A. Chakirov (2014) Heterogeneous values of time in a multi-modal context: An activity and agent-based simulation approach, 14th International Conference on Travel Behaviour Research, Windsor, July 2015.

Heterogeneous values of time in a multimodal context: An activity- and agent-based simulation approach

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14th International Conference on Travel Behaviour Research, Windsor
July 2015

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Motivation and context

Heterogeneous user preferences (e.g. value of time, activity scheduling, perception of comfort, physical conditions) matter:

- Equity and redistribution effects
- Mean value is not always representative (Winners vs. Losers)
- Self – organization effects

Challenges

- Modelling of multiple heterogeneity dimensions
- Lack of data

Alternative approach

- Agent-based simulation with Stochastic User Equilibrium (e.g. MATSim)

MATSim: Multi-Agent Transport Simulation

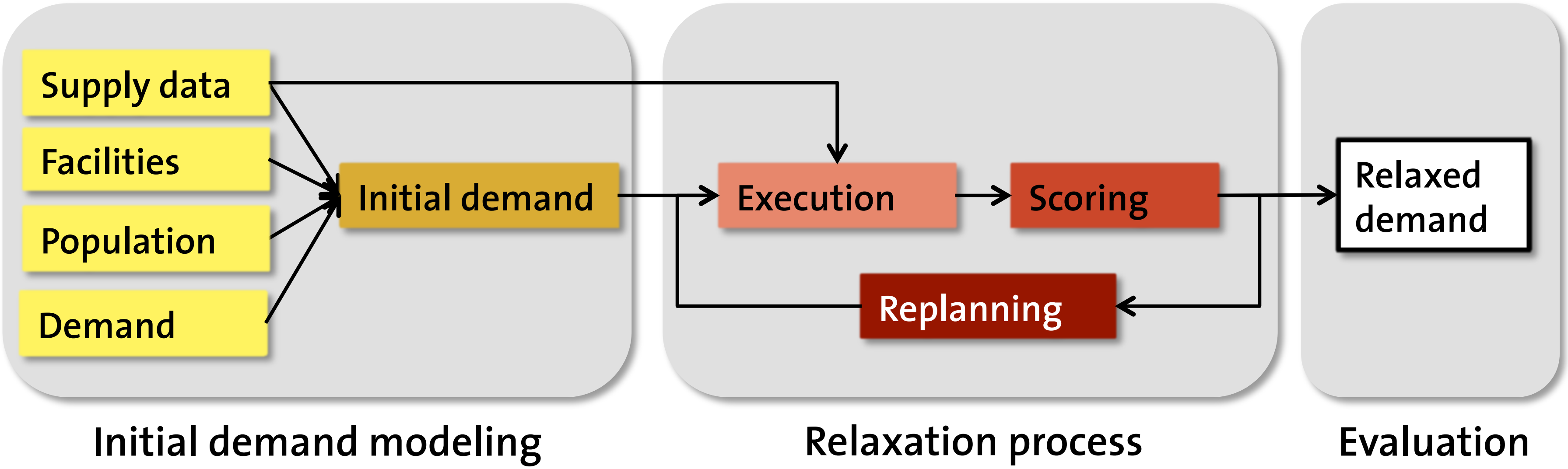
- Stochastic User Equilibrium
- Boundary/initial conditions (land use, transport network, demographics, etc.)
- List of choice dimensions that are adapted
- Parallel Queue Model Approach and **fully integrated public transport simulation**
- Time step: 1sec over 24h period

Choice dimensions

- Route choice
- Mode Choice
- Departure time choice
- (Secondary activity-location choice)

Constraints

- Flow and storage capacity of the network
- Bus vehicle capacity
- Dwell times



Heterogeneity in VOT

α : Value of Time β: Schedule delay early γ – Schedule delay late

Proportional Heterogeneity: α, β, γ vary proportionally => μ, η, λ = const.
- usually strongly income dependent

α - Heterogeneity: **μ = α** / β varies (η = const.)
e.g. type of job, family situation

γ - Heterogeneity: η = γ / β and λ = α / γ vary (μ = const.)
e.g. shift workers vs. flexible hours

$$\mu = \frac{\alpha}{\beta} \qquad \eta = \frac{\gamma}{\beta} \qquad \lambda = \frac{\alpha}{\gamma}$$

Small, K. A. and E. T. Verhoef (2007) The Economics of Urban Transportation, Routledge, Abingdon.

Introducing Heterogeneous Values of Time in MATSim

Marginal Value of Time in an activity – based context:

$$mVTTS_a = \frac{mUTTS_a}{\beta_a^{mon}} = \frac{-\beta_a^{trv(i)} + \beta_a^{act(i+1)} \cdot \frac{t_{typ(i+1)}}{t_{i+1}}}{\boxed{\beta_a^{mon}}}$$

Using continuous interaction from Axhausen et al. (2008): $f(y,x) = \beta_x \left(\frac{y}{\hat{y}}\right)^{\lambda_{y,x}} x,$

$$mVTTS = \frac{-\beta_{mode}^{trv} + \beta^{act} \cdot \frac{t_{typ}}{t}}{\beta_a^{mon}}$$

$$= \frac{-\beta_{mode}^{trv} + \beta^{act} \cdot \frac{t_{typ}}{t}}{\beta^{mon} \left(\frac{inc}{\widehat{inc}}\right)^{\lambda_{inc,mon}}}$$

$$= \frac{\boxed{-\beta^{TT_{mode}} \left(\frac{inc}{\widehat{inc}}\right)^{-\lambda_{inc,mon}}} + \boxed{\beta^{act} \left(\frac{inc}{\widehat{inc}}\right)^{-\lambda_{inc,mon}} \cdot \frac{t_{typ}}{t}}}{\beta^{mon}}.$$

Heterogeneity in Values of Time as a consequence of different marginal utilities for activity performance and disutility of traveling. Marginal utility of money stays constant.

