Discrete Choice Models in R

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Laundry Detergent Choice in Supermarket

Orange Juice Choice in Experiment

If these were your only options, which would you choose?

1 / 16

Brand	Hohes C	Albi	Valensina	NONE: I wouldn't choose any of these.
Price	1,69 €/L	1,09 €/L	1,99 €/L	
FairTrade label	No	Yes	Yes	
Package type	Plastic bottle (PET)	Carton (Tetra Pak)	Plastic bottle (PET)	
	○	○	○	○

Session Choice at eRum... you picked well ;)

10:45-12:15	Methodology 1 (McKinsey session)	Business 1	Packages 1
15:00-16:30	Methodology 2	Business 2	Packages 2
18:20-19:45	Methodology 3	Data workflow 1	BioR

Discrete Choice Models: Background

- **Discrete Choice Models: model and model assumptions (Train, 2009)**
  - Decision maker i obtains utility from alt. j at time t: $U_{ijt} = V_{ijt} + \epsilon_{ijt}$
  - Decision maker is utility maximizer: $U_{ijt} > U_{ikt}, \ \forall k \neq j$
  - Error term is distributed iid type I EV: $P_{ijt} = \frac{\exp\{V_{ijt}\}}{\sum_k \exp\{V_{ikt}\}}$
  - Mixed Logit (MXL) or random effects MNL: decision makers have heterogeneous preferences: $V_{ijt} = x'_{ijt} \cdot \beta_i$ with β_i $MVN(\mu, \Sigma)$
- **Discrete Choice Models are widely accepted**
  - Daniel McFadden: 2000 Nobel Memorial Prize in Economic Sciences (*"for his development of theory and methods for analyzing discrete choice"*)
  - Often used in academia (Chandukala *et al.*, 2007)
  - Often used in practice (e. g., Apple vs. Samsung: The $2 Billion Case, see Netzer/Sambandam, 2014)

Discrete Choice Models in `R`

- **Inference (and selected packages):**
  - Classical (Maximum Simulated Likelihood): `mlogit`, `gmnl`
  - Bayesian (Hierarchical Bayes): `bayesm`, `ChoiceModelR`
- **Stan (probabilistic programming language, see Carpenter et al., 2016):**
  - `Stan` uses Hamiltonian Monte Carlo (NUTS, see Hoffmann/Gelman, 2014); more efficient than Gibbs/Metropolis-Hastings
  - `Stan` is open source, written in C++, and provides interfaces to many other prog. languages including `Python`, `R`, `Stata`, `Matlab`, `Julia`, ...
  - Nice features, e. g. ShinyStan, loo, parallel chains, model checking, output summary, plots, ...
  - But: there is no implementation available for DCM, especially MXL
- **Why is `Stan` a good idea?**
  - MXL models can be difficult to estimate
  - `R` packages use optimized implementations of the "Allenby/Train-method" (see Train, 2009); but what about "non-standard models"?
  - Ben-Akiva/McFadden/Train (2016): *"Stan is the best general-purpose method, but ..."*-argument

