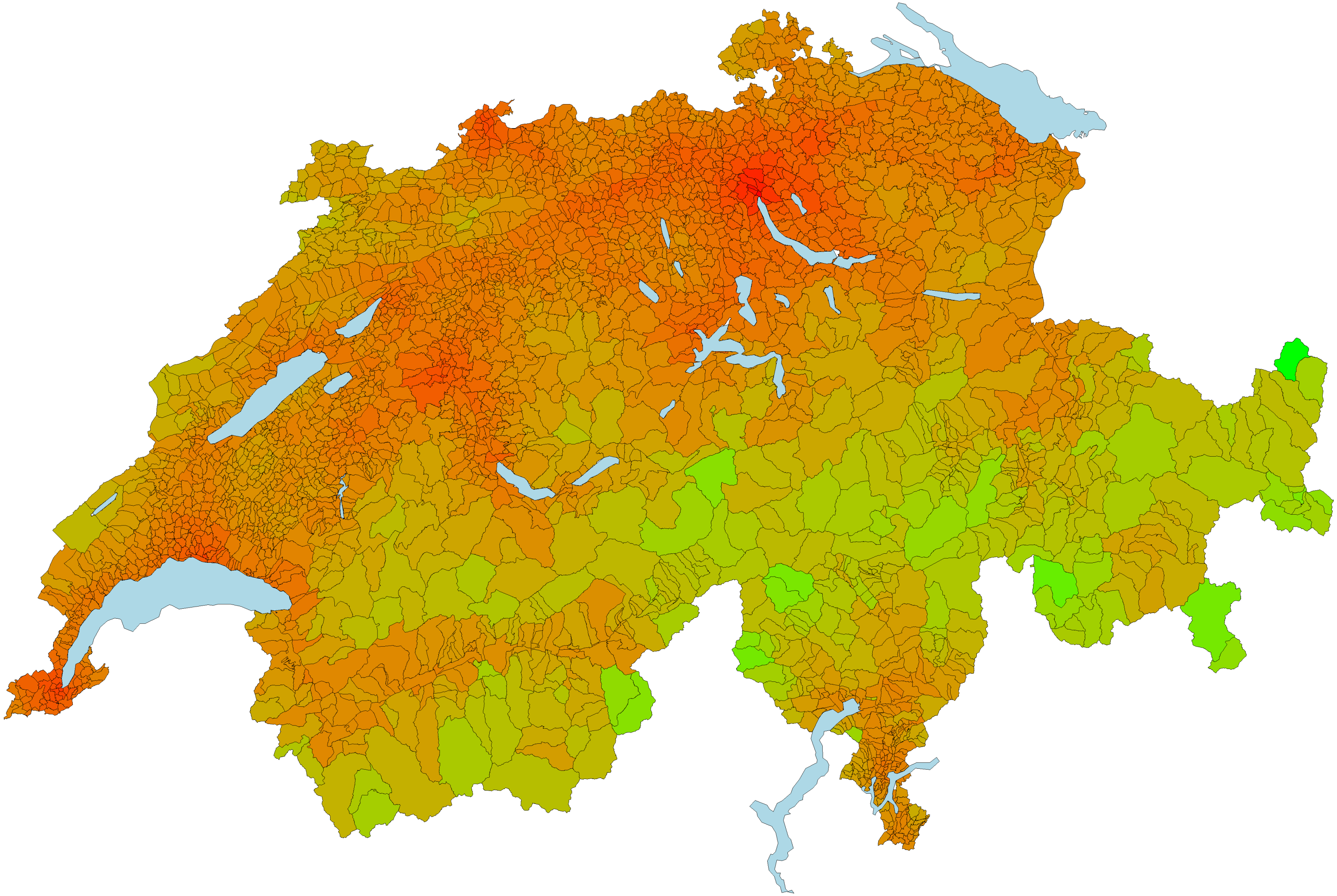
Accessibility and mobility tools: Swiss case



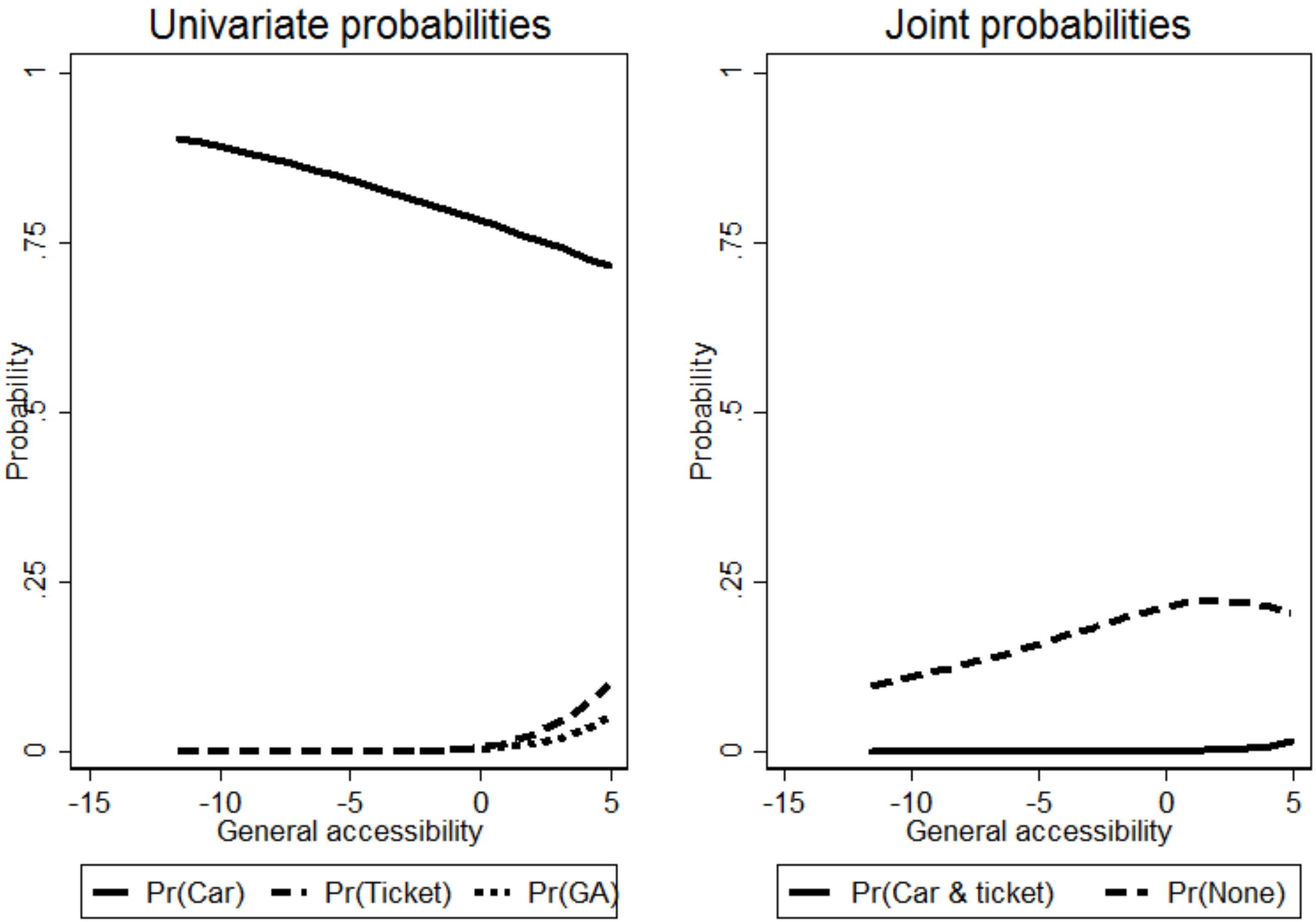
Accessibility and car ownership in Switzerland



