Investigating suppressed demand effects for increasing car travel costs: A latent variable random effects (LVREP) Poisson approach

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Post-Car World: A multi-stage travel survey

- Motivation: Understanding travel behavior in a hypothetical world where privately owned cars are substituted by various forms of shared mobility
- Investigation of pricing mechanisms as a driving force to achieve behavioral reactions

→ Main focus: Transition towards (and not actual state of) such a (Pre-)Post-Car World

- One week travel diary and mobility tool data (stage I) as empirical basis for behavioral experiments (stage II & III)
  - Data collection: Canton of Zurich, 2015 - 2016
  - Average response rate: 55%, N = 220 households

Adaptations in daily scheduling

- How would respondents change their daily travel in the **short-run**, given the increase in travel costs?
- Personalized stated adaptation interviews with preferred household member: max[MIV usage, distance, # trips]
- Interviewers introduced the respondents to their daily plans
- Experimental framing:
  - Road tolls, fuel and congestion taxes
  - Future policy developments to reduce MIV usage
  - Promotion of shared mobility (PT, CS, CP) regarding supply, accessibility and cost

Adaptations in daily scheduling

- Input data: OD-matrix with routed mode-specific travel times and distances for selected day of respondent n
- Mode-specific total RP travel cost $R_{tc,n}$ in the base scenario based on distance, car type and season ticket ownership
- Experimental setting: Four adaptation scenarios with gradual increase in out-of-pocket travel costs (plus trip tax)

Mode	Sc. 1 [in CHF]	Sc. 2 [in CHF]	Sc. 3 [in CHF]	Sc. 4 [in CHF]
Car	$R_{tc,n} \cdot 1.5 + 0.4$	$R_{tc,n} \cdot 2 + 0.8$	$R_{tc,n} \cdot 4 + 1.4$	$R_{tc,n} \cdot 8 + 2$
Moto	$R_{tc,n} \cdot 1.5 + 0.2$	$R_{tc,n} \cdot 12 + 0.4$	$R_{tc,n} \cdot 4 + 0.7$	$R_{tc,n} * 8 + 1$
PT	$R_{tc,n} \cdot 1.1$	$R_{tc,n} \cdot 1.2$	$R_{tc,n} \cdot 1.3$	$R_{tc,n} \cdot 1.5$
CS	$R_{tc,n} \cdot 1.1$	$R_{tc,n} \cdot 1.2$	$R_{tc,n} \cdot 1.3$	$R_{tc,n} \cdot 1.5$
CP	$R_{tc,n} \cdot 1.5$	$R_{tc,n} \cdot 2$	$R_{tc,n} \cdot 4$	$R_{tc,n} \cdot 8$

Adaptations in daily scheduling

Durchschnittlicher OEV-Takt: 3 min.

Zeit zum naechsten Carsharing Fahrzeug: 3min

Zeit zum naechsten Carpooling Fahrzeug: 3min

Aktivitaet:	Zu Hause	Einkauf lfr. Bedar	Arbeit/Ausbildun	Dienstlich	Zu Hause
Ort der Aktivitaet:	Zu Hause	Tomac3	Arbeit/Ausbildun	Dienstlich5	Zu Hause
Strasse:	Nordstrasse 21	Sihlfeldstrasse 53	Seebahnstrasse 8	Plantaweg 21	Nordstrasse 21
Stadt:	Zuerich	Zuerich	Zuerich	Chur	Zuerich
Ankunftszeit:	00:00	08:17	08:24	11:31	14:34
Laenge der Aktivitaet:	08:05	00:05	01:55	01:40	00:44
Abfahrtszeit:	08:05	08:22	10:19	13:11	15:18
Zu Fuss	○	○	○	○	○
Auto(Fahrer)	○	○	●	●	○
Auto(Mitfahrer)	○	○	○	○	○
Velo	●	●	○	○	○
OEV	○	○	○	○	●
Carpooling(Mitfahrer)	○	○	○	○	○
Carsharing	○	○	○	○	○
Motorrad	○	○	○	○	○
Zurueckgelegte Distanz:	2.78	0.88	134.19	134.10	2.43
Reisezeit:	00:12	00:02	01:12	01:23	00:13
Reisekosten	0.00	0.00	36.23	36.21	2.20
	Entfernen	Entfernen	Entfernen	Entfernen	Entfernen

Summe Reisekosten (in CHF): 79.04

Adaptations in daily scheduling

Focus of today:

- Suppressed demand effects for MIV (car driver, car passenger, motorbike) usage: What is the effect on mileage driven, given the increase in travel costs?
- Microeconomic viewpoint (”aggregate” demand function using disaggregate data)
- Assumption: Cost minimizing behavior, given underlying (unobserved) preferences for daily plan
- Advanced econometric methods for modeling (unobserved) heterogeneity