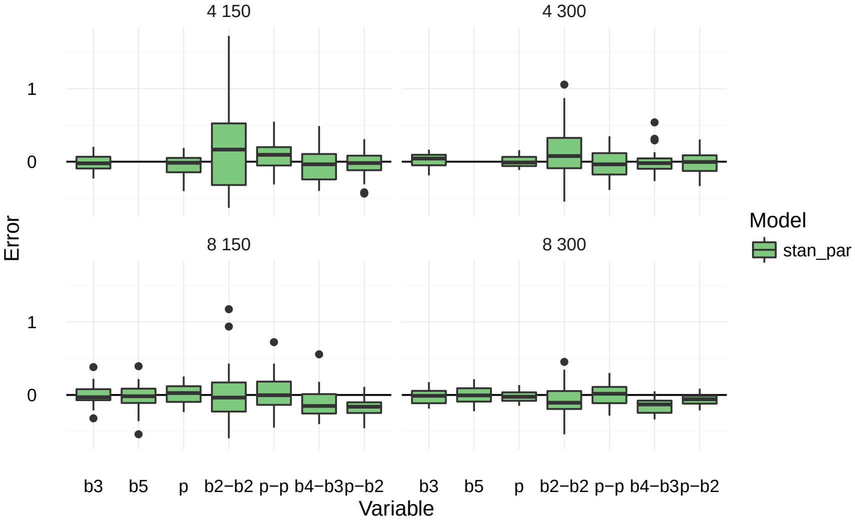
(Our First) MXL in Stan

```
data {
  int<lower = 1> N;                                          // number of obs.
  int<lower = 1> K;                                          // number of par.
  int<lower = 2> J;                                          // number of alts.
  int<lower = 1> I;                                          // number of resp.
  int<lower = 1, upper = J> y[N];                            // dep var
  int<lower = 1, upper = I> id[N];                           // resp. index
  matrix[J, K] x[N];                                         // x arrays
}

parameters {
  vector[K] mu;                                               // mean
  cov_matrix[K] Sigma;                                        // cov matrix
  vector[K] beta[I];                                          // reps. par
}

model {
  mu ~ normal(0, 100);                                        // priors
  Sigma ~ inv_wishart(K, diag_matrix(rep_vector(1.0, K)));

  for (i in 1:I) {
    beta[i] ~ multi_normal(mu, Sigma);                        // sample beta_i
  }
  for (n in 1:N) {
    y[n] ~ categorical_logit(x[n] * beta[id[n]]);             // logLik
  }
}
```

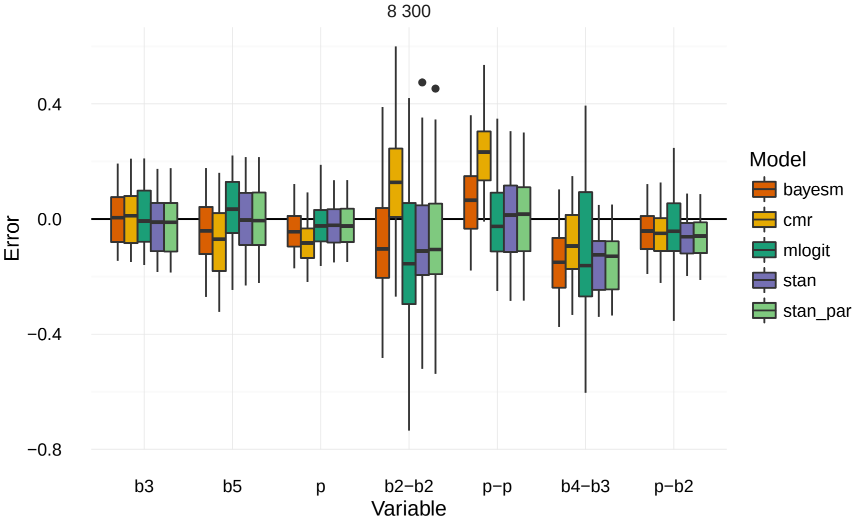
Simulation Study Setup

- **General setup:**
  - Number of alternatives $J \in \{4, 8\}$ (market shares: $ms_4 \in [14\%, 40\%]$ and $ms_8 \in [8\%, 24\%]$) and households $I \in \{150, 300\}$
  - Number of variables $K \in \{4, 8\}$ (price + $(J-1)$ alternative specific constants)
  - Number of estimated coefficients $C = K + K \cdot (K+1)/2$ (means + full covariance matrix)
  - Number of replications $R \in \{1, \ldots, 30\}$
- **Variables:**
  - $asc_{j_1, j_2} = \begin{cases} 1 & \text{if } j_1 = j_2 \\ 0 & \text{otherwise} \end{cases}$
  - $price \sim \mathrm{U}(3, 5)$
  - $\beta_i \sim \mathrm{MVN}(\mu_{nj}, \Sigma_{nj})$
- **Approaches:**
  - ours: `Stan` (single-core), `Stan` (multi-core, $n = 4$)
  - `mlogit`, `bayesm`, and `ChoiceModelR` (cmr)