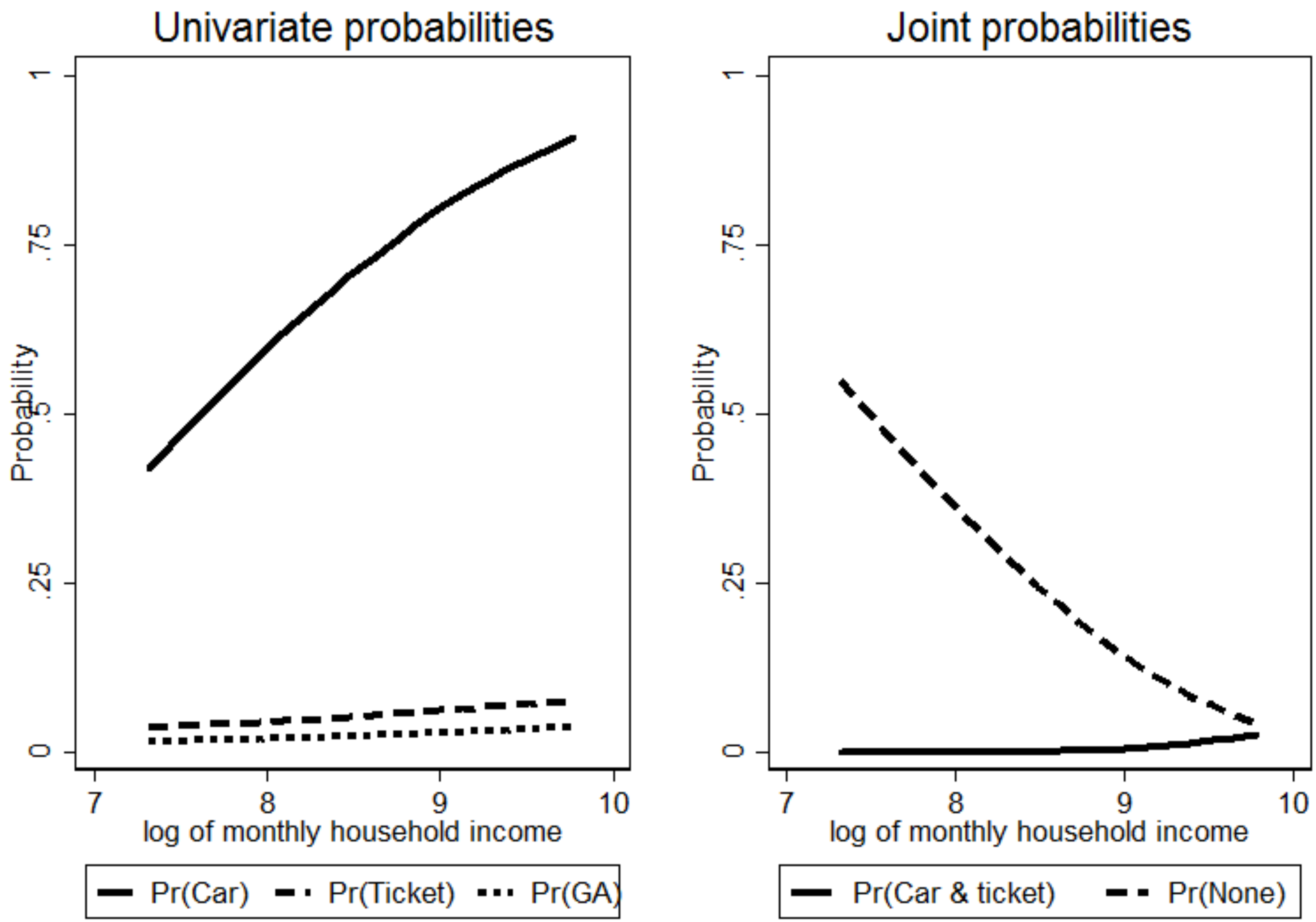
Switzerland: general accessibility



Switzerland: Probabilities by general accessibility



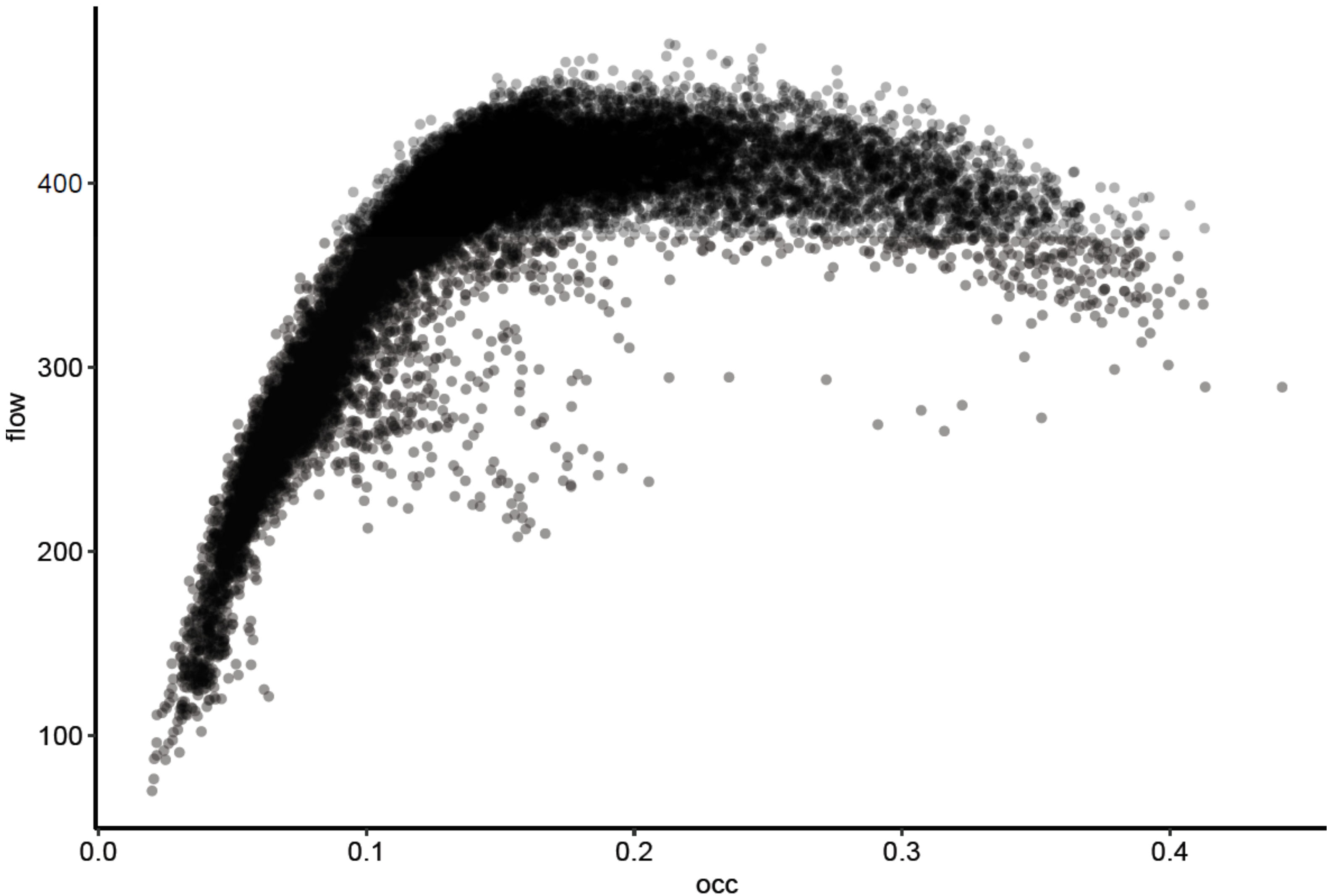
Switzerland: Probabilities by log of income



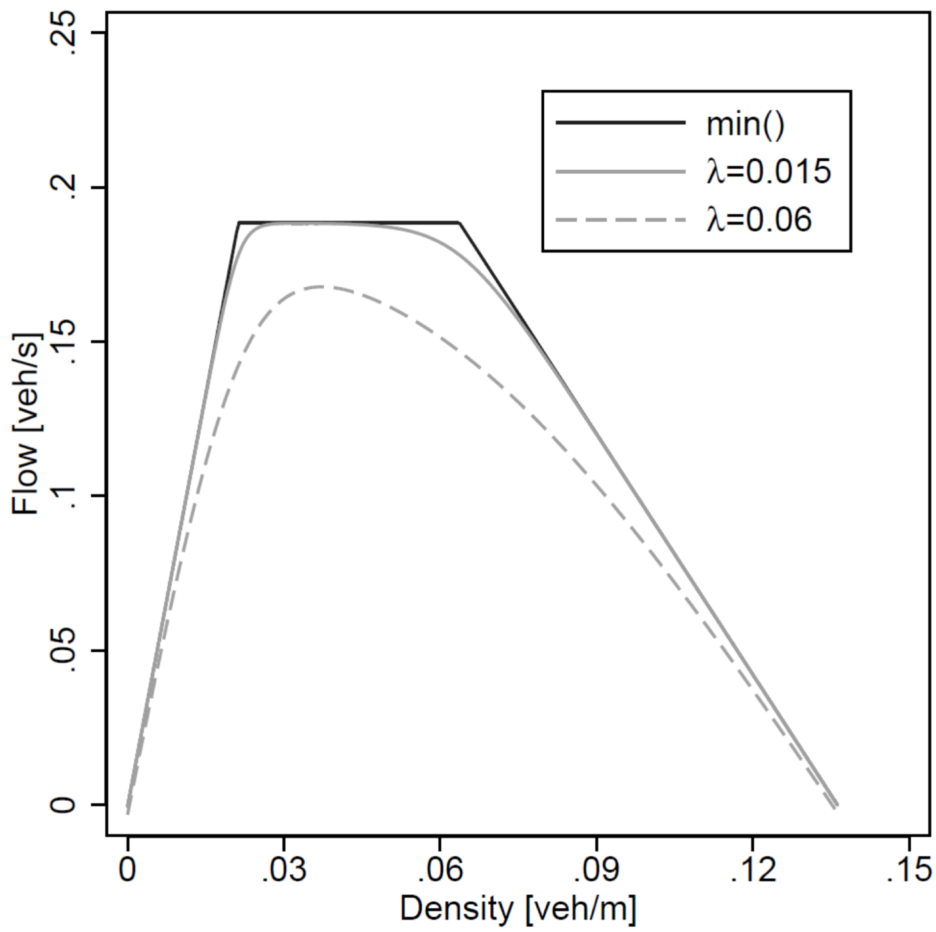
Fleet size and speeds

MFDs as a measure of network capacity

MFD data for one year (Wiedikon, Zürich)

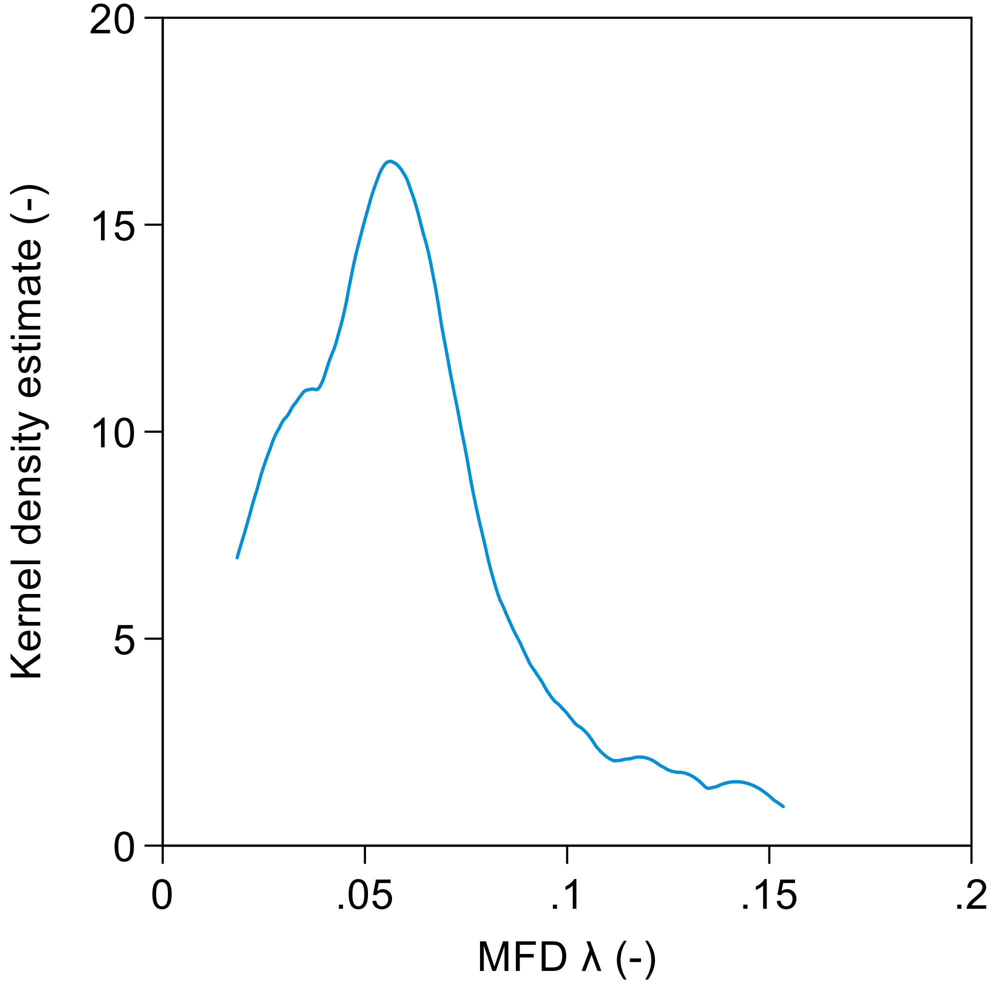


A functional form for the MFD

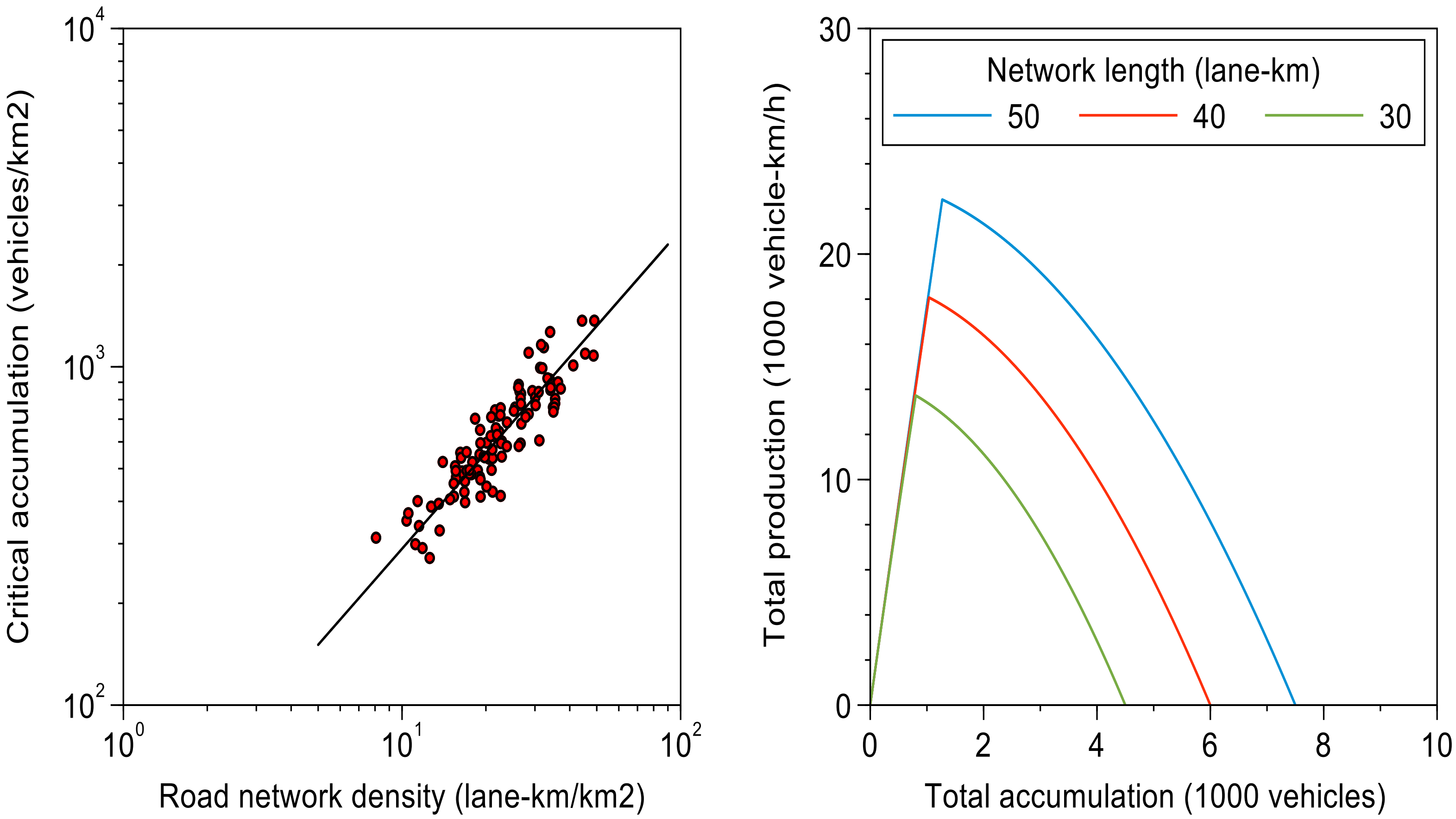


$$q(k) = \min\big(vk; Q; w(\kappa - k)\big)$$
$$\approx -\lambda \ln\left(\exp\left(-\frac{vk}{\lambda}\right) + \exp\left(-\frac{Q}{\lambda}\right)\exp\left(-\frac{w(\kappa-k)}{\lambda}\right)\right)$$