Value of Time and Schedule Delay in MATSim

$$mVTTS_a = \frac{mUTTS_a}{\beta_a^{mon}} = \frac{-\beta_a^{trv(i)} + \beta_a^{act(i+1)} \cdot \frac{t_{typ(i+1)}}{t_{i+1}}}{\beta_a^{mon}}$$

➔

$$\alpha = mVTTS \cdot \beta^{mon} = -\beta^{trv} + \beta^{act}$$
$$\beta = \beta^{act}$$
$$\gamma = \beta^{late}$$

Proportional heterogeneity

$$\alpha = -\beta^{trv} + \beta^{act} = -\beta_{cost}^{trv} \cdot \left(\frac{inc}{\widehat{inc}}\right)^{-\lambda_{inc,mon}} + \beta_{const}^{act} \cdot \left(\frac{inc}{\widehat{inc}}\right)^{-\lambda_{inc,mon}}$$

$$\beta = \beta^{act} = \beta_{const}^{act} \cdot \left(\frac{inc}{\widehat{inc}}\right)^{-\lambda_{inc,mon}}$$

$$\gamma = \beta_{const}^{late} \cdot \beta^{act} = \beta_{const}^{late} \cdot \beta_{const}^{act} \cdot \left(\frac{inc}{\widehat{inc}}\right)^{-\lambda_{inc,mon}}$$

α - heterogeneity

$$\alpha = -\beta^{trv} + \beta^{act} = -\beta_{cost}^{trv} \cdot \left(\frac{inc}{\widehat{inc}}\right)^{-\lambda_{inc,mon}} + \beta_{const}^{act} \cdot \left(\frac{inc}{\widehat{inc}}\right)^{-\lambda_{inc,mon}}$$

$$\beta = \zeta_\beta \cdot \beta^{act} = \zeta_\beta \cdot \beta_{const}^{act} \cdot \left(\frac{inc}{\widehat{inc}}\right)^{-\lambda_{inc,mon}}$$

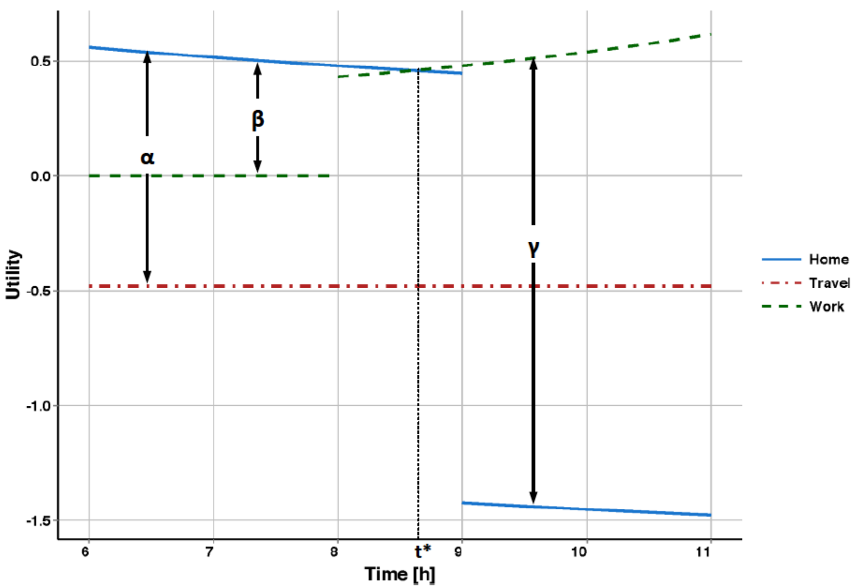
$$\gamma = \eta \cdot \beta$$

γ - heterogeneity

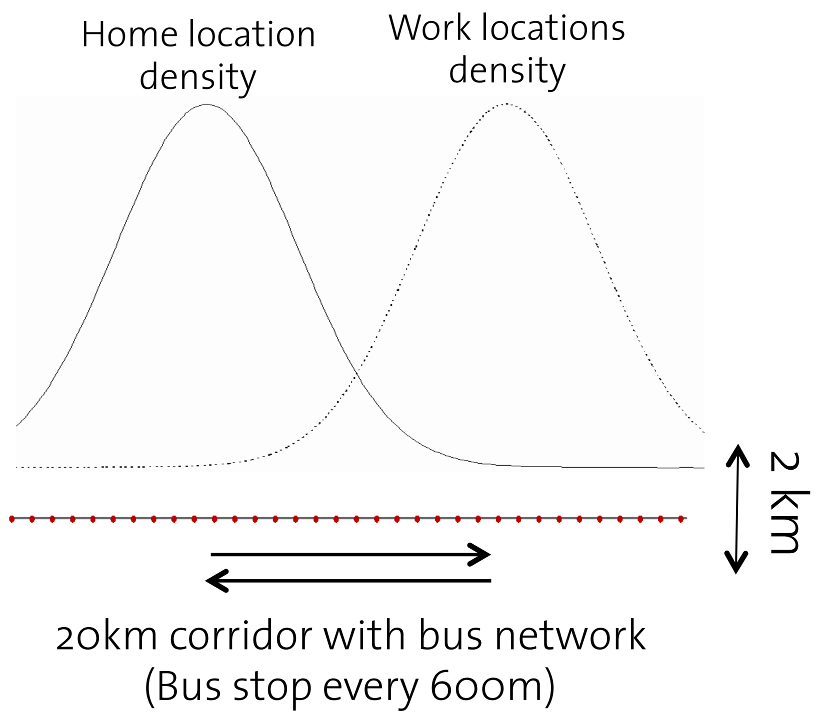
$$\alpha = -\beta^{trv} + \beta^{act} = -\beta_{cost}^{trv} \cdot \left(\frac{inc}{\widehat{inc}}\right)^{-\lambda_{inc,mon}} + \beta_{const}^{act} \cdot \left(\frac{inc}{\widehat{inc}}\right)^{-\lambda_{inc,mon}}$$

