# Predicting marketplace demand using Volumetric Conjoint Analysis

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# Introduction

# Demand predictions in packaged goods

Need to understand *primary* and *secondary* demand

Consumers demand *variety*; do not buy most goods

Consumers trade-offs between *quantity* and *quality*

CPGs need to rely on *choice experiments*, because new features are introduced, or sales data is too expensive or unavailable

# Challenges of Marketplace Predictions

**Market share** predictions are generally well-understood (*secondary* demand)

However, real vs hypothetical choices create challenges

- **Few vs many choice alternatives** (this paper)
- Real vs hypothetical money (incentive-alignment), engagement
- Motivation to buy (goals, consumption occasion, ...)
- ...

**Volume predictions** (including *primary* demand) create additional challenges, because primary depends on assortment size or variety

$\rightarrow$ assortment size elasticity of demand

# Demand Models and assortment size elasticity of demand

**'Market Share only' and 'quantity-then-choice'**

Ignore primary demand, or Poisson/Multinomial

$\rightarrow$ inelastic primary demand

**'Latent occasion'**

Latent occasion (Dubé, 2004)

$\rightarrow$ Containing acceptable choice alternatives

**Quantity demand models with economic foundation (Dubé, 2019)**

Deal with horizontal variety, corner solutions, any quantity of any alternative (e.g., Kim et al. (2002); Allenby et al. (2017); Bhat (2018))

$\rightarrow$ Variety Seeking

# Variation in choice-set size

Empirical research suggests mixed results on assortment elasticity (Boatwright and Nunes, 2001; Sloot et al., 2006; Borle et al., 2005).

Behavioral research is rich in theories on choice-set size variation (Meissner et al., 2019; Scheibehenne et al., 2010)

Choice set size often sees as a ‘complexity’ proxy (Dellaert et al., 2012)

However, no research investigates role of choice-set size in volumetric demand models

# Model

# The extant volumetric demand model

$$\text{Max } u(x,z) = \sum_{j=1}^{N} \frac{\psi_j}{\gamma} \ln(\gamma x_j + 1) + \psi_z \ln(z) \quad \text{s.t. } \sum_{j=1}^{N} p_j x_j + z = E$$

$$\text{where } \psi_j = \exp\left(a_j^T \beta + \varepsilon_j\right)$$

- Diminishing marginal returns of inside and outside goods
- Rate of satiation of inside goods $\gamma$
- Multiplicative error term $\varepsilon_j$ for each of the N inside goods
- $\psi_z = 1$ for identification

# Kuhn-Tucker conditions

Use Lagrange approach:

$$\text{Max } L = u(x,z) + \lambda \left\{ E - \sum_{j=1}^{N} p_j x_j - z \right\}$$

Associating first-order conditions with observed demand yields:

$$\begin{aligned} u_j &= p_j \cdot u_z && \text{if} \quad x_j > 0 \\ u_j &< p_j \cdot u_z && \text{if} \quad x_j = 0 \end{aligned}$$

where

$$\begin{aligned} u_j &= \frac{\partial u\left(x,z\right)}{\partial x_j} = \frac{\exp\left(a_j \beta + \varepsilon_j\right)}{\gamma x_j + 1} \\ u_z &= \frac{\partial u\left(x,z\right)}{\partial z} = \frac{\psi_z}{z} = \frac{1}{z} \end{aligned}$$

# Likelihood

Applying logarithms:

$$\begin{aligned} \varepsilon_j &= g_j \qquad && \text{if} \qquad x_j > 0 \\ \varepsilon_j &< g_j \qquad && \text{if} \qquad x_j = 0 \end{aligned}$$

where

$$g_j = -a_j\beta + \ln(p_j) + \ln(\gamma x_j + 1) - \ln(z)$$

Assuming standard Normal errors, the probability of observed demand where $R$ goods are chosen out of $N$ goods considered can be expressed as:

$$\Pr(x) = |J_R| \left\{ \prod_{i=1}^{R} \phi(g_i) \right\} \left\{ \prod_{j=R+1}^{N} \Phi(g_j) \right\}$$