Variance of the λ



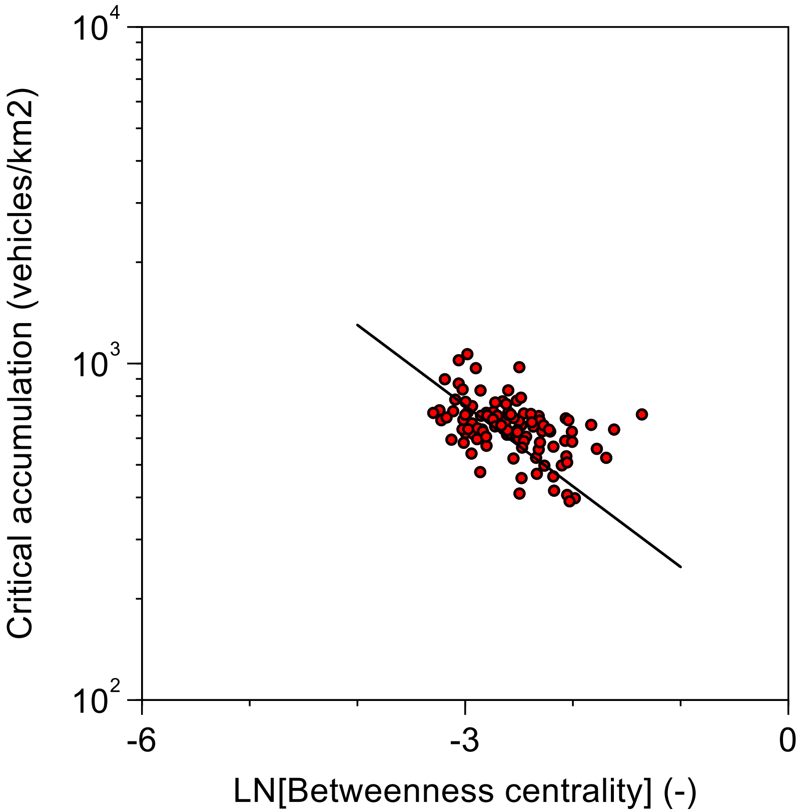
Influence of road network density

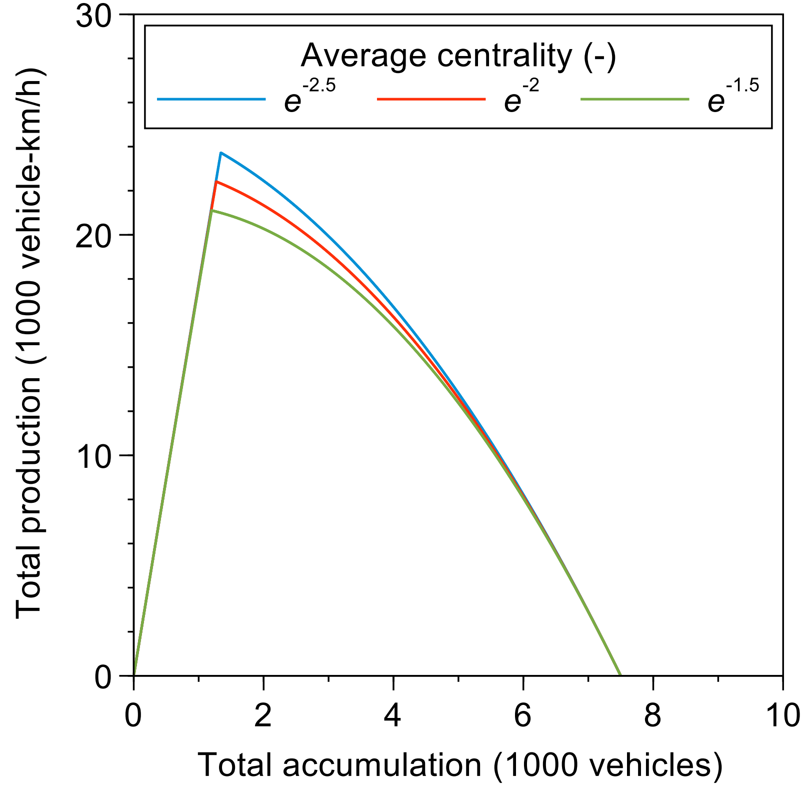


Elasticity $\varepsilon \approx 0.8$ (sublinear) → Decreasing marginal returns from road network expansion

Loder et al. (2019). Scientific Reports (in press).

Influence of network design: Betweenness-Centrality

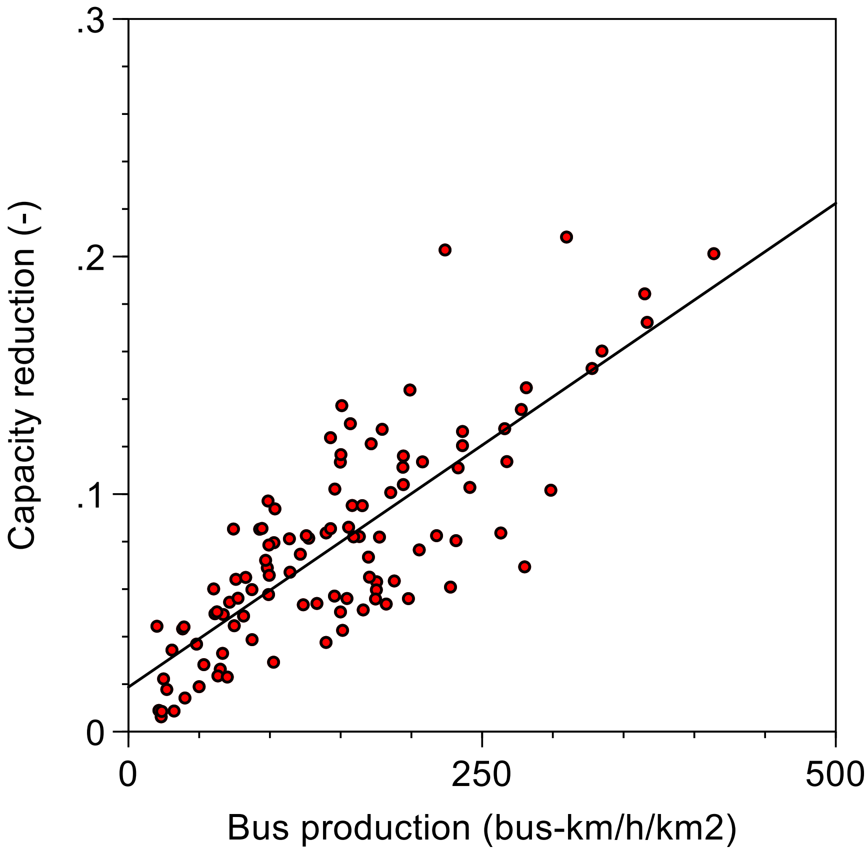


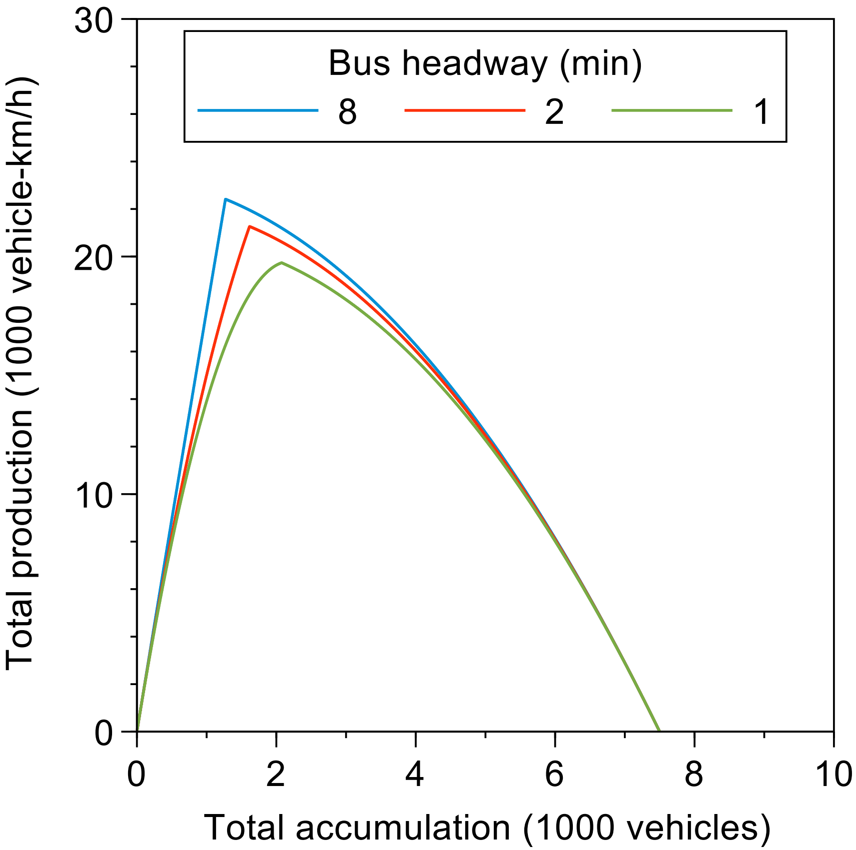


Network design measured in average betweenness centrality. Higher value indicates more bottlenecks (e.g. bridges)

Loder et al. (2019). Scientific Reports (in press).

Influence of bus operations





Loder et al. (2019). Scientific Reports (in press).

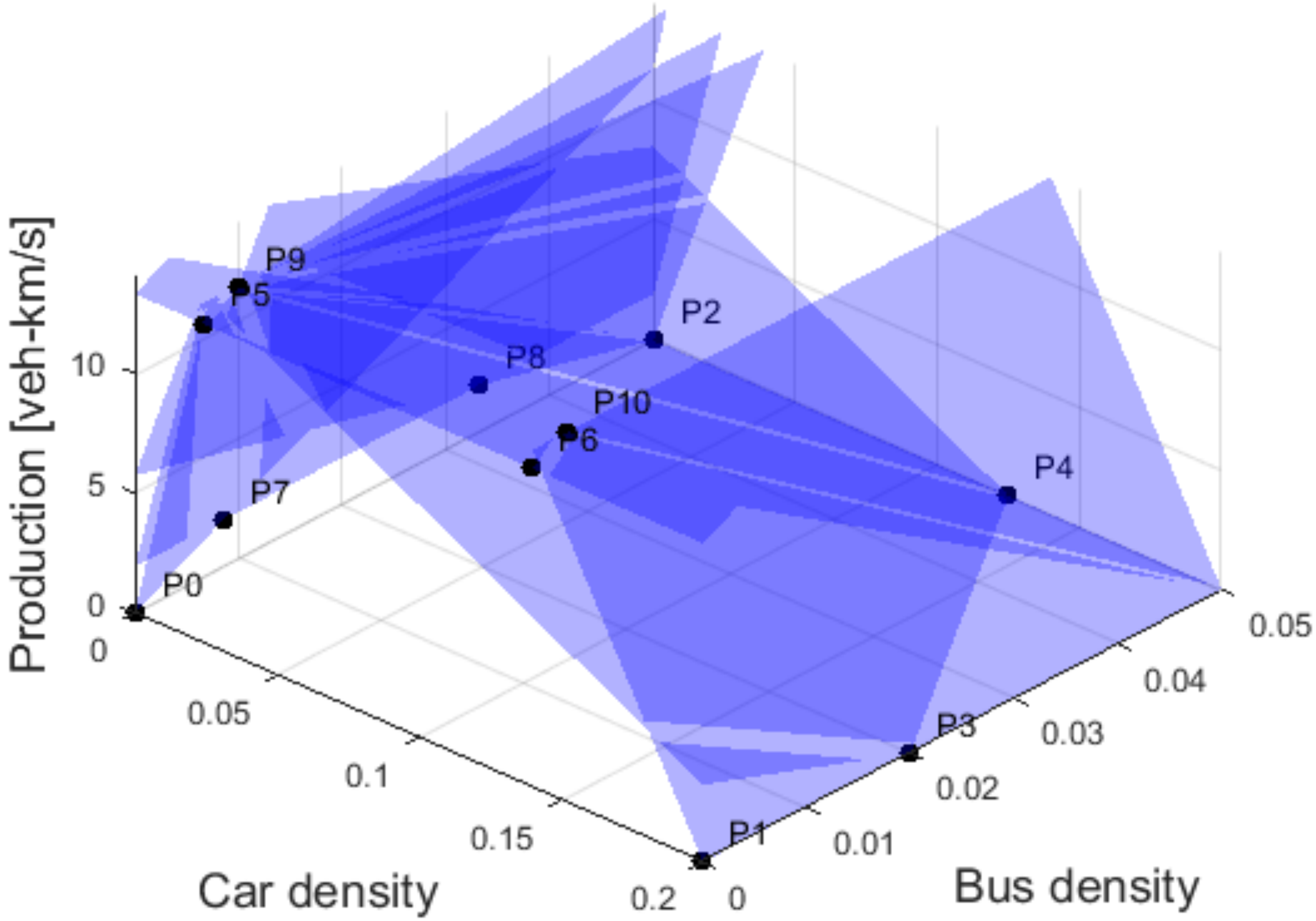
Extending the approach to 3 modes and 3D MFDs