$$\beta = \beta^{act} = \beta_{const}^{act} \cdot \left(\frac{inc}{\widehat{inc}}\right)^{-\lambda_{inc,mon}}$$

$$\gamma = \zeta_\gamma \cdot \beta^{act} = \zeta_\gamma \cdot \beta_{const}^{act} \cdot \left(\frac{inc}{\widehat{inc}}\right)^{-\lambda_{inc,mon}}$$



Simulation setup: Corridor scenario



- 8000 agents
- Home – Work – Home activity chains
- Distance between bus stops: 600m
- Bus headway: 5 min
- Bus capacity: 90 (MAN NL323F)
- Bus length: 7.5m
- Dwell time per passenger: 1 sec

Behavioural and monetary parameters and activity constrains

Parameter	Value
β_{act}	+ 0.48 [utlis/h]
$\beta_{tr,car}$	- 0.48 [utlis/h]
$\beta_{tr,pt}$	-0.66 [utlis/h]
$\beta_{tr,walk}$	-1.401 [utlis/h]
$\beta_{wait,pt}$	-1.458 [utlis/h]
β_{cost}	-0.062 [utils/$]
$\beta_{0,car}$	-0.562 [utils]
$\beta_{0,pt}$	-0.124 [utils]
$\beta_{0.walk}$	0.0 [utils]

Parameter	Value
PT Fare	2 $ / trip
Car cost per km	0.2 $ / km
Parking cost	6$ / trip (= 12$ / day)

Activity	Typical duration	Opening time	Latest start time	Earliest end time	Closing time
Home	14h	-	-	-	-
Work	9.5h	8.00am	9.00am	6.00pm	7.00pm

Tirachini, A. D.A. Hensher and J.M. Rose (2012) Multimodal Pricing and Optimal Design of Public Transport Services: The Interplay between Traffic Congestion and Bus Crowding, in Proceedings of the Kuhmo Nectar Conference on Transportation Economics, Berlin.

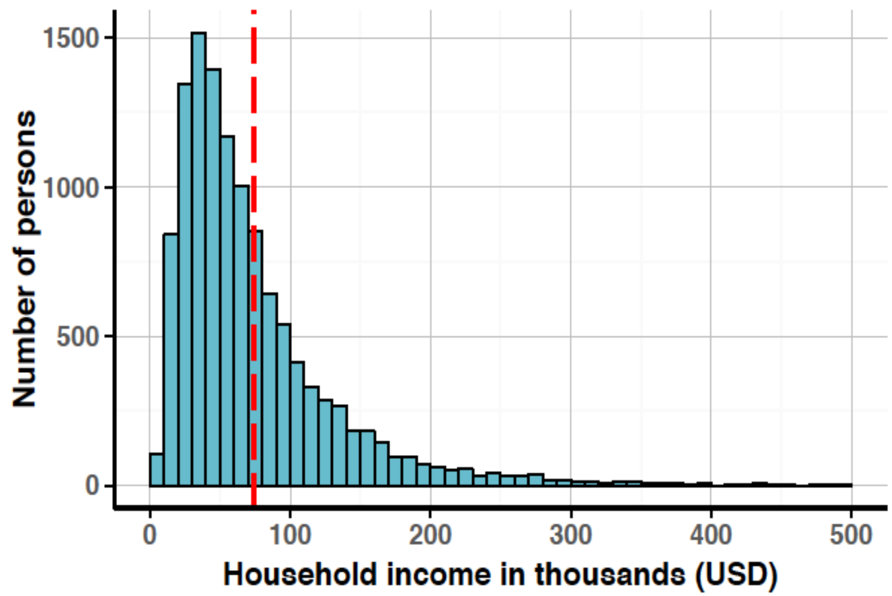
Chakirov, A. and P. Fourie (2014) Enriched Sioux Falls Scenario with Dynamic and Disaggregate Demand, *Working paper*, FCL, SEC, Singapore.