# Variation in choice-set size

Given variation in choice-set size, $N_t$ is not a constant anymore

$$u\left(\mathbf{x_t}, z\right) = \sum_{k}^{N_t} \frac{\psi_{kt}}{\gamma} \ln\left(\gamma \mathbf{x}_{kt} + 1\right) + \psi_z \ln(z_t)$$

Variation in $N_t$ means variation in choice context

Expected baseline marginal utility $\psi_z$ changes if scale of error variance increases

Larger assortments can imply more uncertainty with respect to the outside good

However, $\psi_z = 1$ is fixed for identification ...

# Proposed location adjustment

We adjust the location of *inside good baseline marginal utilities*, yielding consistent estimates of $\beta$ across assortment sizes; adjustment is a function of $N$ (similar to Ackerberg and Rysman (2005))

We use a simple log specification

$$\psi^*_{kt} = \exp(\mathbf{a}_k \beta + \varepsilon - \ln(\delta N_t + 1))$$
$$\text{where } \delta > 0$$

This is equivalent to:

$$u(\mathbf{x_t}, z_t) = \sum_k \frac{\psi_{kt}}{\gamma} \ln(\gamma \mathbf{x}_{kt} + 1) + (\delta N_t + 1) \ln(z_t)$$

Ignoring the location shift would lead to a shift in inside good intercepts across different choice-set sizes

# Proposed model

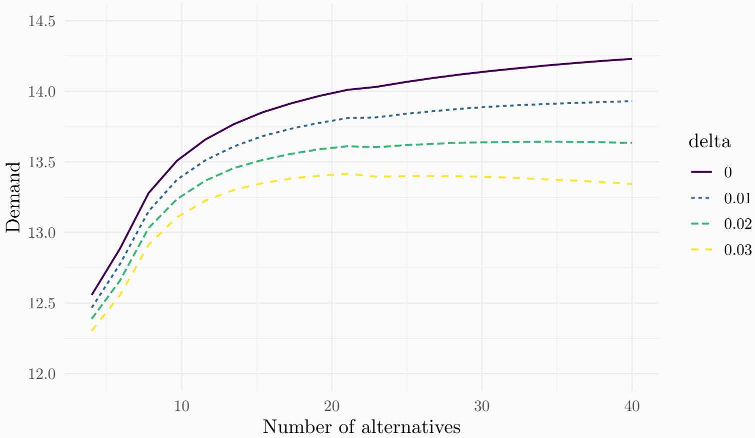
Now the marginal utility of the outside good is:

$$u_{zt} = \frac{\partial u\left(\mathbf{x}_t, z_t\right)}{\partial z_t} = \frac{\delta N_t + 1}{z_t}$$

The resulting likelihood function comprises mass and density contributions based on $g_{kt}$:

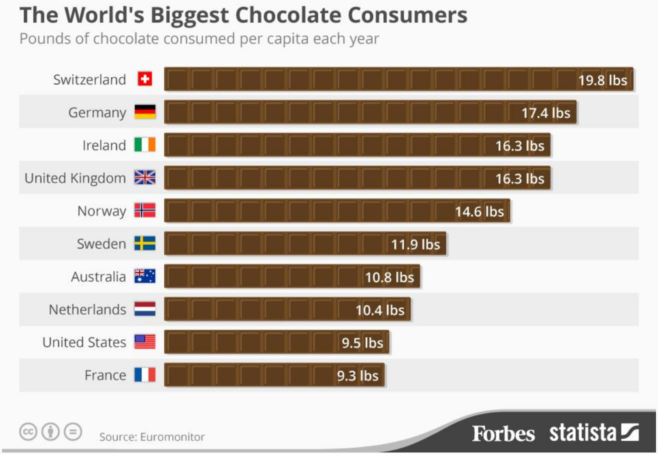
$$g_{kt} = -\mathbf{a}_{kt}\beta + \ln\left(\delta N_t + 1\right) + \ln\left(\mathbf{p}_{kt}\right) + \ln\left(\gamma \mathbf{x}_{kt} + 1\right) - \ln\left(z_t\right)$$

