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# A latent variable exponential family modeling approach to estimate suppressed demand effects for increasing car travel costs

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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 mode-specific total RP travel cost $R_{tc,n}$

| 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 | $R_{tc,n} \cdot 1.5$ | $R_{tc,n} \cdot 2$ | $R_{tc,n} \cdot 4$ | $R_{tc,n} \cdot 8$ |

- Experimental framing:
  - Road tolls, fuel and congestion taxes
  - Future policy developments to reduce MIV usage
  - Promotion of shared mobility (PT, CS, CP)

# 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 daily mileage driven, given the increase in travel costs?
- "Aggregate" response function (given low sample size) using highly disaggregate data (activity-based perspective)
- Assumption: Cost minimizing behavior, given underlying (unobserved) preferences for daily plan
- "Two-step approach" for modeling (unobserved) heterogeneity

# 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

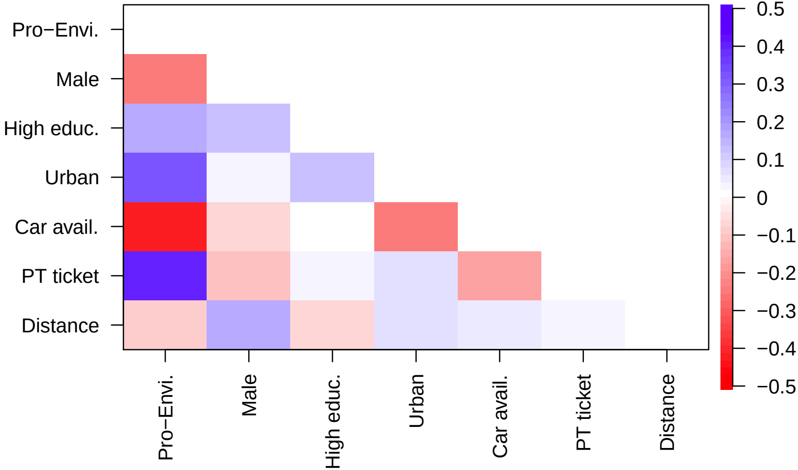
**envi5:** Zurich without cars is inconceivable

**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

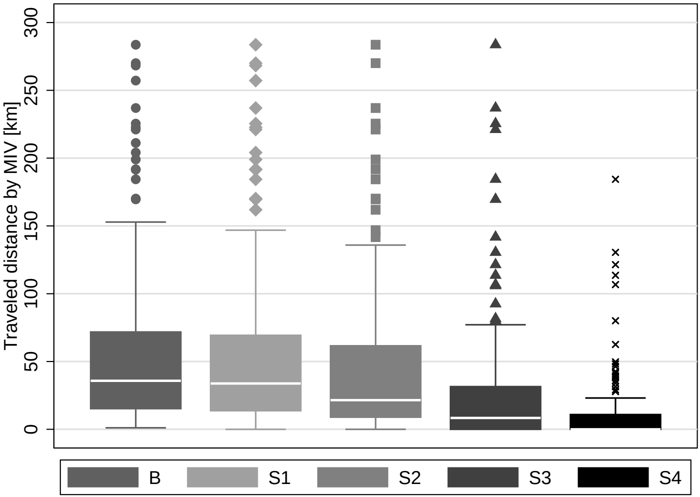
# … and socio-demographic characteristics



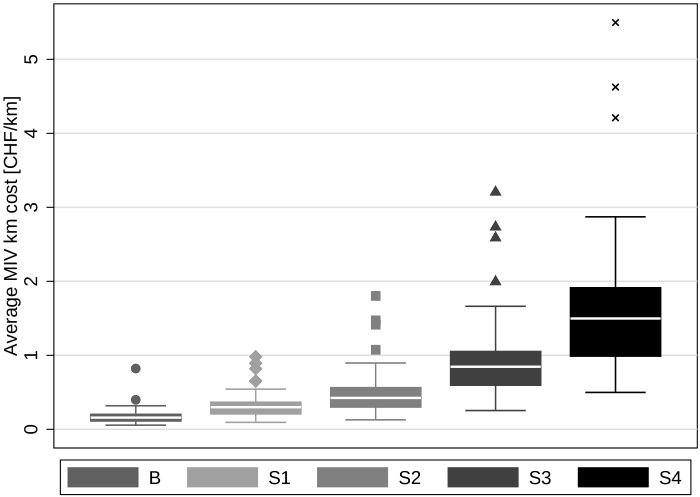
# Data

- N = 162 respondents, 810 initial choice scenarios
- Dependent variable: Distance traveled by MIV
  $y_{n,t} \equiv km_{n,t}$ after adaptation in **current** scenario
  - Highly right-skewed data with some zeros (respondents might choose not to use MIV anymore)
  - Pseudo-balanced panel: After drop-out, respondents are excluded ($\rightarrow$ 735 actual choice observations)
- Main explanatory variable: Average MIV travel cost per km
  $x_{n,t} \equiv \log(CHF_{n,t-1})$ after adaptation in **previous** scenario