Income-based heterogeneity in VOT

Modeling of value of time heterogeneity based on household income:

continuous interaction from Axhausen et al. (2008): $f(y,x) = \beta_x \left(\frac{y}{\hat{y}}\right)^{\lambda_{y,x}} x,$

Income distribution



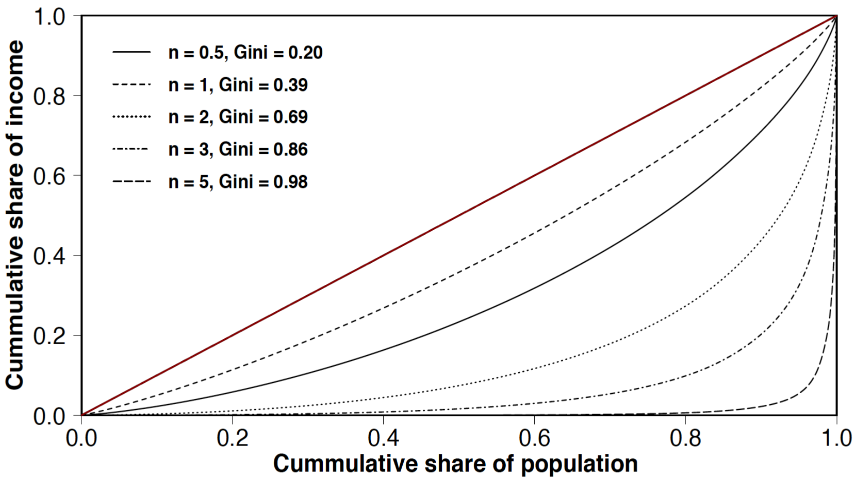
Chakirov, A. and P. Fourie (2014) Enriched Sioux Falls Scenario with Dynamic and Disaggregate Demand, *Working paper*, FCL, SEC, Singapore.

Varying degrees of heterogeneity

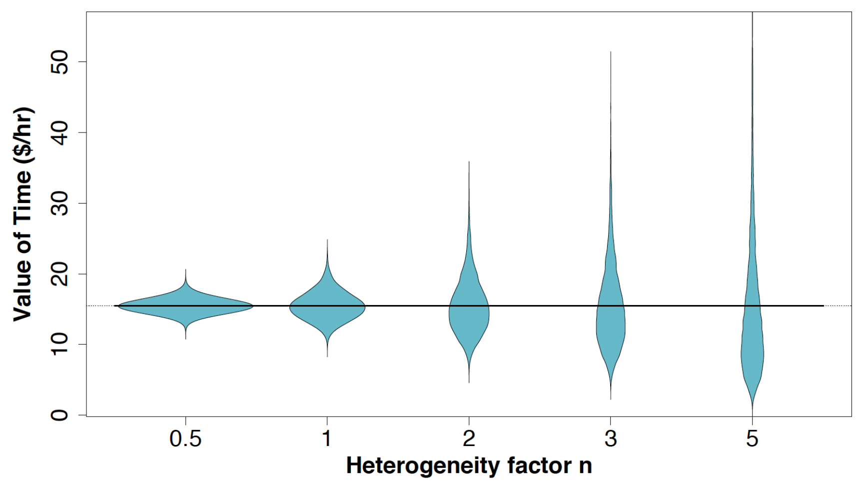
Axhausen et al. (2008) estimate λ = 0.1697 for $\left(\frac{inc}{\widehat{inc}}\right)^{\lambda_{inc,mon}}$

Different degree of heterogeneity are tested for $\eta * \lambda_{inc,mon}$ with n = 0, 1, 2, 3, 5

Lorenz curves



Value of Time Distribution

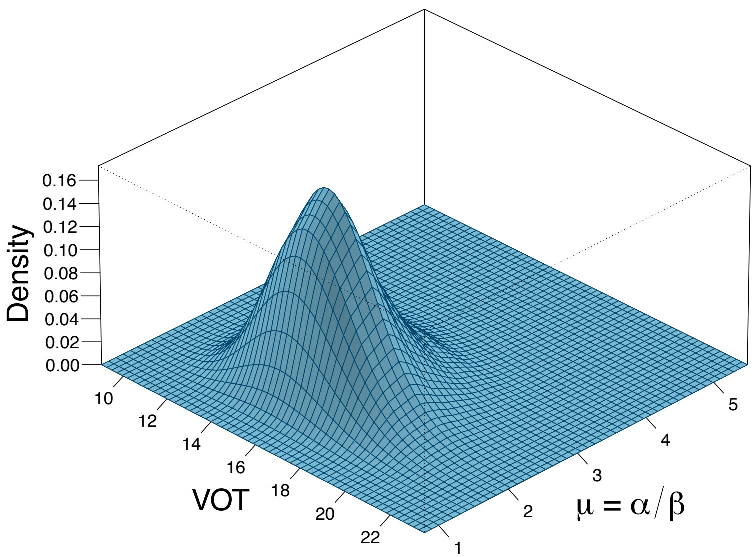


Axhausen, K. W., S. Hess, A. König, G. Abay, J. J. Bates and M. Bierlaire (2008) Income and distance elasticities of values of travel time savings: New Swiss results, Transport Policy, 15 (3) 173–185.