Defining a functional form for the 3D MFDs

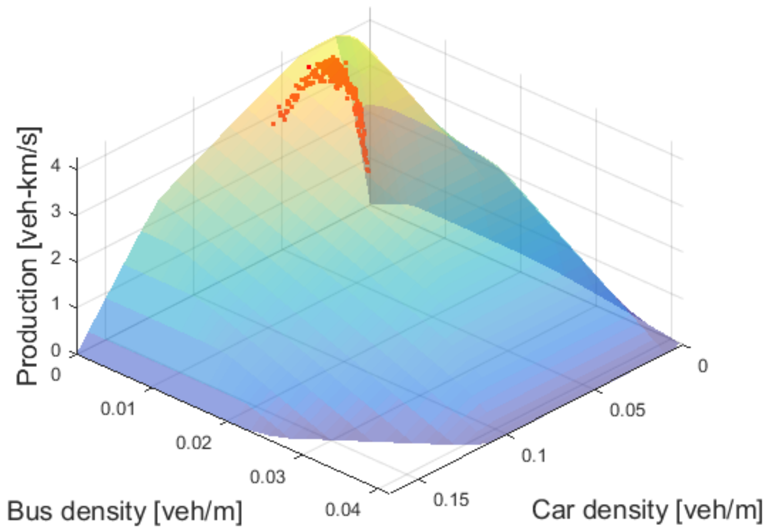
Define the planes (cuts) as upper limits for the 3D-MFD

- Road network
- Signal control
- Bus priority strategy
- Bus headway
- Stop headway
- Bus network design (e.g. hub and spoke)
- Dedicated lanes

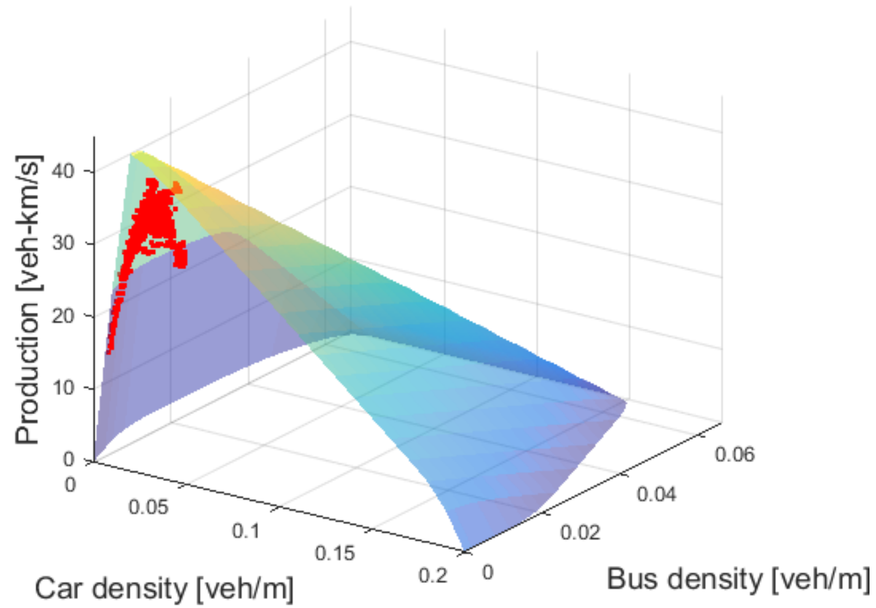
Create planes



First results using the approximation approach



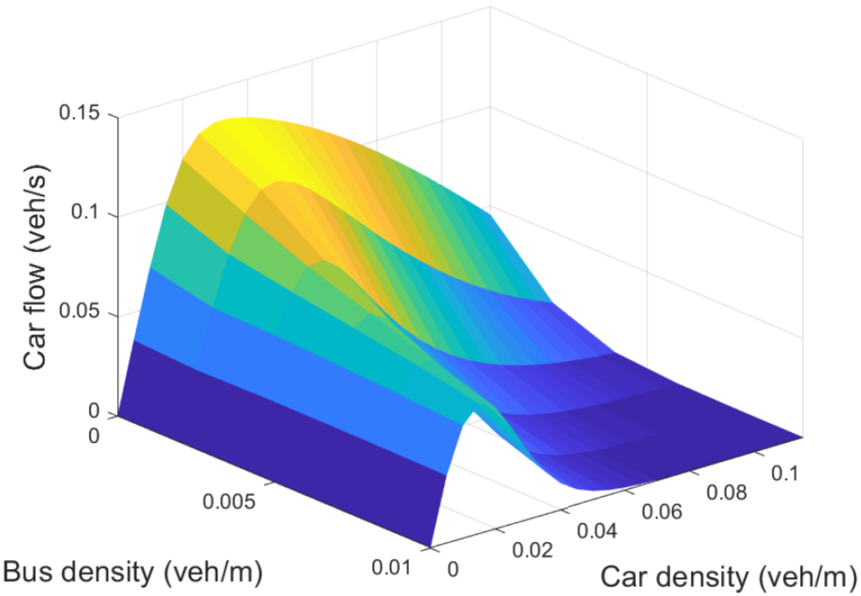
Zurich

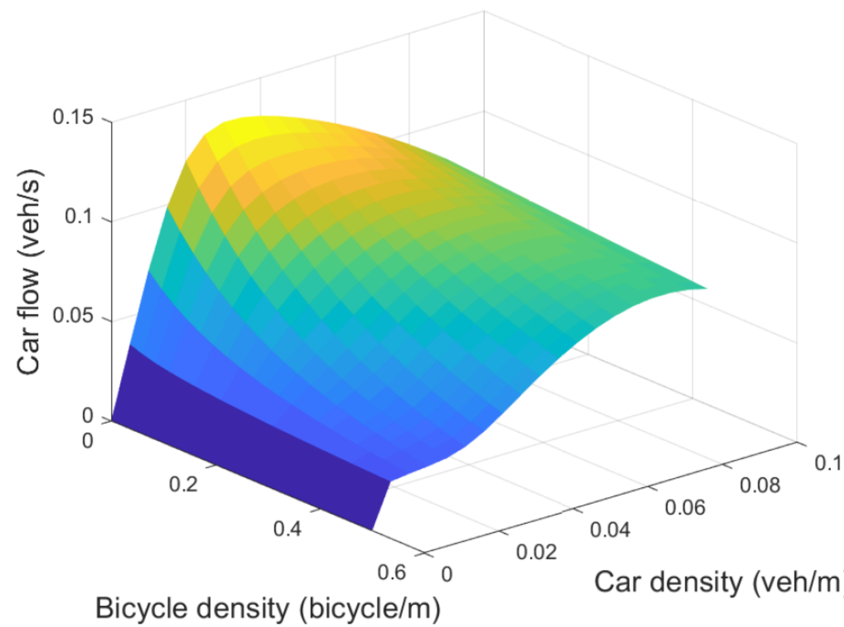


London

Loder, Bressan, Ambühl, Bliemer and Axhausen (2018)

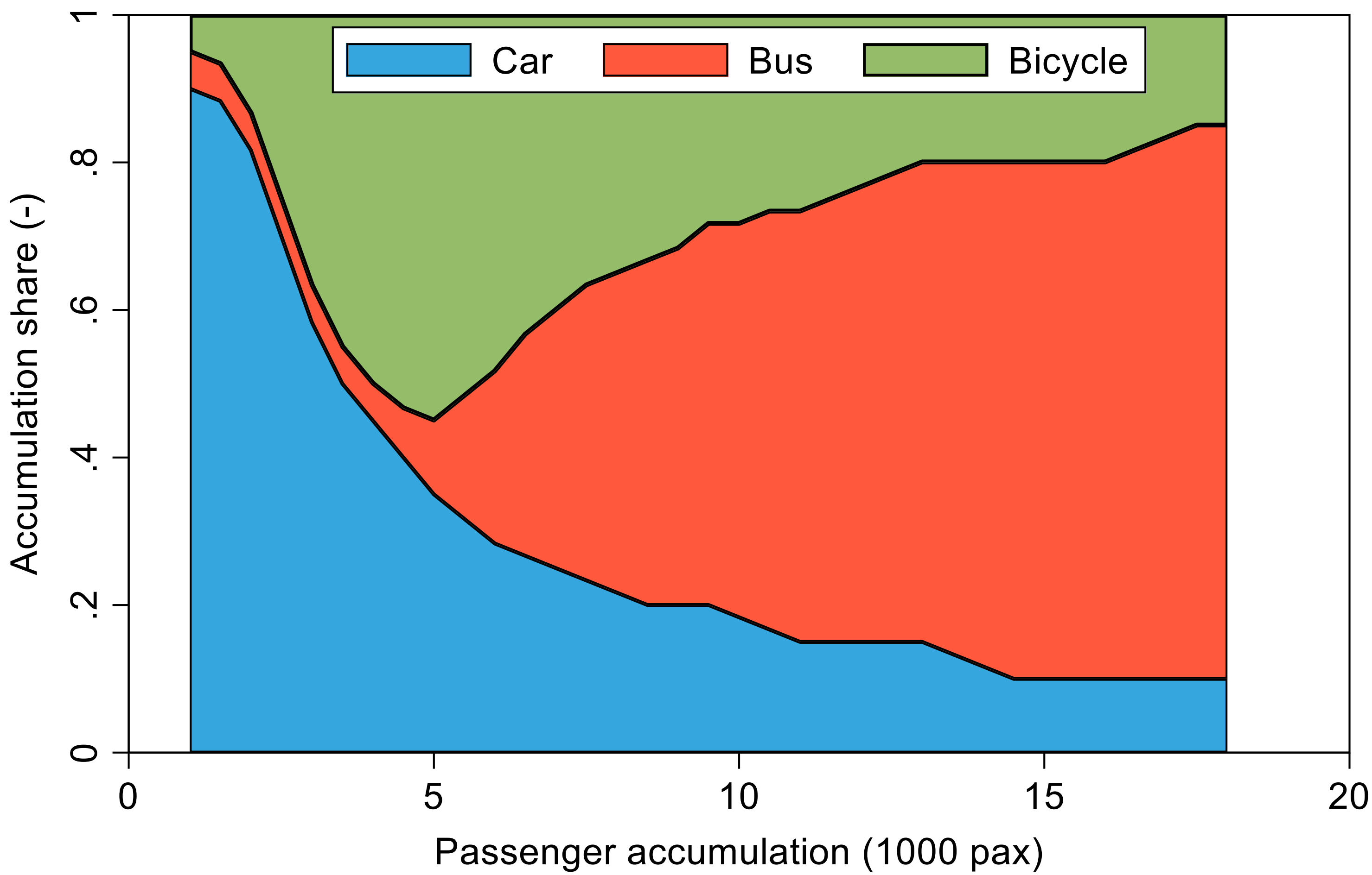
The resulting multimodal MFDs extending 2-fluid model





Loder, A. et al. [illegible]al framework for multi-modal macroscopic fundamental diagrams. Transp. Res. Part B Methodol. review, (2019).

Applications: Passenger 3D-MFD



Loder, A. et al. Capturing network properties with a functional form for the three-dimensional macroscopic fundamental diagram. Transp. Res. Part B Methodol. 129, 1–19 (2019).
Loder, A. et al. A general framework for multi-modal macroscopic fundamental diagrams. Transp. Res. Part B Methodol. review, (2019).