$\Longrightarrow$ Latent variable random effects Poisson (LVREP) model

Environmental sensitivity / car loving traits ...

envi1: Higher fuel prices should subsidize public transport

envi2: Daily life without car is impossible

envi3: Car driving is bad for the environment

envi4: I could imagine to give up car usage completely

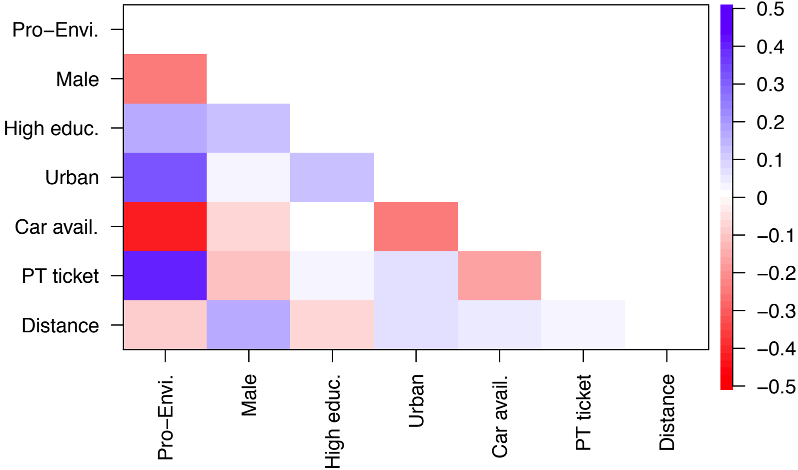
envi5: Zurich without cars is inconceivable

envi6: Environmental problems get too much attention

envi7: The never-ending discussions about the greenhouse effect is exaggerated

envi8: Fuel prices should increase to reduce pollution of the environment

… and socio-economic characteristics



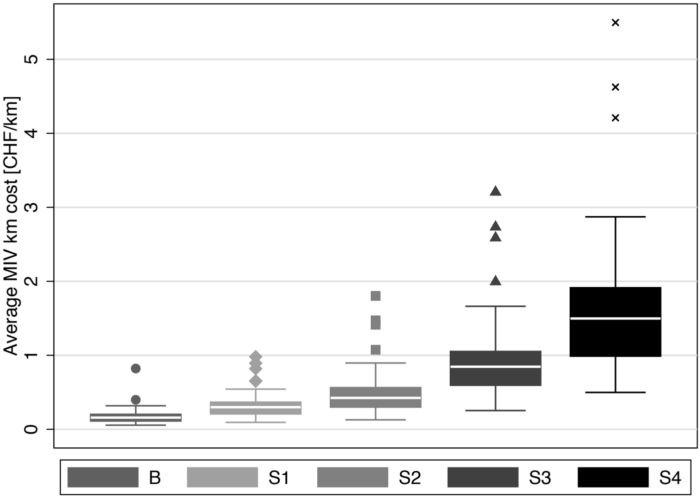
Data

- N = 162 respondents, 810 choice scenarios
- Highly right-skewed data with many zeros (respondents might choose not to use MIV anymore) → OLS inconsistent!

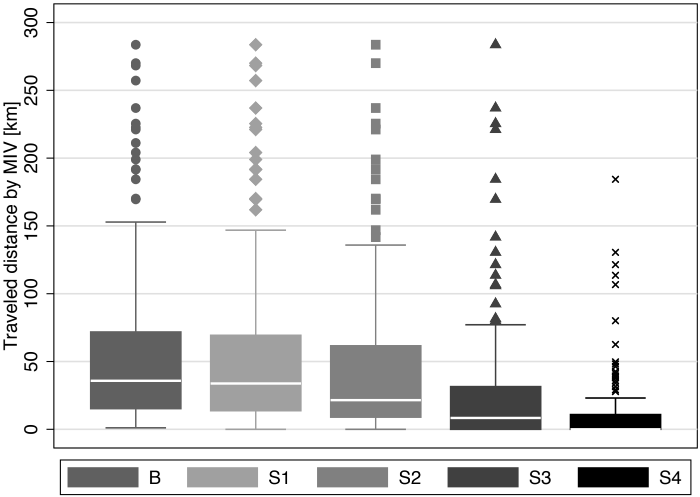
→ Exponential family modeling approach (Hausman et al., 1984)

- Poisson regression:
  - Simple and robust (c.p.t. negative-binomial)
  - Main interest: Estimation of a constant elasticity mean function
  - One parameter $\lambda_{s,n,t}$ that defines the mean and the variance (equidisperision); RE approach further relaxes this assumption
  - Automatically accounts for heteroscedasticity