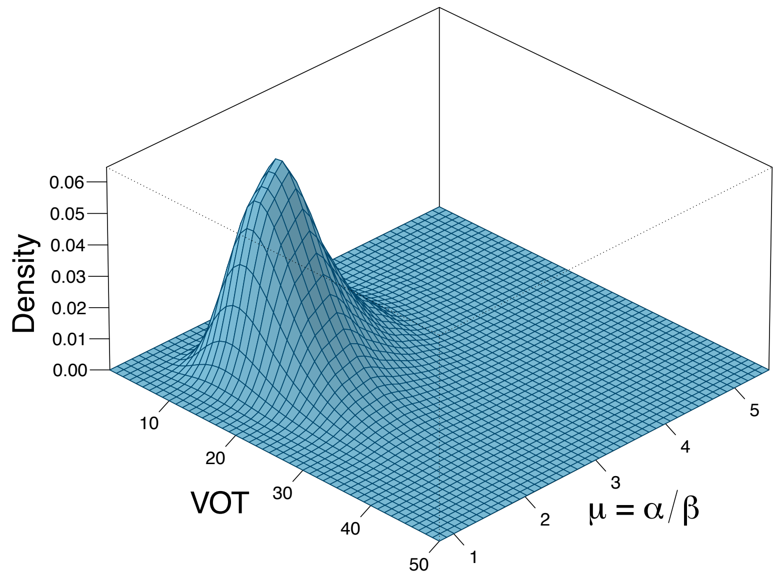
Adding α heterogeneity

Joint probability density distribution for VOT α and α / β

n = 1

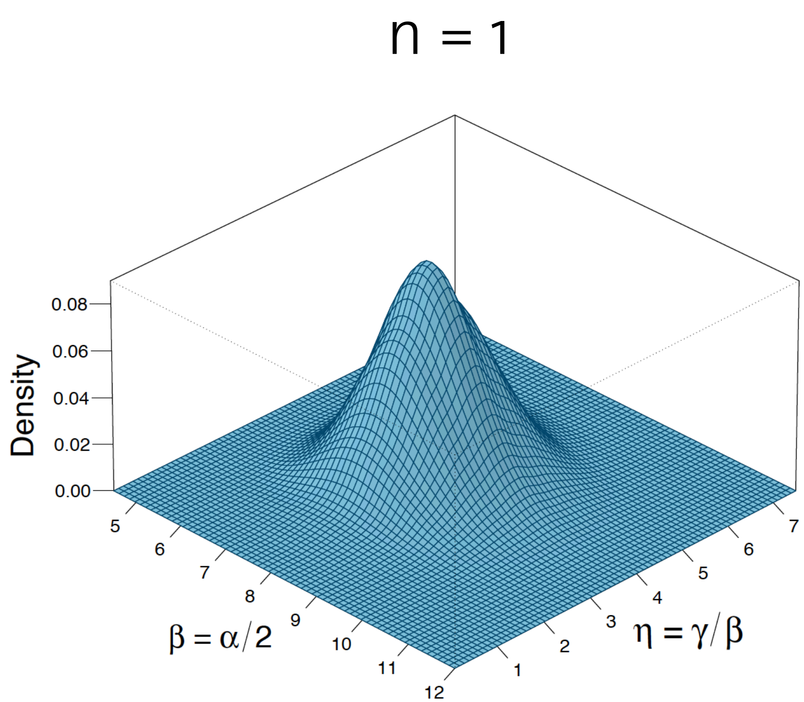


n = 3



Adding γ heterogeneity

Joint probability density distribution for schedule delay late γ and γ / β



Congestion pricing: first – best toll approximation

Implementation of first – best pricing approximation according to *Lämmel and Flötteröd (2009)* Towards System Optimum: Finding Optimal Routing Strategies in Time-Dependent Networks for Large-Scale Evacuation Problems, KI 2009: Advances in Artificial Intelligence, 5803, pp. 532-539.

External cost: $C(t_0) \approx t^e(t_0) - \tau^{free} - t_0.$

Queue encountered when entering the link at t_0 to dissolves at $t_e(t_0)$

Time bins in MATSim implementation: 5 min

Economic evaluation

Social Welfare = Consumer Surplus + Toll Revenue +
PT Fare Revenue + PT Operation Cost

Logsum (Expected Maximum Utility)

$$V_J = \frac{1}{\mu} \cdot \ln \sum_{j=1}^{J} e^{\mu V_j}$$

Choice Set Generation:
Chosen alternative, activity shift +1hr, -1hr, activity extension +1hr, -1hr, mode shift (total of 14 alternatives)
Evaluation using a pseudo – simulation approach

Bus operation cost according to Australian Transport Council (2006)

$$C = (d_{vkm} \cdot c_{vkm} + t_{vh} \cdot c_{vh}) \cdot O + N_v \cdot c_{vday}$$

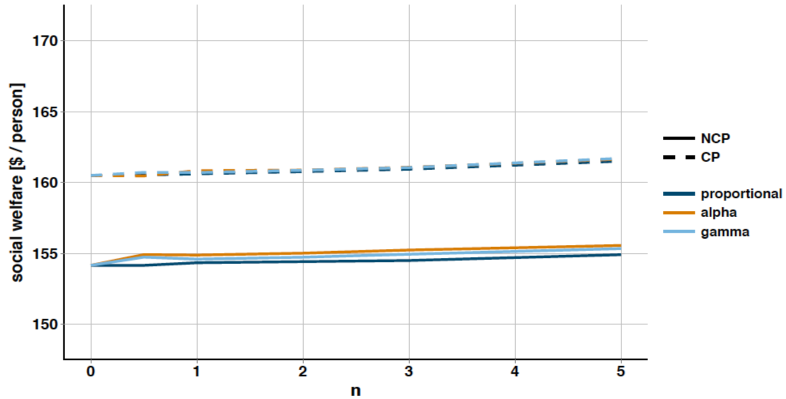
c_{vkm}	0.006 · capacity + 0.513 [$/vkm]
c_{vday}	1.6064 · capacity + 22.622 [$ / vday]
c_{vh}	33 [$ / vh]
O	1.21