Defining an AV future

Some scenarios for a 2030 Level 5 vehicle future

Facets

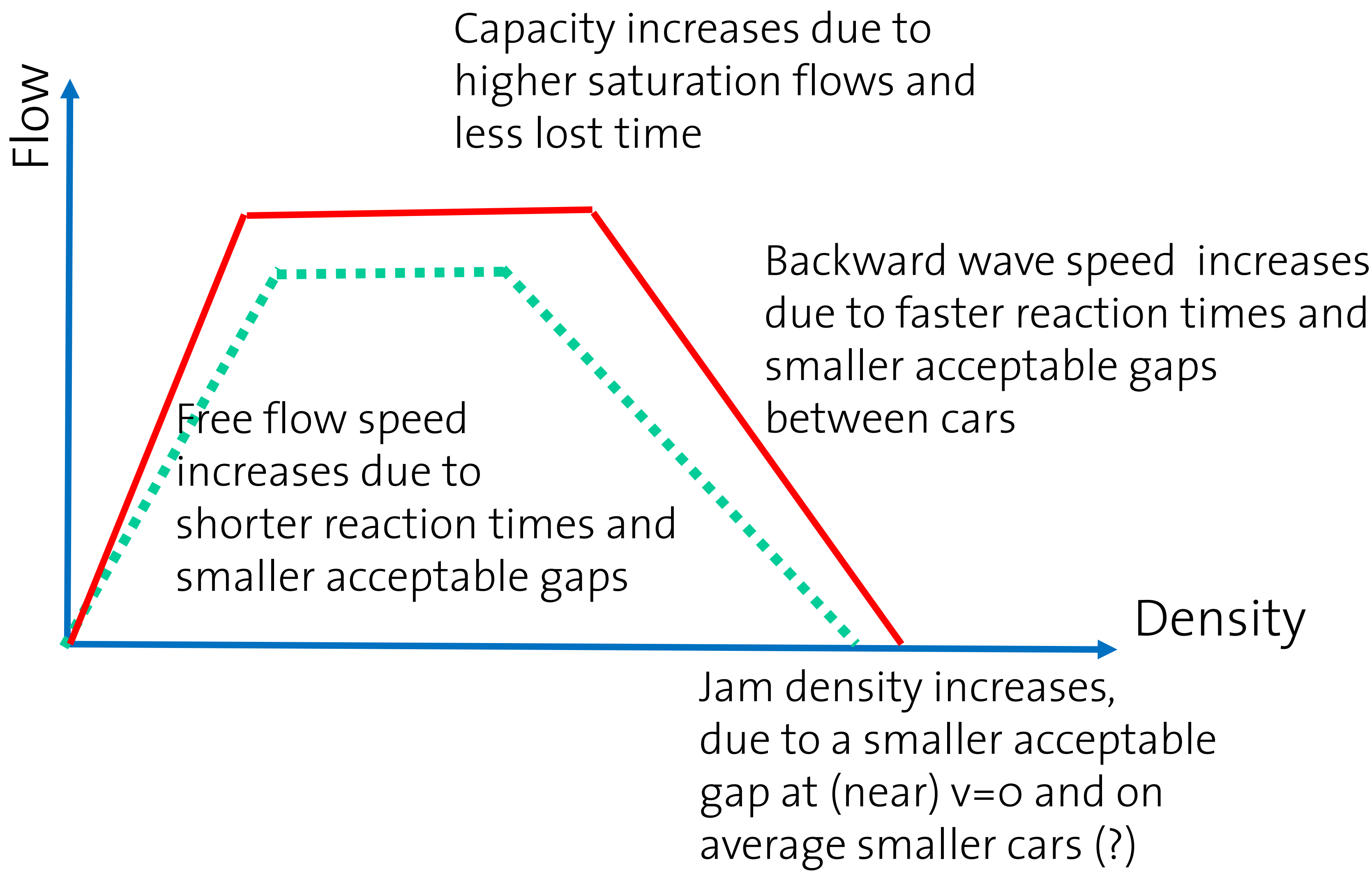
- Market structure (monopoly, oligopoly, dispersed)
- Role and extent of public transport
- System target (system optimum, user equilibrium)
- Type of traffic system manager
- Road space allocation
- Share of autonomous vehicles

Example scenario: Uber et al. take over

- Oligopoly of fleet owners
- Public transport scaled down to the high capacity modes
- System optimum via dynamic tolls and parking charges
- Operators negotiate slots with each other
- Road space allocation tends towards the slow modes
- 100% share of mixed size autonomous vehicles for cost reasons
- 100% share of electric vehicles for climate reasons

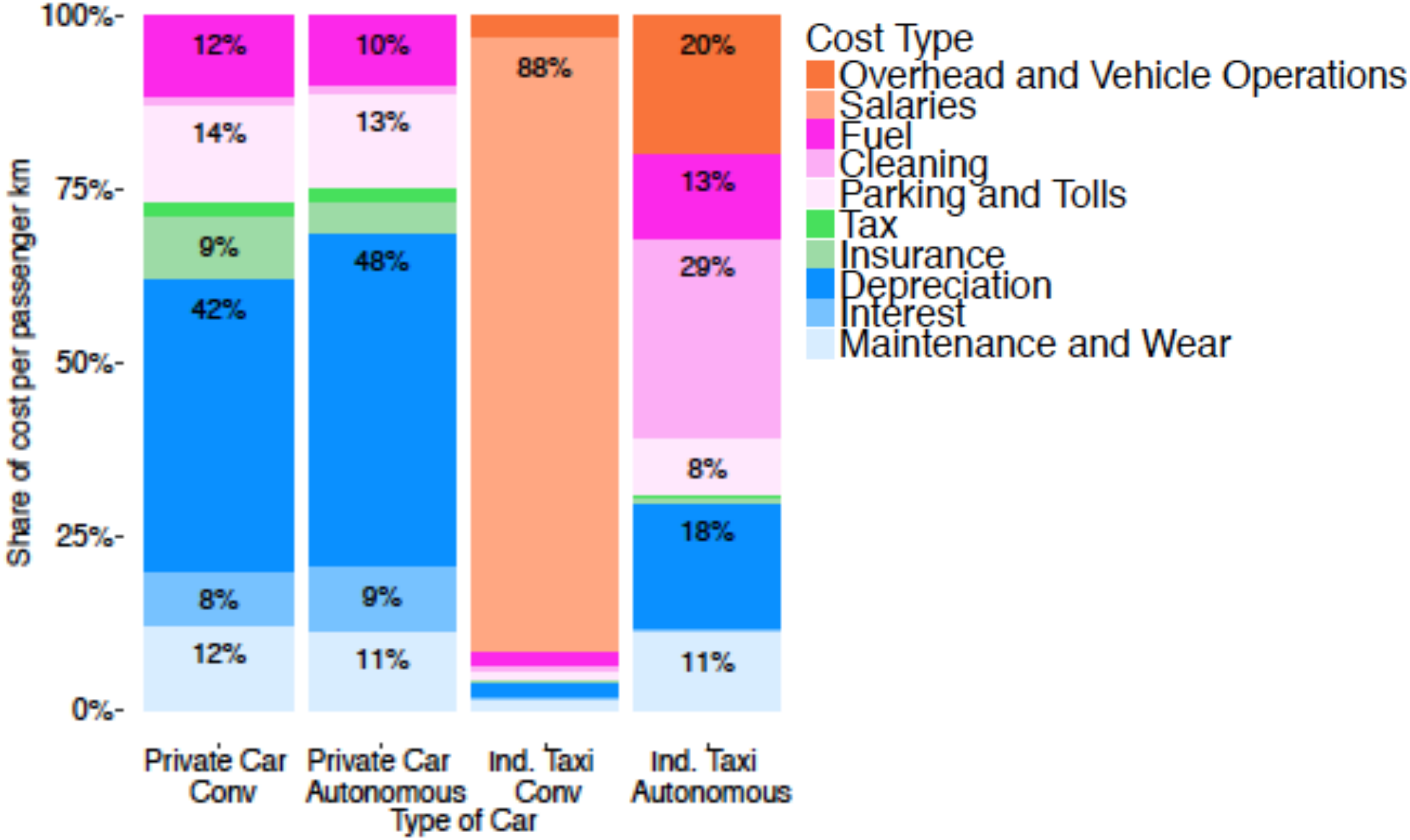
Changed network capacities?

Capacity effects at the network level: MFD before/after

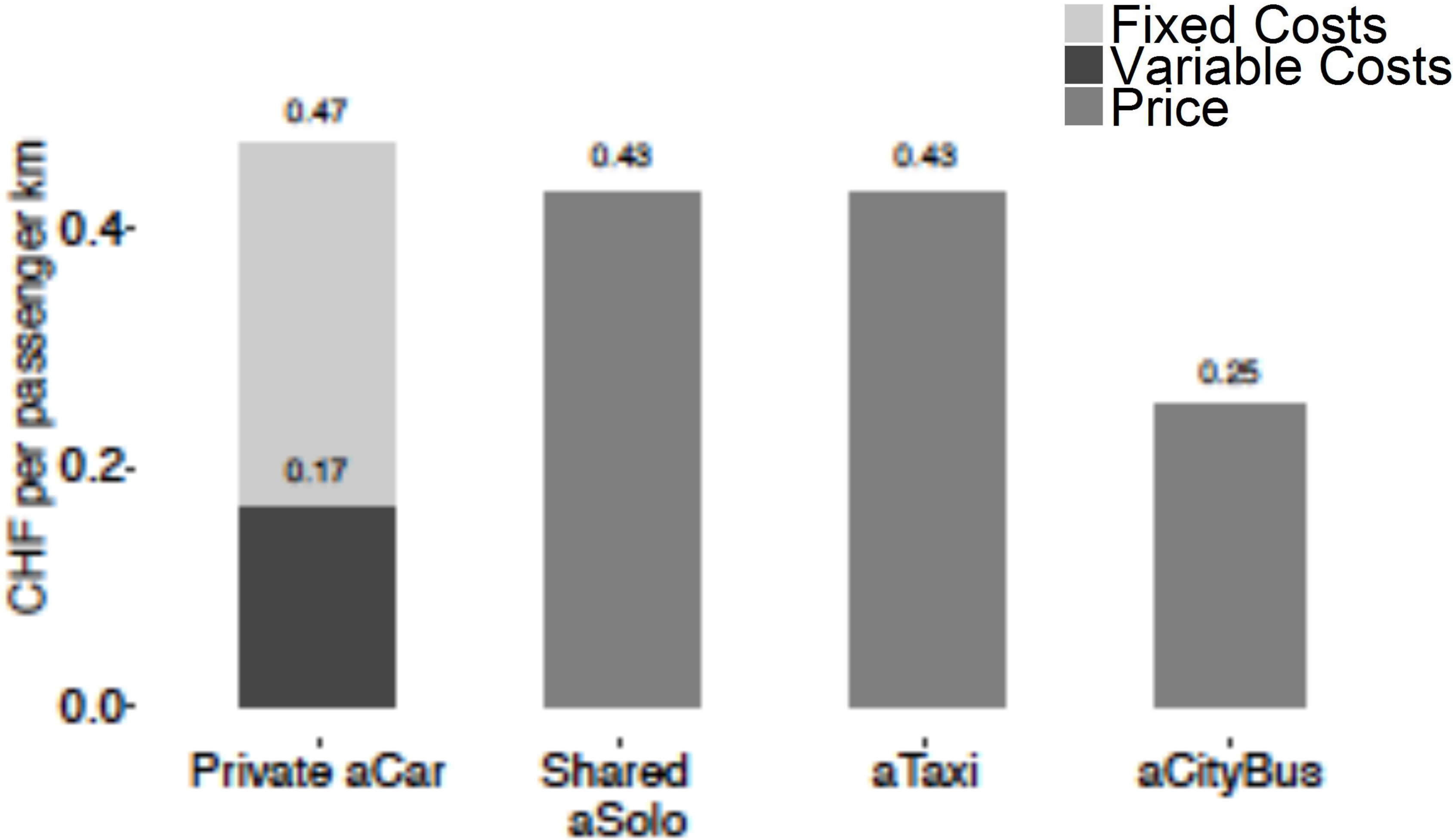


A forecast of the full costs of AVs

Updated full cost/pkm estimate (current occupancy levels)