Change in MIV travel cost



Adaptation patterns in distance traveled



Modeling framework

- Dependent variable: Distance traveled by MIV
  $y_{n,t} \equiv km_{n,t}$ after adaptation in **current** scenario
- Main explanatory variable: Average MIV travel cost per km
  $x_{n,t} \equiv log(CHF_{n,t-1})$ after adaptation in **previous** scenario
- Large variety in respondents' characteristics and their daily plans $\rightarrow$ use panel structure to account for unobserved heterogeneity
- Starting point: Poisson regression for a continuous dependent variable (Gourieroux, Monfort & Trognon, 1984) with random intercept (Hausman test: H_0 plausible)

Modeling framework: Log-linear index

$$\lambda_{1,n,t} = \epsilon_n \cdot \exp\left(\alpha + \beta_{COST} \cdot x_{n,t} \cdot \left(\frac{dist_{n,0}}{\overline{dist}}\right)^{\omega_{DIST}}\right)$$

$$\lambda_{2,n,t} = \epsilon_n \cdot \exp\Bigg(\alpha + \alpha_{INC} \cdot inc_n + \alpha_{ENVI} \cdot envi_n +$$

$$(\beta_{COST} + \beta_{INC} \cdot inc_n + \beta_{ENVI} \cdot envi_n) \cdot x_{n,t} \cdot \left(\frac{dist_{n,0}}{\overline{dist}}\right)^{\omega_{DIST}}\Bigg)$$

$$\lambda_{3,n,t} = \epsilon_n \cdot \exp\left(\alpha - \exp(\beta_{COST} + \psi_n) \cdot x_{n,t} \cdot \left(\frac{dist_{n,0}}{\overline{dist}}\right)^{\omega_{DIST}}\right)$$

$$\lambda_{4,n,t} = \epsilon_n \cdot \exp\Bigg(\alpha + \alpha_{INC} \cdot inc_n + \alpha_{ENVI} \cdot envi_n$$

$$- \exp(\beta_{COST} + \beta_{INC} \cdot inc_n + \beta_{ENVI} \cdot envi_n + \psi_n) \cdot$$

$$x_{n,t} \cdot \left(\frac{dist_{n,0}}{\overline{dist}}\right)^{\omega_{DIST}}\Bigg)$$

Modeling framework: Estimation

- Analytical solution **(random intercept)**: Assuming that $\epsilon_n \sim \Gamma(1,\theta)$, $y_{n,t}$ is distributed Poisson with mean $\widetilde{\lambda_{s,n,t}} \equiv \lambda_{s,n,t}/\epsilon_n$ and $u_n \equiv (1/\theta)/(1/\theta + \sum_{t=1}^{T_n} \widetilde{\lambda_{s,n,t}})$, the likelihood of observing the sequence $Y_{n,t}$ given $X_{n,t}$ and z_n of respondent n is given by

$$
\begin{aligned}
\mathcal{LL}_n(Y_{n,t}|X_{n,t}, z_n, \Lambda) = \log \Gamma\left(1/\theta + \sum_{t=1}^{T_n} y_{n,t}\right) - \sum_{t=1}^{T_n} \log \Gamma\left(1 + y_{n,t}\right) - \\
\log \Gamma(1/\theta) + 1/\theta \cdot \log(u_n) + \log(1-u_n) \sum_{t=1}^{T_n} y_{n,t} + \\
\sum_{t=1}^{T_n} y_{n,t} \cdot \log\left(\widetilde{\lambda_{s,n,t}}\right) - \left(\sum_{t=1}^{T_n} y_{n,t}\right) \log\left(\sum_{t=1}^{T_n} \widetilde{\lambda_{s,n,t}}\right)
\end{aligned}
$$

Modeling framework: Estimation

- Simulation **(random coefficient or LV)**: The expected likelihood $\mathcal{L}_n^*(.)$ over all possible values of ψ_n and/or LV_n is given by the integral of the exponent of the log-likelihood function over the distribution of ψ_n or LV_n

$$\mathcal{L}_n^*(Y_{n,t}, I_{w,n}|X_{n,t}, z_n, \Omega) = \int_{\psi_n, LV_n} \exp\left(\mathcal{LL}_n(Y_{n,t}|X_{n,t}, z_n, \Lambda, \psi_n)\right) u(I_{w,n}|LV_n, \tau_{I_w}, \sigma_{I_w}) \times h(\psi_n|R)\, g(LV_n|z_n, \rho_z, \eta_{LV_z})\, d\psi_n\, dLV_n$$

$$\widetilde{\mathcal{L}_n^*}(Y_{n,t}, I_{w,n}|X_{n,t}, z_n, \Omega) = \frac{1}{R}\sum_{r=1}^{R} \exp\left(\mathcal{LL}_n(Y_{n,t}|X_{n,t}, z_n, \Lambda, \psi_n)\right) u(I_{w,n}|LV_n, \tau_{I_w}, \sigma_{I_w})$$

$$\max \widetilde{\mathcal{LL}}(\Omega) = \sum_{n=1}^{N} \log\left(\widetilde{\mathcal{L}_n^*}(Y_{n,t}|X_{n,t}, z_n, \Omega)\right)$$