# Adaptation patterns in distance traveled



# Change in MIV travel cost



# Modeling framework: GLM

- Log-linear OLS model is **inconsistent**
  - $E[\log(\eta_{n,t})|X_{n,t}] \neq 0$ if CEF is exponential ($\eta_{n,t}$ is LN) and presence of heteroscedasticity (*Jensen's inequality*)
  - Incompatible with mass point at zero
- Exponential family modeling approach using *pseudo* maximum likelihood techniques (Gourieroux et al., 1984)

$$f(Y_{n,t}|X_{n,t}, z_n, \Lambda) = \exp\left(\frac{Y_{n,t} f(X_{n,t}, z_n, \Lambda) - b(f(X_{n,t}, z_n, \Lambda))}{a(\phi)} + c(\phi, Y_{n,t})\right)$$

→ FOC score vector: GLM **consistent** as long as CEF is correctly specified (Santos-Silva and Tenreyro, 2006)
  - Poisson: $E[Y_{n,t}|X_{n,t}, z_n] = \exp(f(X_{n,t}, z_n, \Lambda))$
  - Heterosced.: $E[Y_{n,t}|X_{n,t}, z_n] = \mathrm{Var}[Y_{n,t}|X_{n,t}, z_n] = \lambda_{n,t}$
  - Globally concave, simple and fast in convergence

# Modeling framework: Panel structure

- Large variety in respondents' characteristics and their daily plans (unobserved heterogeneity)
- Starting point: Poisson regression for a continuous, non-negative dependent variable with mixed effects (Hausman test: $H_0$ plausible $\rightarrow$ RE more efficient)
- Hausman et al. (1984): Equidispersion assumption further relaxed by the RE specification $\text{Var}[Y_{n,t}|X_{n,t}] = \lambda_{n,t} + \theta\lambda^2_{n,t}$
- Huber/White sandwich estimator for SEs (Arellano, 1987)

# Modeling framework: Log-linear index

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

$$\lambda_{2,n,t} = \epsilon_n \cdot \exp\Bigg(\alpha + \alpha_{INC} \cdot inc_n + \alpha_{ENVI} \cdot envi_n + (\beta_{COST} + \beta_{INC} \cdot inc_n + \beta_{ENVI} \cdot envi_n) \cdot \log(CHF_{n,t-1}) \cdot \left(\frac{dist_{n,0}}{\overline{dist}}\right)^{\omega_{DIST}}\Bigg)$$

$$\lambda_{3,n,t} = \epsilon_n \cdot \exp\left(\alpha - \exp(\beta_{COST} + \psi_n) \cdot \log(CHF_{n,t-1}) \cdot \left(\frac{dist_{n,0}}{\overline{dist}}\right)^{\omega_{DIST}}\right)$$

$$\lambda_{4,n,t} = \epsilon_n \cdot \exp\Bigg(\alpha + \alpha_{INC} \cdot inc_n + \alpha_{ENVI} \cdot envi_n - \exp(\beta_{COST} + \beta_{INC} \cdot inc_n + \beta_{ENVI} \cdot envi_n + \psi_n) \cdot \log(CHF_{n,t-1}) \cdot \left(\frac{dist_{n,0}}{\overline{dist}}\right)^{\omega_{DIST}}\Bigg)$$

# Modeling framework: Estimation (1)

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

$$\mathcal{L}\mathcal{L}_n(Y_{n,t}|X_{n,t}, z_n, \Lambda) = \log \Gamma\left(1/\theta + \sum_{t=1}^{T_n} y_{n,t}\right) - \sum_{t=1}^{T_n} \log \Gamma\left(1 + y_{n,t}\right) -$$

$$\log \Gamma(1/\theta) + 1/\theta \cdot \log(u_n) + \log(1 - u_n) \sum_{t=1}^{T_n} y_{n,t} +$$

$$\sum_{t=1}^{T_n} y_{n,t} \cdot \log\left(\widetilde{\lambda_{s,n,t}}\right) - \left(\sum_{t=1}^{T_n} y_{n,t}\right) \log\left(\sum_{t=1}^{T_n} \widetilde{\lambda_{s,n,t}}\right)$$