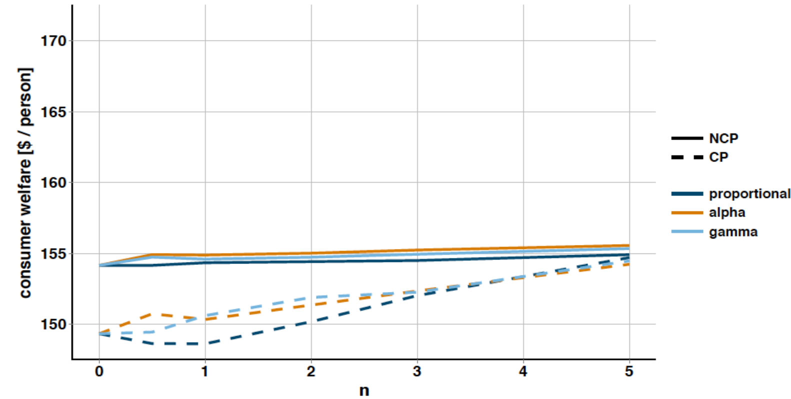
Social Welfare and Consumer Surplus before and after pricing

Social welfare

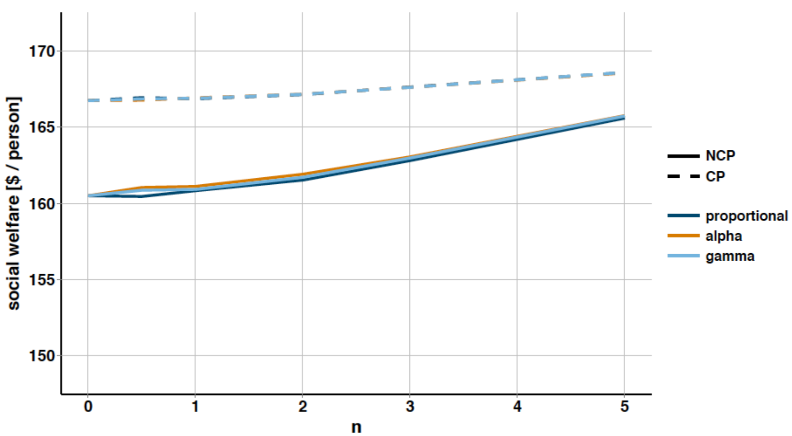
Consumer surplus

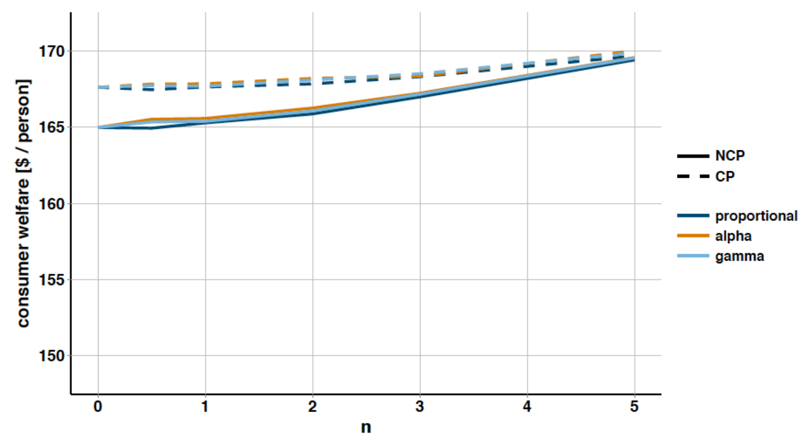
No bus service





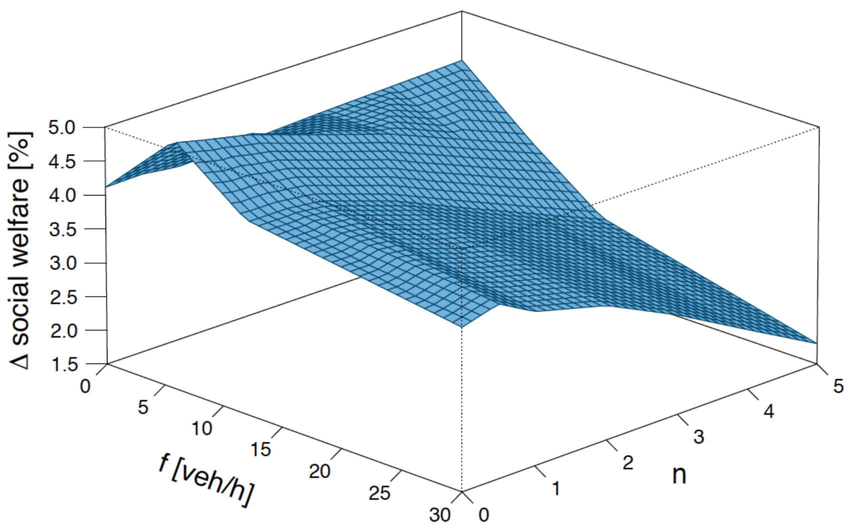
2 min bus headway



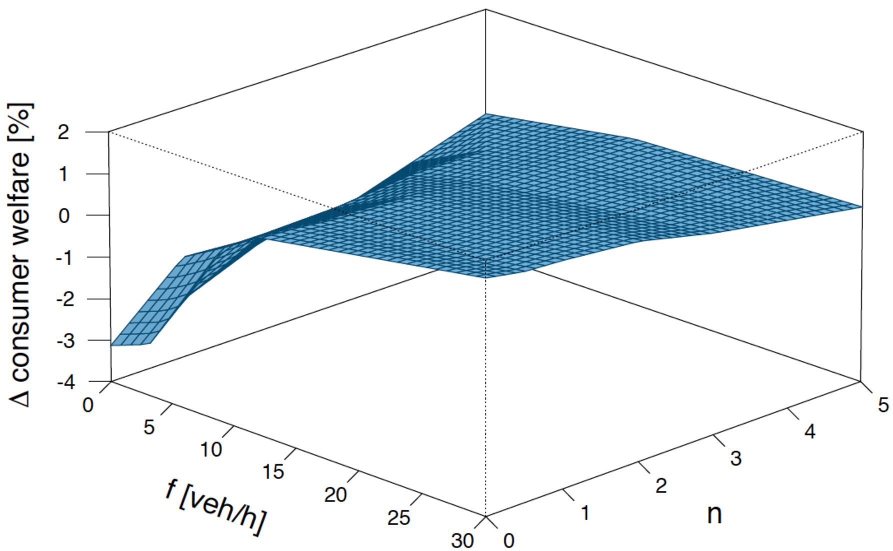


Changes in Welfare and Consumer Surplus after congestion pricing

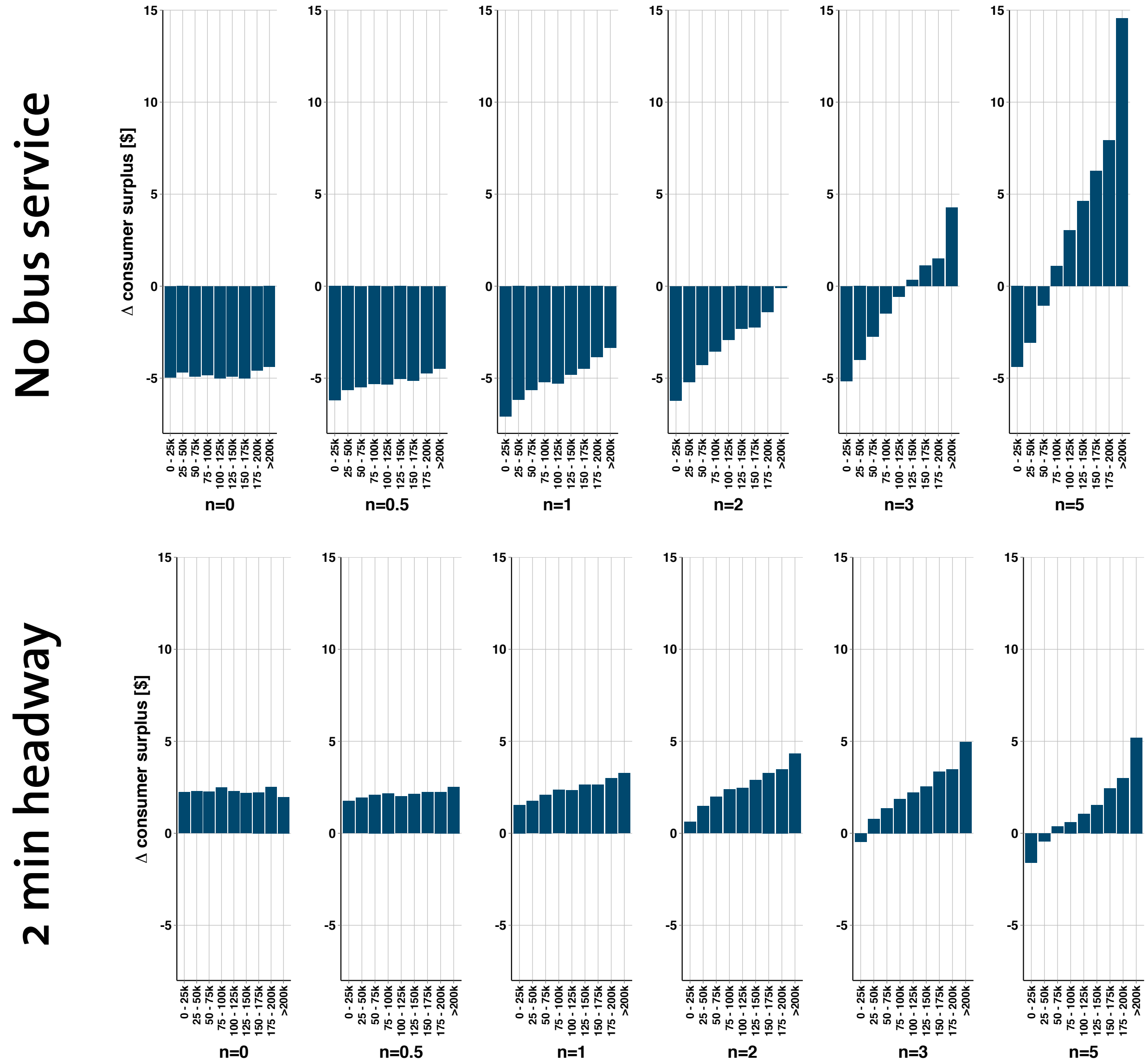
Social welfare



Consumer surplus

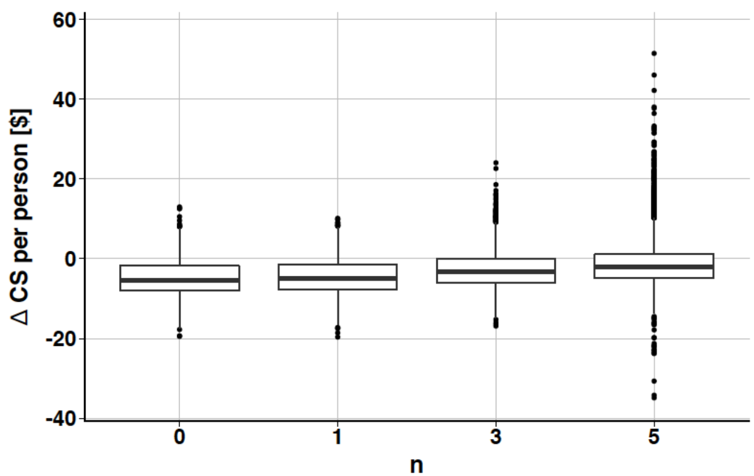


Changes in Consumer Surplus vs. Income