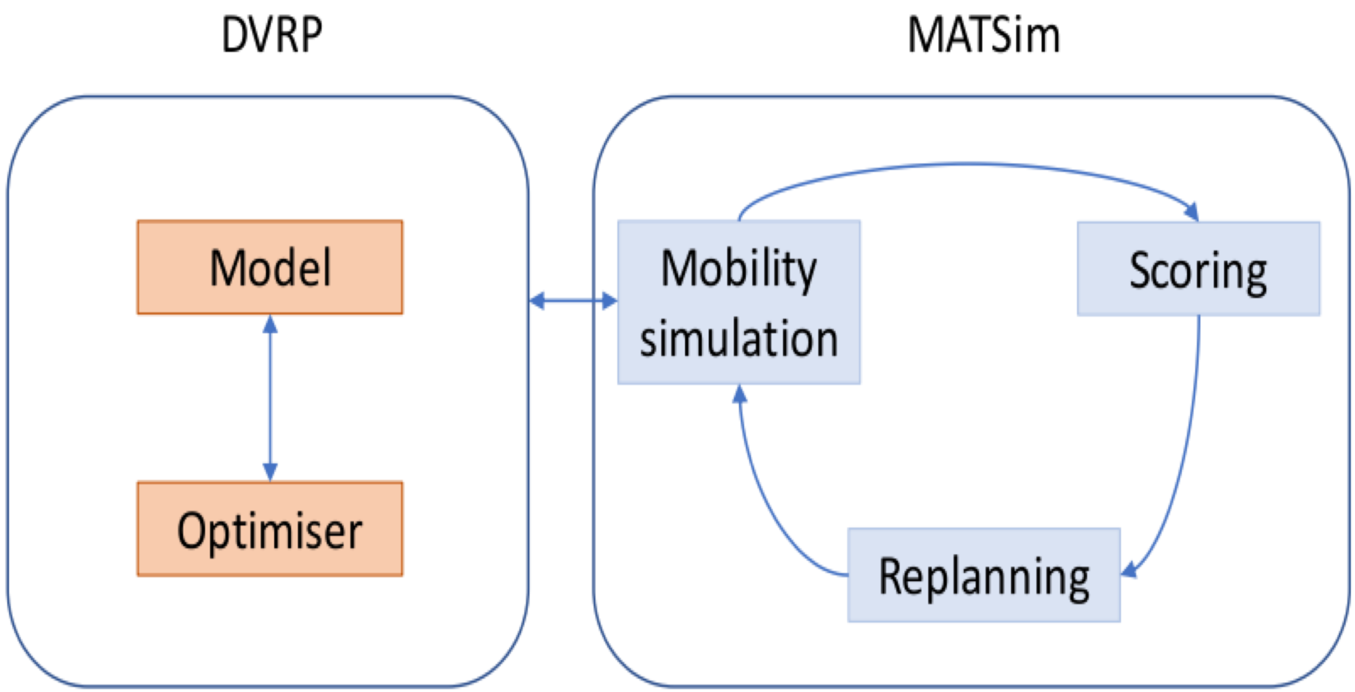
Updated full cost/pkm estimate (current occupancy levels)



What impact would the AV taxis have?

MATSim: An open-source agent based simulation

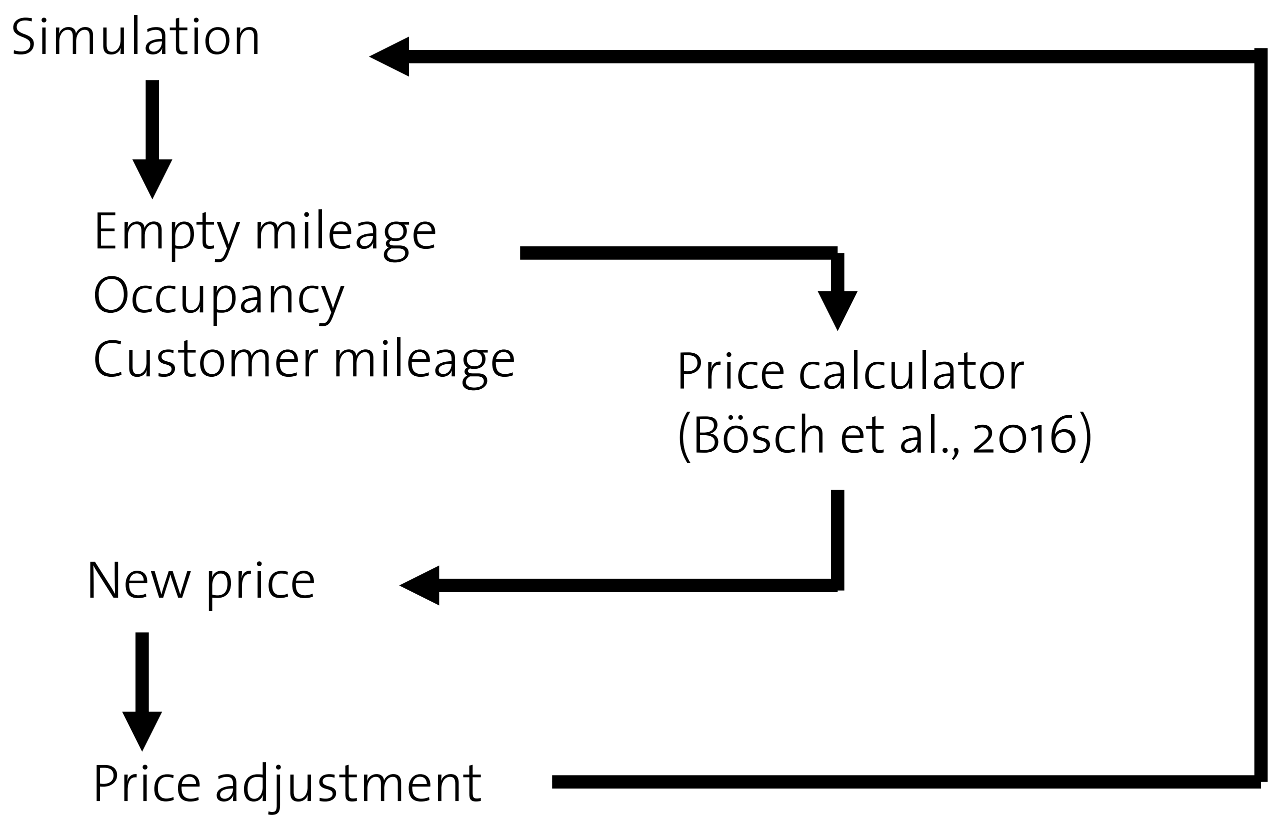
Simulation Framework: DVRP extension



Maciejewski et al. (2017)