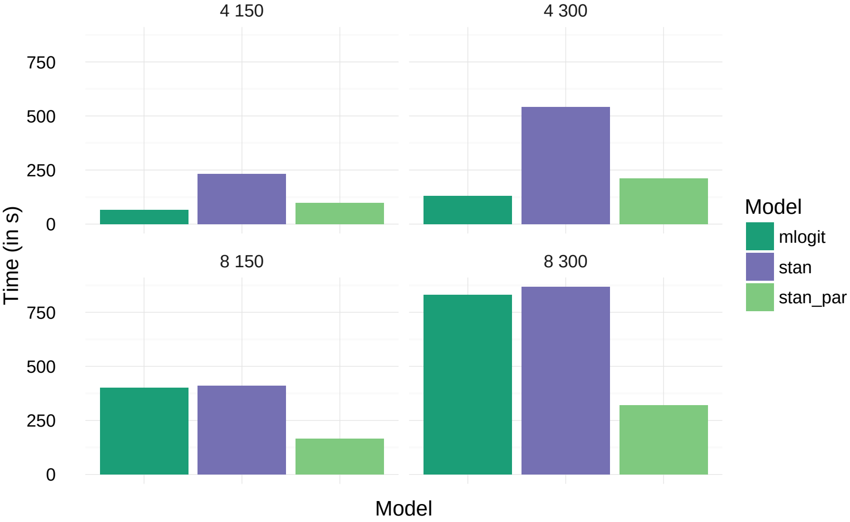
Simulation Study Results (1)



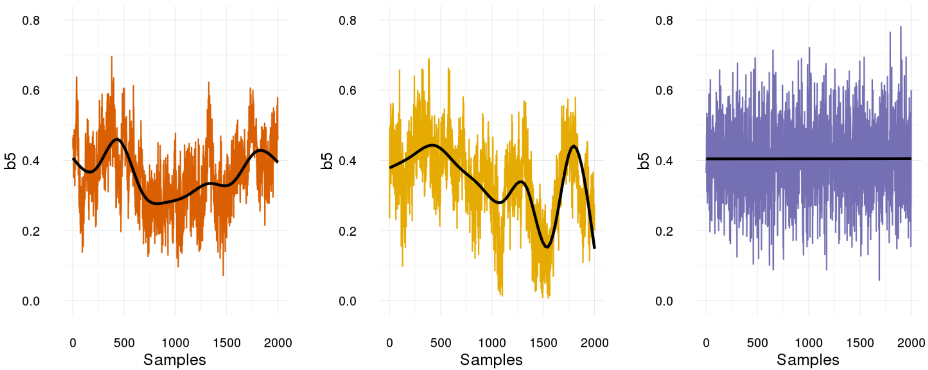
Simulation Study Results (2)



Runtime


4 150
4 300
8 150
8 300
750
500
250
0
750
500
250
0
Time (in s)
Model
Model
mlogit
stan
stan_par