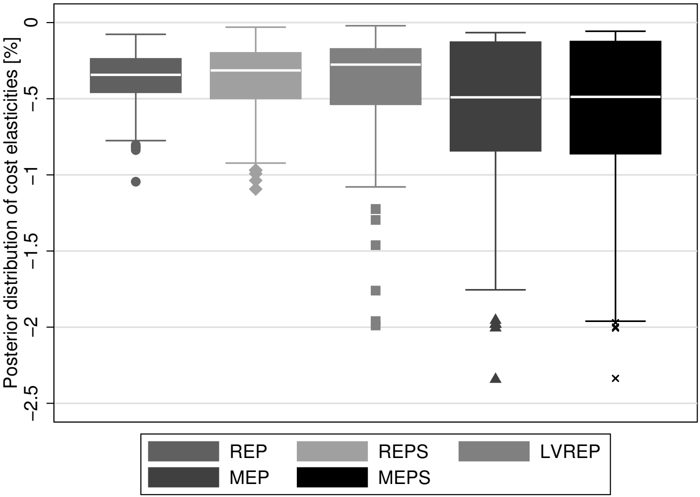
→ Posterior analysis of cost elasticity

Estimation results

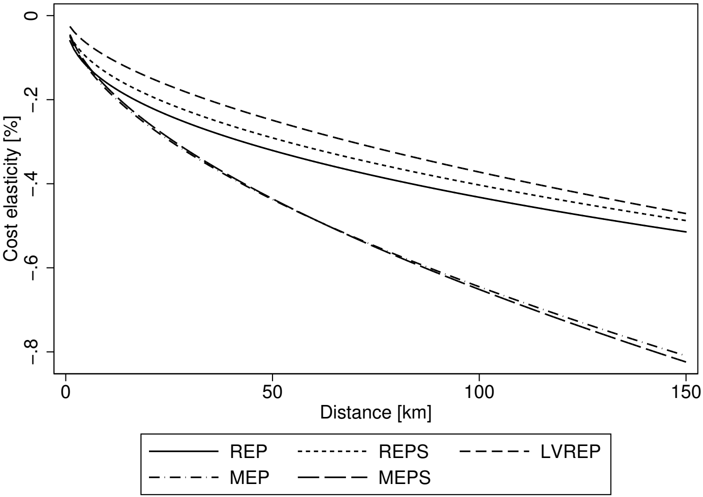
	REP Coef./(SE)	REPS Coef./(SE)	LVREP Coef./(SE)	MEP Coef./(SE)	MEPS Coef./(SE)
α	3.20***	3.15***	3.06***	3.08***	3.05***
α_{INC}	–	0.17	0.16	–	0.16
α_{ENVI}	–	−0.13***	−0.62***	–	−0.11**
θ	0.65***	0.59***	0.51***	1.32***	1.27***
β_{COST}	−0.43***	−0.44***	−0.87***	−0.72***	−0.70***
ω_{DIST}	0.43***	0.47***	0.58***	0.56***	0.58***
β_{INC}	–	0.03	−0.08	–	−0.28**
β_{ENVI}	–	−0.05***	0.65***	–	0.08
σ_{COST}	–	–	–	1.09***	1.06***
# param.	4	8	30	5	9
# respond.	162	162	162	162	162
# obs.	735	735	735	735	735
# draws	–	–	2000	2000	2000
$\mathcal{LL}^*_{final}$	−7029.08	−6911.64	−6621.37	−6047.25	−6039.25
AICc	14066.41	13840.23	13154.70	12104.89	12097.69

Robust standard errors: *** : $p < 0.01$, ** : $p < 0.05$, * : $p < 0.1$
Note: LV-model coefficients not reported in the table.

Results: Distribution of cost elasticities



Results: Distance dependency



Conclusions

- Median elasticity: If MIV travel costs increase by 1%, distance decreases by $\approx$ 0.3 - 0.4% (re-weighted with MZMV distance)
- Random coefficient approach substantially increases cost elasticity estimates
- Strong, non-linear distance dependency
- Only weak effect of income
- Relatively high elasticities compared to related literature; usually between -0.1 (SR) and -0.4 (LR)
  - Sampling bias / low sample size / survey design
  - Very high variation in travel cost
- Respondents with pro-environmental attitudes travel less **and** show a stronger adaptation behavior