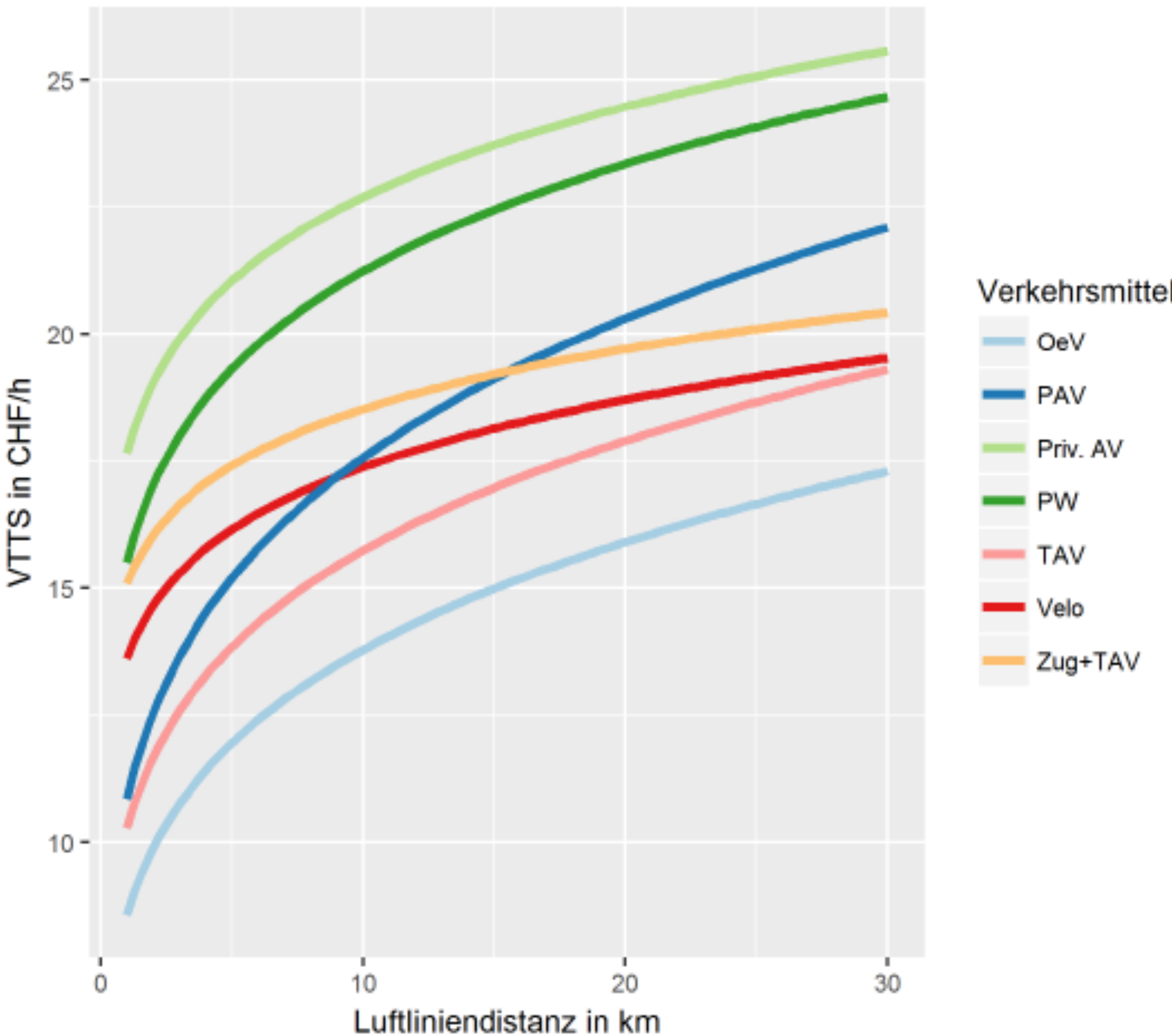
Zürich AV scenarios

aTaxi price and fleet size determination



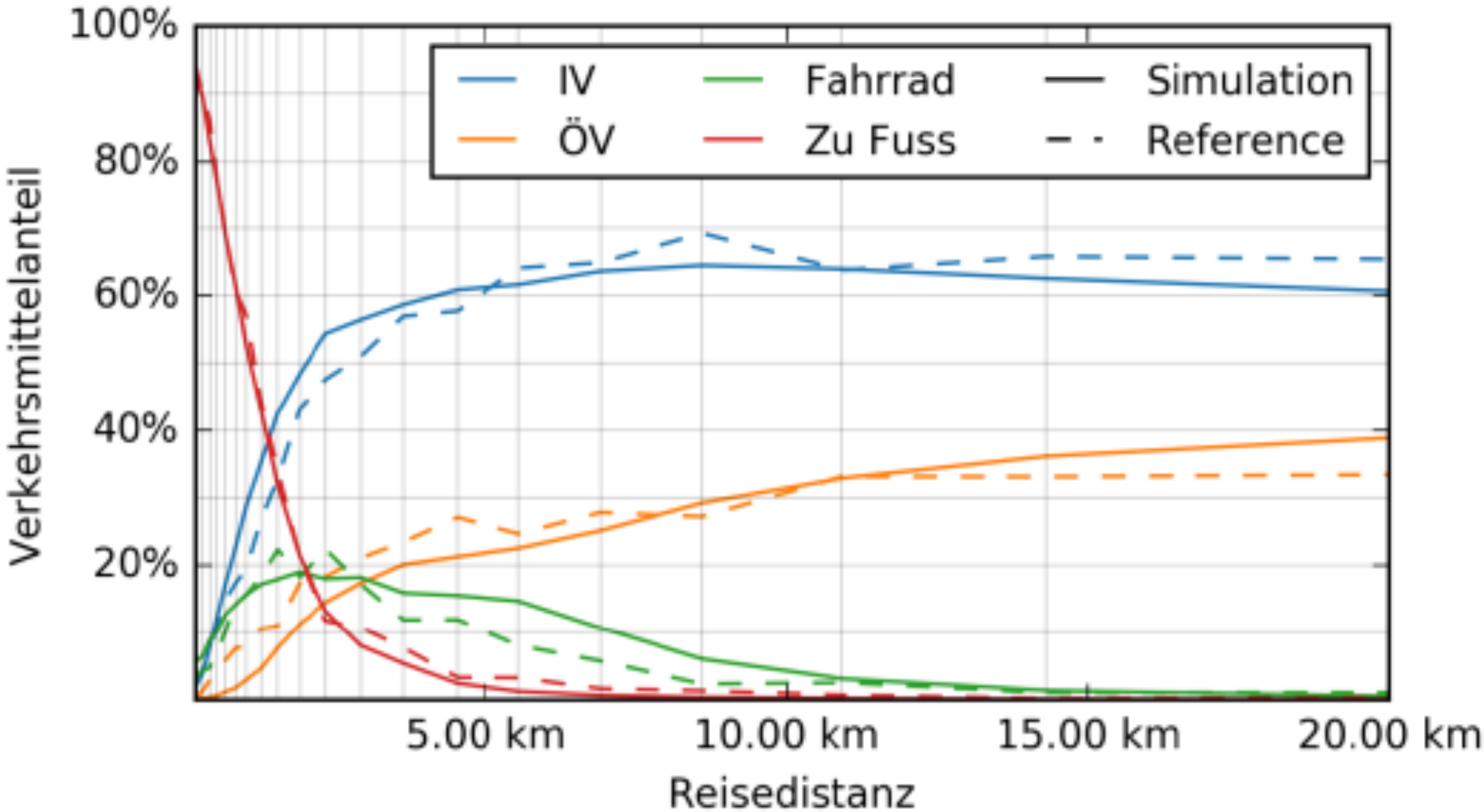
SC-based mode choice model

VOT by mode



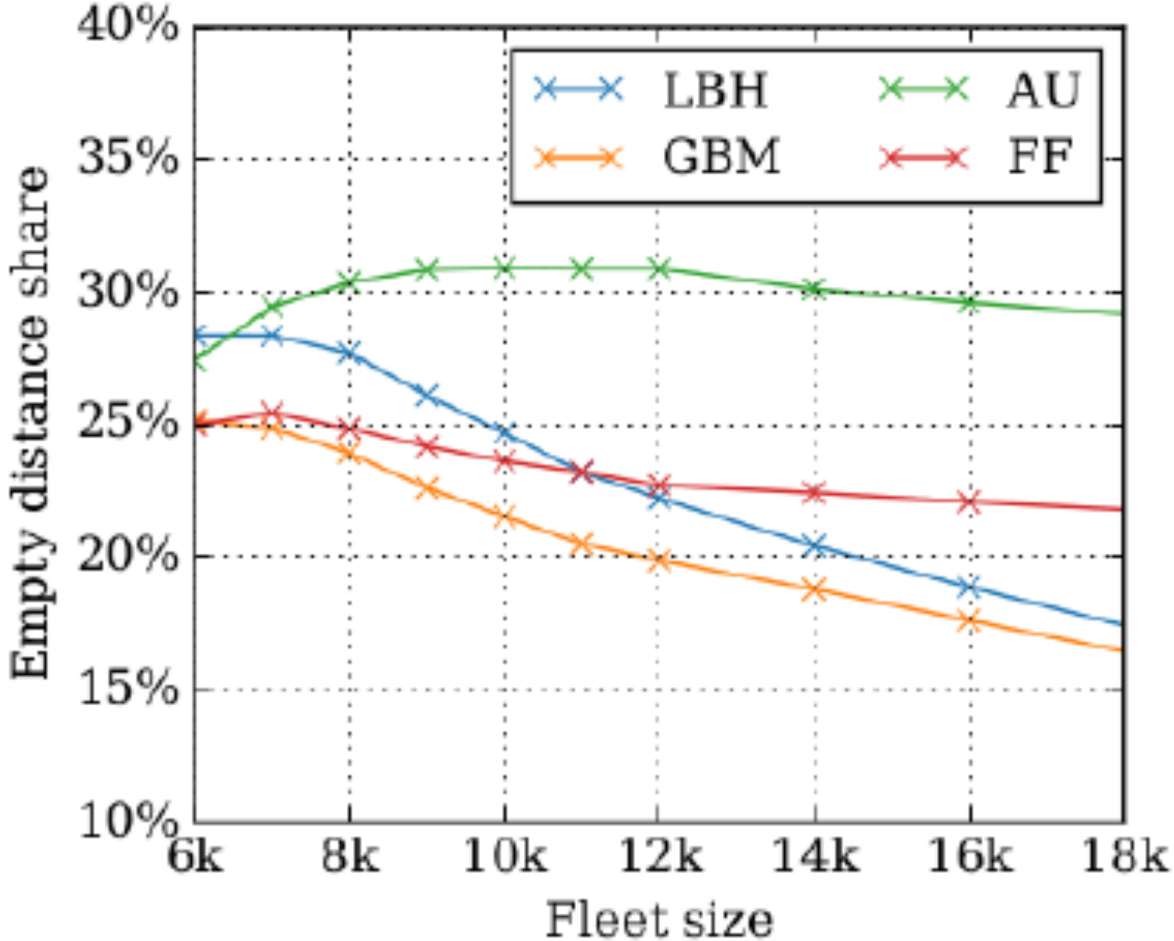
Lyons 18

Calibration of the base scenario: Mode by distance



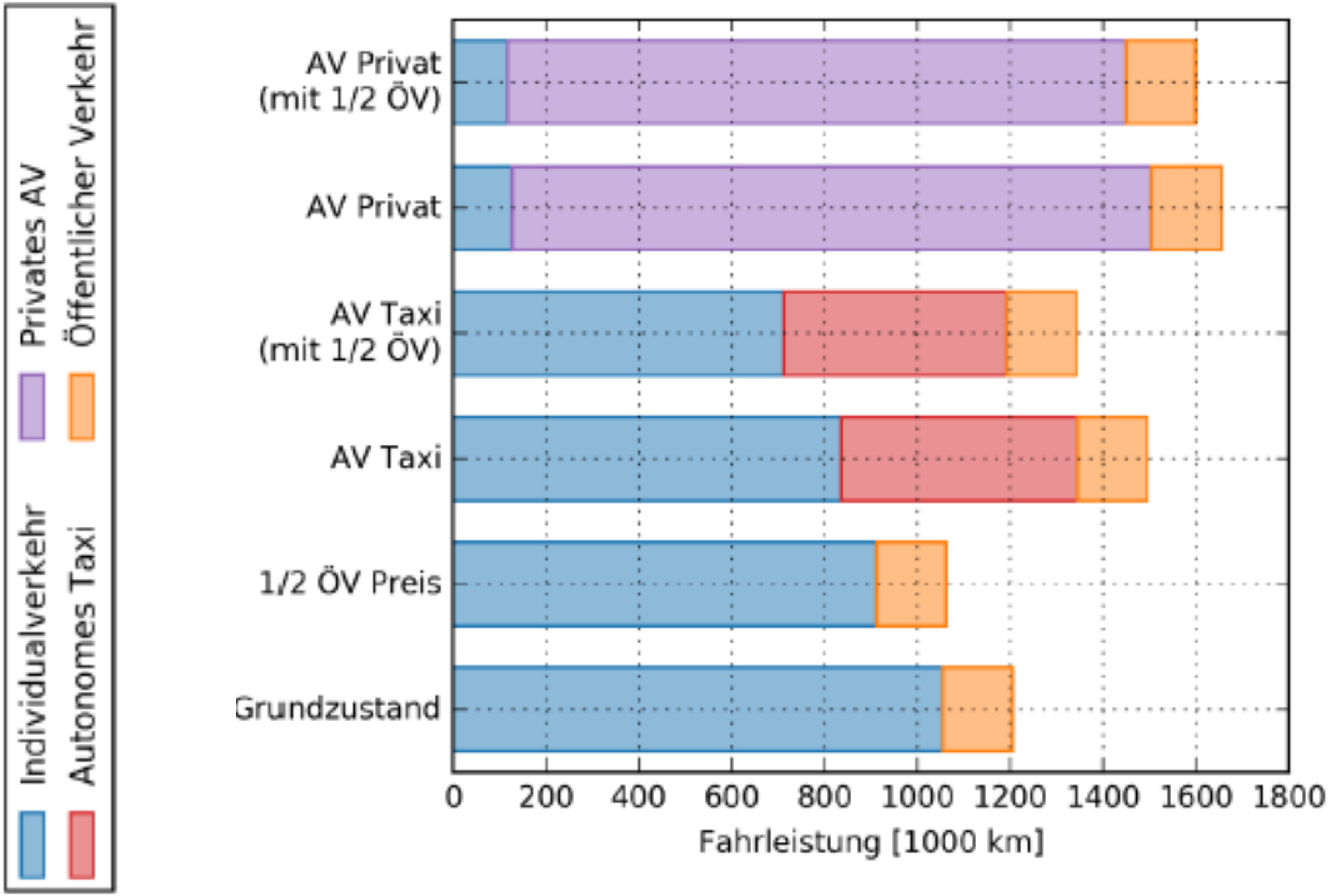
Fleet size determination

AV dispatch – Empty mileage for 4 algorithms

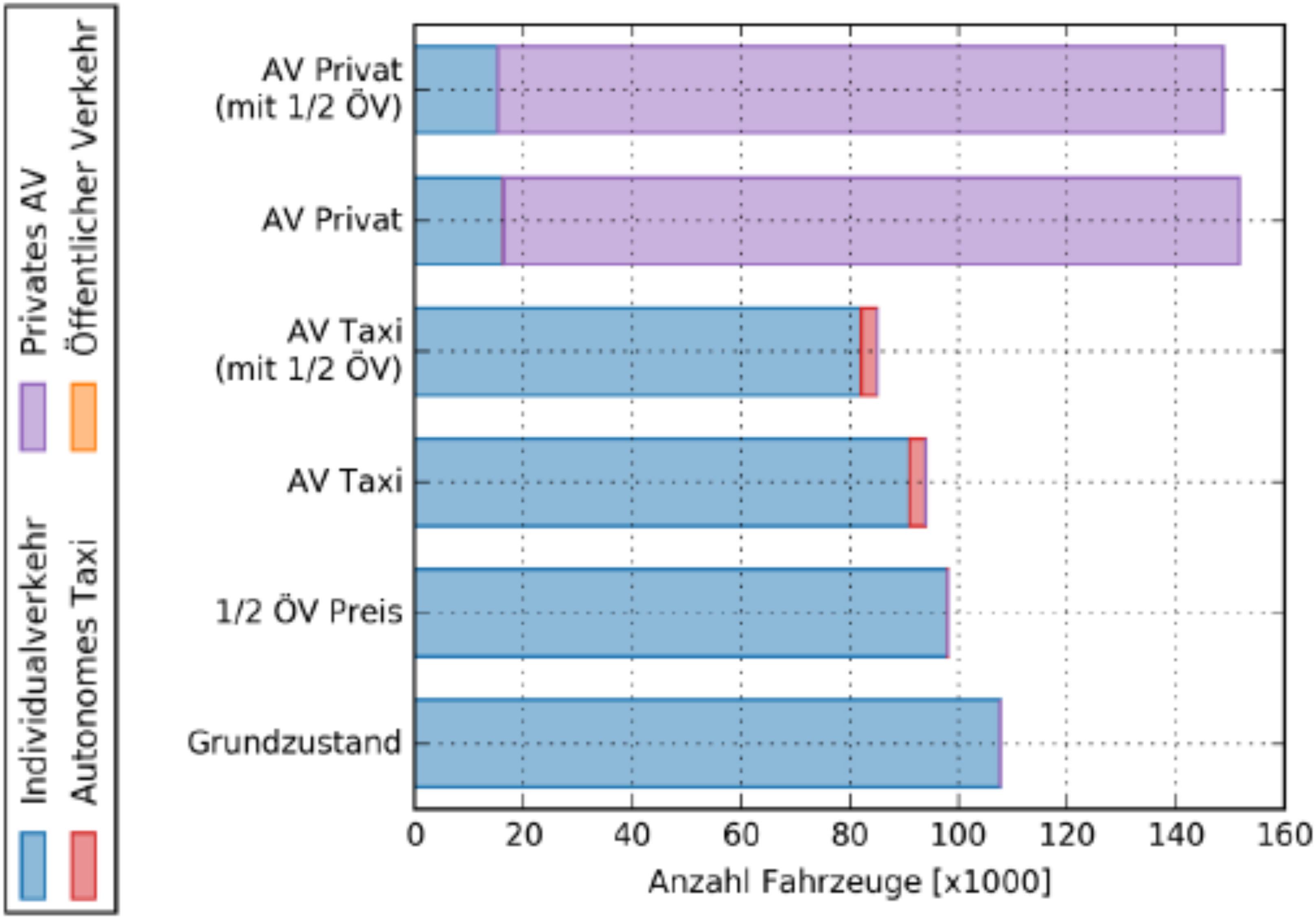


What happens in the city?