# Modeling framework: Estimation (2)

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

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

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

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

$\rightarrow$ Posterior analysis of cost elasticity

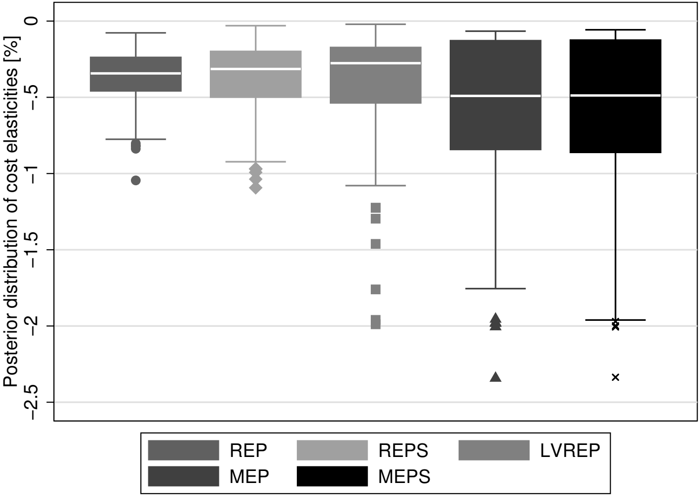
# Estimation results

| | REP Coef./(SE) | REPS Coef./(SE) | LVREP Coef./(SE) | MEP Coef./(SE) | MEPS Coef./(SE) |
|---|---|---|---|---|---|
| $\alpha$ | 3.20*** | 3.15*** | 3.06*** | 3.08*** | 3.05*** |
| $\alpha_{INC}$ | – | 0.17 | 0.16 | – | 0.16 |
| $\alpha_{ENVI}$ | – | −0.13*** | −0.62*** | – | −0.11** |
| $\theta$ | 0.65*** | 0.59*** | 0.51*** | 1.32*** | 1.27*** |
| $\beta_{COST}$ | −0.43*** | −0.44*** | −0.87*** | −0.72*** | −0.70*** |
| $\omega_{DIST}$ | 0.43*** | 0.47*** | 0.58*** | 0.56*** | 0.58*** |
| $\beta_{INC}$ | – | 0.03 | −0.08 | – | −0.28** |
| $\beta_{ENVI}$ | – | −0.05*** | 0.65*** | – | 0.08 |
| $\sigma_{COST}$ | – | – | – | 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 | −6911 | −6621 | −6047 | −6039 |
| AICc | 14066 | 13840 | 13154 | 12104 | 12097 |

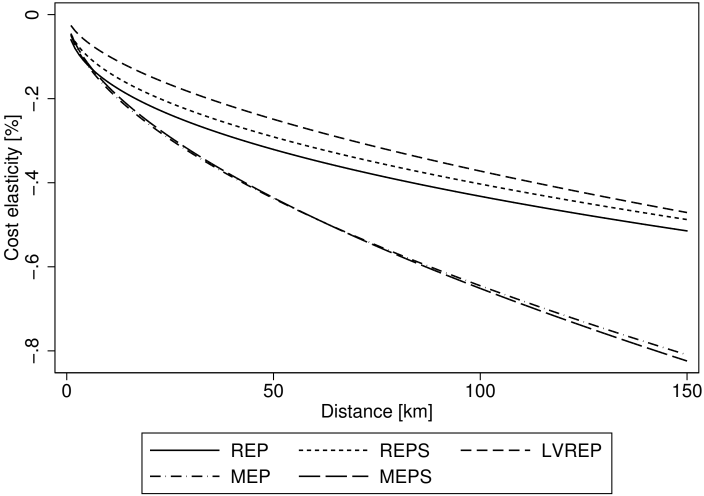
Robust standard errors: $^{***}: p < 0.01$, $^{**}: p < 0.05$, $^{*}: p < 0.1$

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 to 0.4% (re-weighted by MZMV distances)
- Remaining issues: Potential endogeneity of $dist_{n,0}$
- Strong, *positive* distance dependency
- Relatively high elasticities compared to related literature; usually between $-0.1$ (SR) and $-0.4$ (LR)
  - Sampling bias / low sample size
  - Survey design (daily travel, activity-based approach, etc.)
  - Very high variation in travel cost
- Respondents with pro-environmental traits travel less **and** show a stronger adaptation behavior

# Questions?