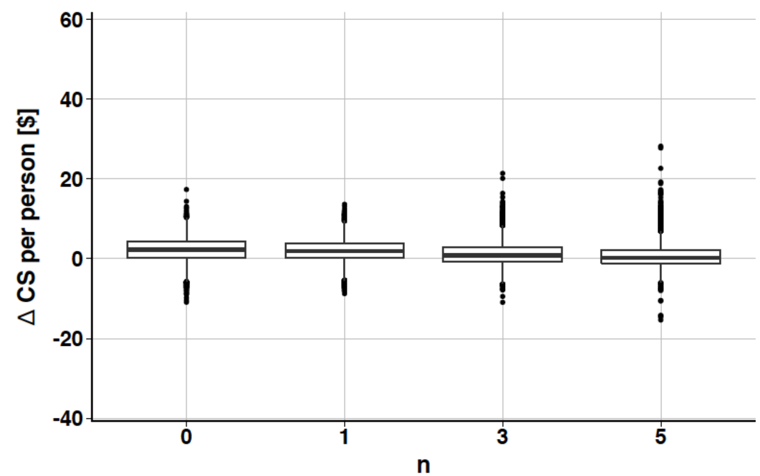


Spread of consumer surplus changes

(a) α heterogeneity, no bus service

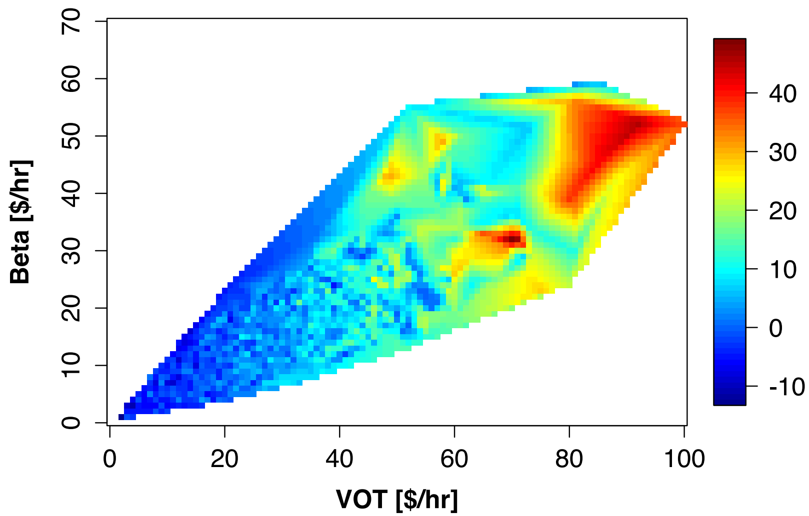


(b) α heterogeneity, 2 min headway

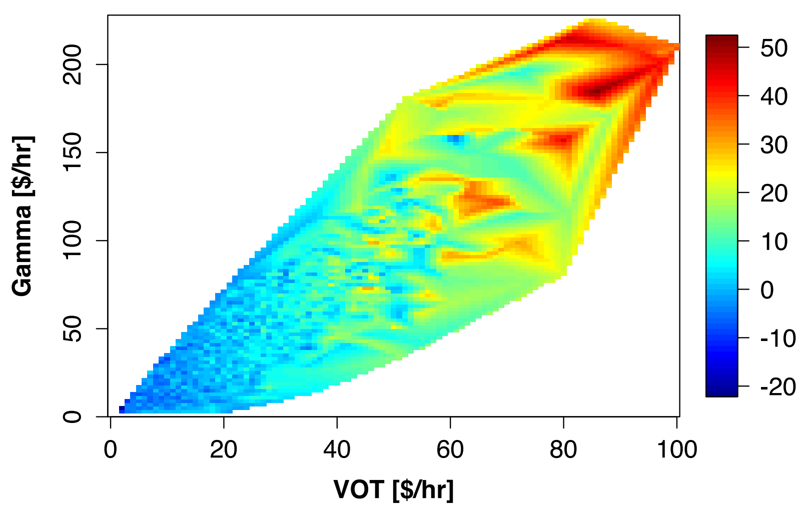


Changes in Consumer Surplus vs. α and β / α and γ

α heterogeneity, n = 5



γ heterogeneity, n =5



Key Findings and Outlook

- Significant self-organization effect with alternative mode of transport and heterogeneous user preferences
- Relative welfare gains from congestion pricing diminishes with increasing user heterogeneity given availability of alternative mode
- Changes in consumer surplus are strongly dependent on availability and service level of alternatives
- Public transport users can be the one who loose from congestion pricing in case mode shift leads to crowding and associated delays

Future Work

- Transfer to a realistic medium to large scale scenario (e.g. Sioux Falls, Singapore)
- Questions of spatial inequality
- Combination of different heterogeneity characteristics (Value of Time, Schedule Delay, Trip Distances, Activity Types