Effective Samples

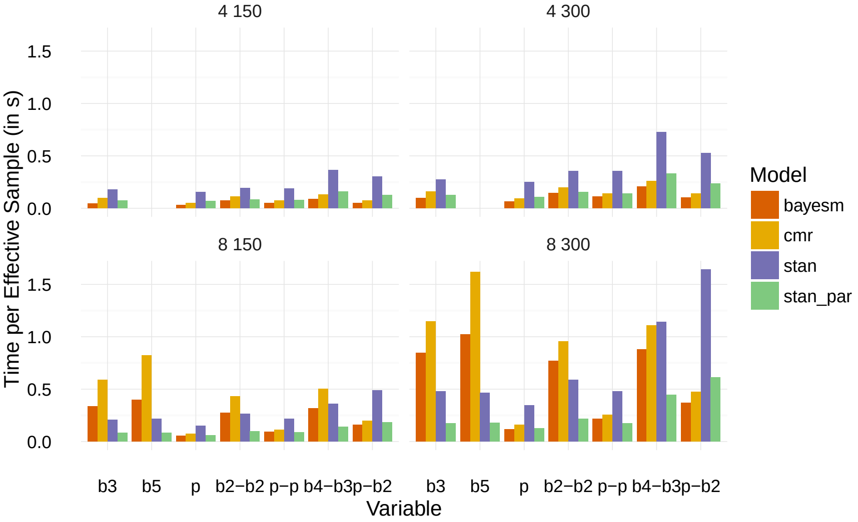


- 162 s for 40,000 samples
- 225 effective samples

- 223 s for 40,000 samples
- 115 effective samples

- 842 s for 4,000 samples
- 2,490 effective samples

Time per Effective Sample



Willingness-to-pay for a Fair Trade Label

- Willingness-to-pay (WTP) is an essential measure in QME (Netzer/Sambandam, 2014)
- Marginal rate of substitution between attribute and price: $WTP = \frac{\partial V / \partial x}{|\partial V / \partial price|}$
- Scholars advocate estimation of DCM in WTP-space (Sonnier *et al.*, 2007)
  - Preference-space: $V_{ijt} = x'_{ijt} \cdot \beta_i - \alpha_i \cdot price_{ijt}$
  - WTP-space: $V_{ijt} = \lambda_i \cdot (x'_{ijt} \cdot \omega_i - price_{ijt})$
- MVN-prior directly on WTP (ω) instead of preferences (β)
- No `R`-package available for estimating DCM in WTP-space "out-of-the-box" in a bayesian framework (but there is `gmnl` using MSL)
- However, product of parameters makes estimation more challenging
  - Even higher correlation in standard samplers
  - More iteration
  - Extreme thinning (*"...kept every 100th draw"*)

Setup

- **Setup:**
  - Data from choice experiment of Paetz/Guhl (2016)
  - 4 attributes: brand (Albi, Granini, HohesC, Valensina), packaging (carton, PET), FT label (yes, no), price (1.09, 1.39, 1.69, 1.99 Euro)
  - 200 respondents
  - 16 choices each
  - 4 alternatives (3 brands + no-buy)
- **Stan:**
  - We run `Stan` in parallel (4 chains)
  - 3,500 iterations incl. 1,000 for "warmup" = 10,000 draws
  - Successful convergence: all $\widehat{R}$-values are < 1.005
  - Runtime: 38 minutes
  - Efficiency: between 0.75 and 1.5 s/n_{eff}
- **gmnl**:
  - 4000 Halton draws
  - BHHH for optimization
  - Runtime: 43 minutes

WTP estimates ("standard errors" in parentheses)

	Stan		gmnl	
Attribute	**Mean**	**Std dev**	**Mean**	**Std dev**
No-buy option	-1.425 (0.059)	0.655 (0.053)	-1.434 (0.018)	0.633 (0.025)
Albi	-0.088 (0.036)	0.392 (0.035)	-0.066 (0.019)	0.460 (0.021)
Granini	0.024 (0.032)	0.352 (0.033)	0.055 (0.016)	0.319 (0.018)
Hohes C	0.240 (0.042)	0.512 (0.040)	0.234 (0.016)	0.541 (0.021)
FT label (yes)	0.258 (0.028)	0.345 (0.026)	0.260 (0.012)	0.352 (0.014)
Packaging (carton)	0.144 (0.040)	0.506 (0.035)	0.166 (0.013)	0.567 (0.019)

Status

- **Main idea similar to `rstanarm`:**
  - Pre-compiled `Stan` models for "standard" DCMs
  - Employs `rstan` as `R` interface to call `Stan`
- **Data handling:**
  - Provides functions to create data for `dcm`
  - Reshape `bayesm`, `ChoiceModelR`, and `mlogit` data
- **Supported models:**
  - "plain vanilla" MNL and MXL
  - MXL in WTP-space
  - MXL with log-norm price parameter
  - Models with μ as function of observables ("observed heterogeneity")
- **Outlook:**
  - About to release first version of `dcm` on github
  - More models (additional help + feedback is welcome!)
  - More convenience functions (e. g., analyzing output from `bayesm` or `ChoiceModelR` using `rstan`)

Conclusion

- `Stan` seems work well for estimating Discrete Choice Models
- Our implementation outperforms specialized and optimized implementations of standard models in `R`
- Speed comparisons are worthless w/o taking the effective sample size into account
- Additional flexibility is great for research ("non-standard-models")
- Coding models in `Stan` is easy + great resources online (e. g., manuals, tutorials, case studies, ...)
- However, high performance code needs (some) optimization + "tricks"

Thank you very much for your attention!

Questions?

References

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Train, K. (2009): *Discrete Choice Methods with Simulation*. 2nd edition, Cambridge University Press.

Server spec

- **CPU:**
  - E5-2690 v2
  - Intel Xeon (Ivy Bridge EP)
  - 3,0GHz
  - 25MB L3 Cache
  - DDR3 1866
- **RAM:**
  - 256GB DDR3 1866 DIMM
  - REG
  - ECC