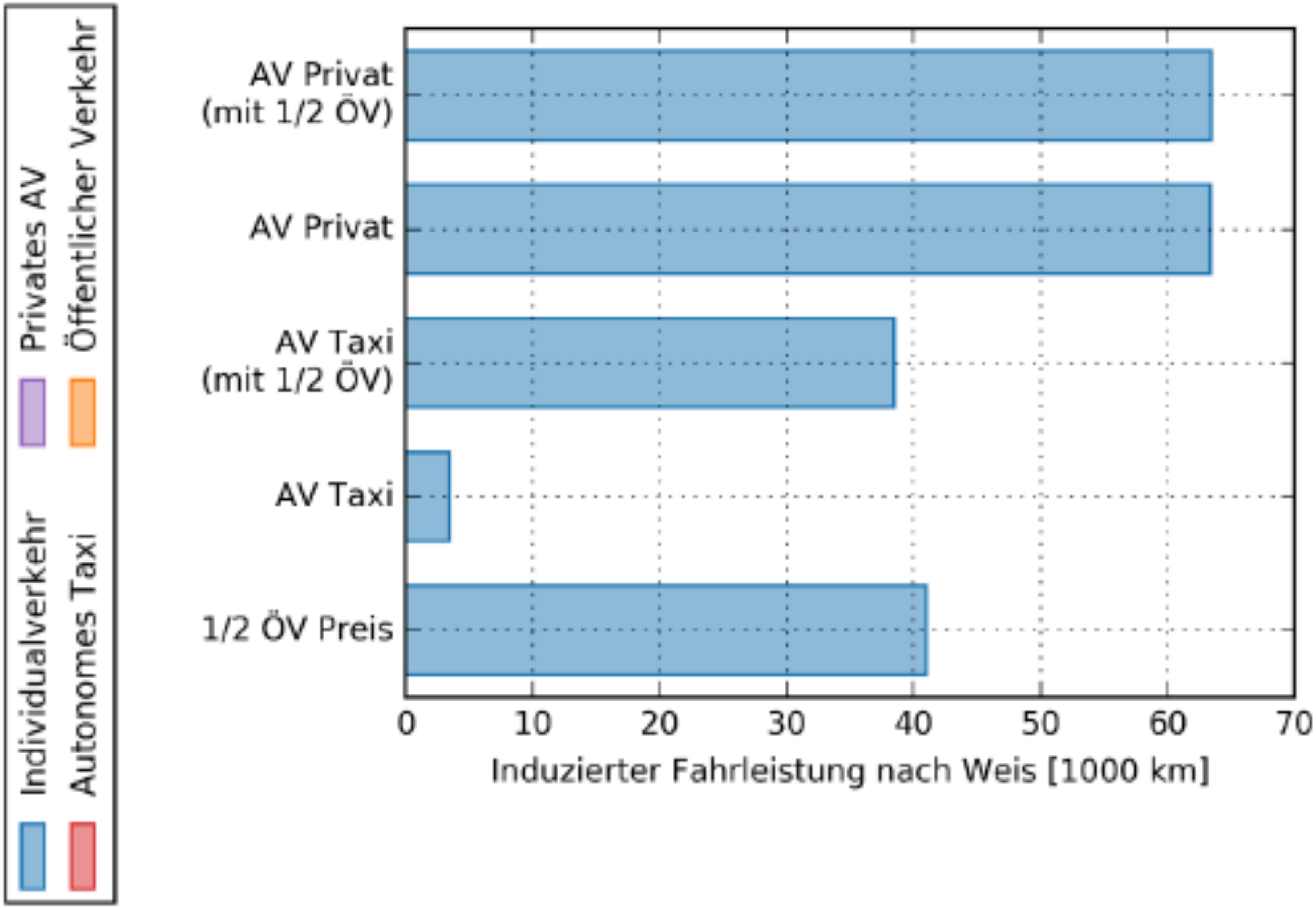
Results – city only: VKT



Results city only: Number of vehicles



Results city only: Induced VKT



What should we do next?

Next steps on AVs

- More work on acceptance of AV
  - By age and education
  - By location of residence
- More work on future cost/prices by type of operator
- More work on the efficiency of the fleets (empty kilometres, parking, drop off/pick up, rebalancing, dispatch)
- More work on how to achieve system optimum with fleet operators
- More work on future ‘public transport’ ?

Next steps on the basic dilemma

- More work on acceptance of pricing
  - By income and “perspective”
  - By location of residence

- More work on the productivity elasticities
- More work on the impact of automation on urban form (e-commerce) and productivity

- More work on the structure of electric AV fleets to cope with long distance travel

Necessary public choices

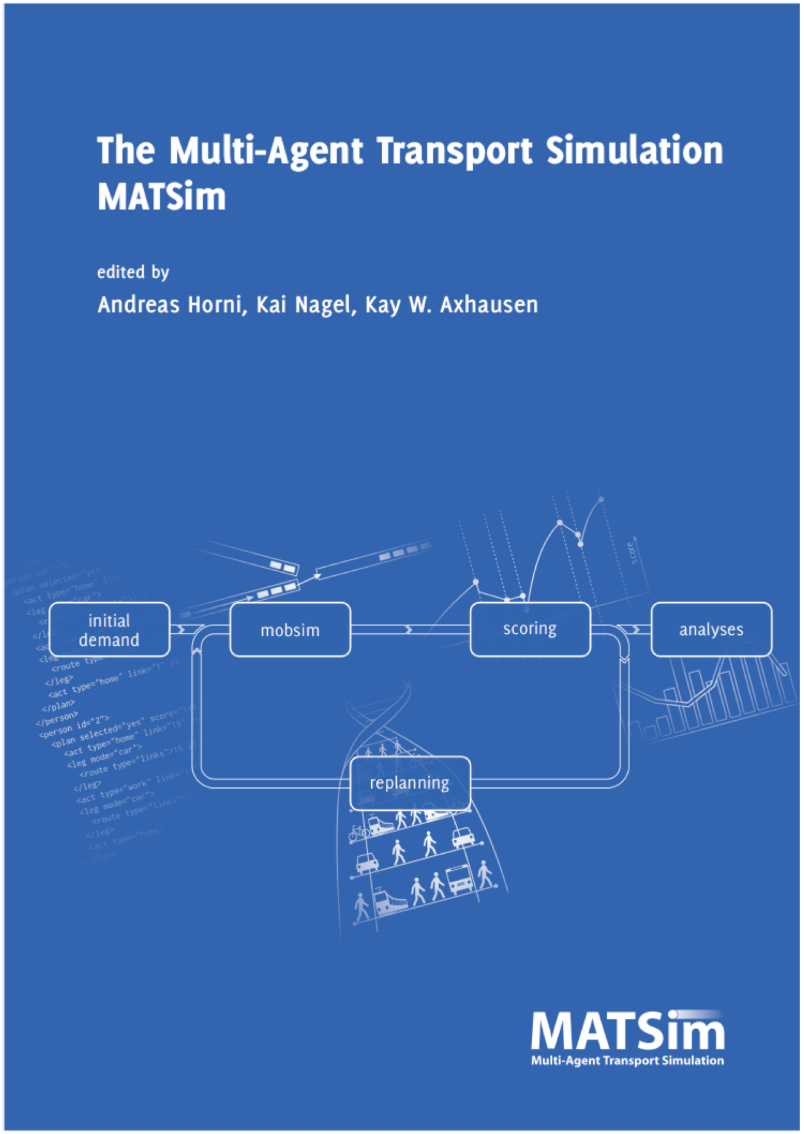
- Full cost of transport allocated to the users or rationierung of PKm/TKm per «tradable permits»
  - Tolls
  - Dynamic congestion pricing
  - Dynamic parking pricing
  - Dynamic public transport pricing

- CO_2 tax

- Flexible working hours and labour regimes
- More intense «lived» land use

- Locally funded AV fleets, e.g. VBZ 4.0

Questions ?


The Multi-Agent Transport Simulation
MATSim
edited by
Andreas Horni, Kai Nagel, Kay W. Axhausen
initial
demand
mobsim
scoring
analyses
replanning
MATSim
Multi-Agent Transport Simulation

Literature

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Graham, D.J. (2007) Agglomeration, Productivity and Transport Investment, *Journal of Transport Economics and Policy*, **41** (8) 317–43.
Jenkins, S. P., L. Cappellari, P. Lynn, A. Jäckle, and E. Sala (2006)Patterns of consent: Evidence from a general household survey, *Journal of the Royal Statistical Society: Series A (Statistics in Society)*,**169** (4) 701–722.
Cappellari, L., and S. P. Jenkins (2006) Calculation of multivariate normal probabilities by simulation with applications to maximum simulated likelihood estimation, *Stata Journal*, **6** (2) 156–189.

Appendix

Spatial error model: Part 2

	2000		2005		2010	
Y: Ln mean salary	Estimate	Sig.	Estimate	Sig.	Estimate	Sig.
Men	0.17	***	0.07	***	0.13	***
Tertiary education	0.83	***	0.66	***	0.54	***
Professional training	0.55	***	0.22	***	0.32	***
Further vocational training	0.23	***	0.17	***	0.23	***
Teaching degree	0.20	**	0.21	***	0.32	***
Highschool diploma	0.60	***	0.18	*	0.26	**
Vocational training	0.07	***	0.03	.	0.02	
Positions with highest demands	0.42	***	0.39	***	0.41	***
Positions with qualified indep. work	0.20	***	0.25	***	0.25	***
Positions with professional skills	0.14	***	0.20	***	0.14	***
Working (3rd sector)	0.21	***	0.15	***	0.06	.
Working (other private sector)	-0.10	***	-0.10	***	-0.06	***
Working (manufacturing)	-0.23	***	-0.25	***	-0.11	***
Working (FIRE)	0.15	***	0.01		0.09	***
Working (hotel, restaurants)	-0.13	***	-0.13	***	-0.11	***

Axhausen et al., 2015

Model formulation 1/2

Choice environment

Case	Choice	Probability
1	None	$P_1 = \Phi_2(-x_1\beta_1; -x_2\beta_2; \mathbf{P}_2)$
2	Car & no ticket	$P_2 = \Phi_2(-x_1\beta_1; x_2\beta_2; \mathbf{P}_2)$
3	Car & local ticket	$P_3 = \Phi_3(x_1\beta_1; x_2\beta_2 - x_3\beta_3; \mathbf{P}_3)$
4	Car & GA	$P_4 = \Phi_3(x_1\beta_1; x_2\beta_2; x_3\beta_3; \mathbf{P}_3)$
5	No car & local ticket	$P_4 = \Phi_3(x_1\beta_1; -x_2\beta_2; -x_3\beta_3; \mathbf{P}_3)$
6	No car & GA	$P_5 = \Phi_3(x_1\beta_1; -x_2\beta_2; x_3\beta_3; \mathbf{P}_3)$

Likelihood function

$$\mathcal{L}(\boldsymbol{\alpha}) = \delta \iiint_{\boldsymbol{x_{low}}}^{\boldsymbol{x_{up}}} \phi_3(\beta_1\hat{x}_1, \beta_2\hat{x}_2, \beta_3\hat{x}_3; \boldsymbol{P_3}) d\hat{\boldsymbol{x}} + (1-\delta) \iint_{\boldsymbol{x_{low}}}^{\boldsymbol{x_{up}}} \phi_2(\beta_1\hat{x}_1, \beta_2\hat{x}_2; \boldsymbol{P_2}) d\hat{\boldsymbol{x}}$$

Estimation method:

- Maximum simulated likelihood in Stata using Newton Raphson technique
- Using draws to compute the integral

Model formulation 2/2

δ	Sample selection dummy, equal to 1 if observation holds season ticket
Φ_n	N-dimensional cumulative distribution function of the normal distribution
ϕ_n	N-dimensional probability density function of the normal distribution
β	Parameters of the model
Σ	Symmetric correlation matrix with typical elements ρ_{ij} and $\rho_{ii} = 1$. The same correlations appear in both Σ_2 and Σ_3 by using their Cholesky decomposition and estimating the Cholesky factors in the model
α	Parameter vector to be estimated that contains all β and Cholesky factors of Σ
$\boldsymbol{x}_{\text{up,low}}$	Upper and lower limits of integration domain, determined by values of each observation

Switzerland: Ownership models (1/2)

	Season-ticket owner		Car available	
Age	-0.059	***	0.099	***
Age squared	0.052	***	-0.088	***
Male	-0.132	***	0.439	***
Working	0.066	***	0.258	***
University level education	0.146	***	-0.054	**
Log of monthly household income	0.075	***	0.391	***
Center of agglomeration	0.132	***	-0.22	***
Constant	0.052		-6.039	***

Switzerland: Ownership models (2/2)

	Season-ticket owner		Car available	
Local access to public transport: E	-0.474	***	0.505	***
Local access to public transport: D	-0.348	***	0.384	***
Local access to public transport: C	-0.253	***	0.286	***
Local access to public transport: B	-0.097	***	0.154	***
General accessibility	0.089	***	-0.028	***
Surplus public transport acc.	-0.005	***	-0.066	***
Surplus workplace accessibility	0.729	***	-0.527	***

Switzerland: GA given season ticket (2/2)

	General abonnement	
Secondary residence	0.302	***
Log of monthly household income	0.128	***
Self-reported distance [1000km]	0.005	***
Constant	-2.188	***

Error **correlations**		
	Car available	GA
Season ticket	-0.44	0.62
Car available		-0.24