# Number of alternatives, $\delta$, and primary demand (simulation)



# Empirical Application

# Germans consume a lot of chocolate

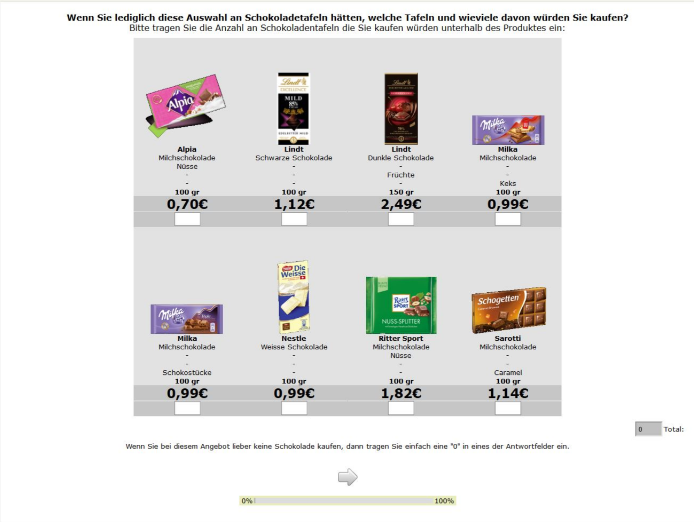


# Experimental Setup

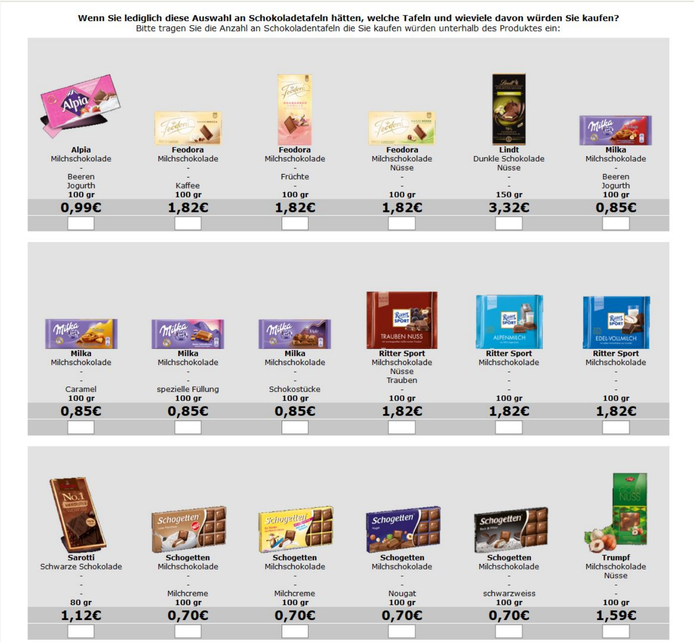
| Condition | Choice | Number of alternatives during first 8 tasks | Number of alternatives during second 8 tasks | sample size |
|---|---|---|---|---|
| 1 | Volumetric | 8 | 8 | 314 |
| 2 | Volumetric | 18 | 18 | 278 |
| 3 | Volumetric | 8 | 18 | 302 |

All respondents see 16 choice tasks

# Choice task (8 alternatives)



# Choice task (18 alternatives)



# Attributes and Levels

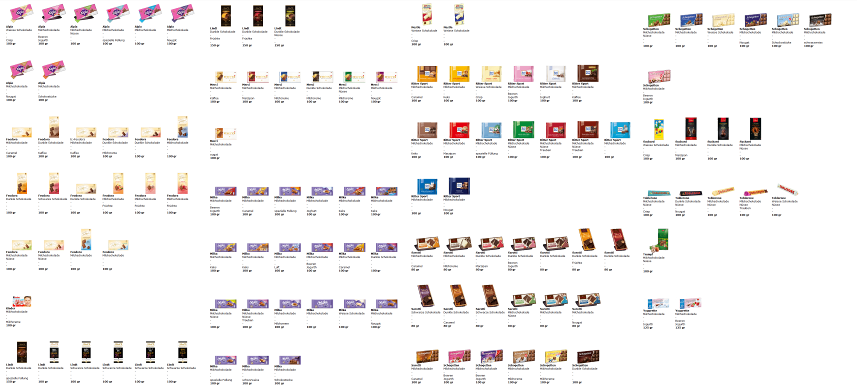
Attribute space based on existing features on market:

| Attributes | Levels |
|---|---|
| **Brand** | Alpia, Feodora, Kinder, Lindt, Merci, Milka, Nestle, Ritter, Sarotti, Schogetten, Suchard, Tobler, Trumpf, Ferrero/Yogurette |
| **Chocolate** | Milk, Dark, Black, White |
| **Nut** | Nut, No Nut |
| **Fruit** | Fruit, Berry, Grape, No Fruit |
| **Filling** | None, Yogurt, Choc Chunk, Coffee, Cookie, Black and White, Crisp, Nougat, Caramel, Milk Ccreme, Special, Marzipan |

Able to capture 80% of sales using this attribute space

Few SKUs are merged to keep attribute space manageable (e.g. 70% and 72% dark chocolate)

# Common marketplace offering



100+ items can be mapped to attribute space

Many more alternatives than presented on typical choice experiment task

# Empirical Application

## Descriptive Analysis

# Descriptive Statistics

| Data | | Units per task | | Varieties per task | | EUR spent | | Maximum spent | | Units where $\sum_i x_i > 0$ | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| # Alternatives | | mean | sd | mean | sd | mean | sd | mean | sd | mean | sd |
| 18 | | **2.27** | 0.48 | 1.67 | 0.27 | 2.73 | 0.61 | **8.50** | 3.40 | 2.73 | 0.53 |
| 18 | after 8 | **2.38** | 0.80 | 1.78 | 0.44 | 2.84 | 1.02 | **7.30** | 4.10 | 2.80 | 0.84 |
| 8 | | **1.66** | 0.45 | 1.22 | 0.26 | 1.98 | 0.65 | **7.21** | 5.78 | 2.25 | 0.54 |
| 8 | before 18 | **1.61** | 0.54 | 1.22 | 0.35 | 1.90 | 0.65 | **5.37** | 2.32 | 2.19 | 0.62 |

Primary demand is higher in 18 alternative condition

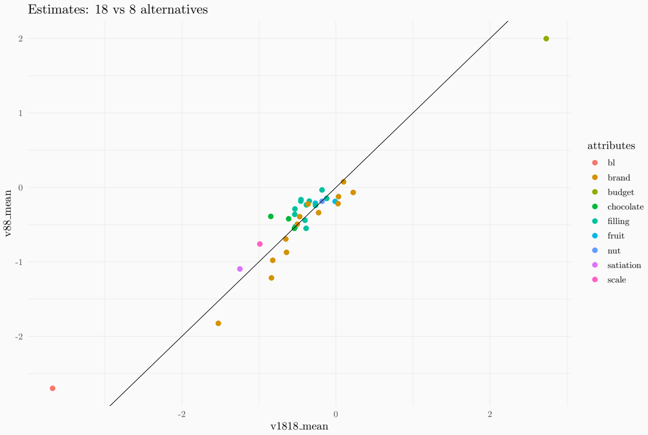
Demand for variety is higher, total expenditure is higher in 18 alternative condition

# Empirical Application

## Comparing 8 vs 18 alternatives

# Estimates: Using 18 vs 8 alternatives

| | 18 | | 8 | |
|---|---|---|---|---|
| par | mean | sd | mean | sd |
| baseline | **-3.68** | 0.12 | **-2.70** | 0.09 |
| **Brand** | | | | |
| Alpia | **-0.65** | 0.07 | **-0.69** | 0.07 |
| Feodora | **-1.53** | 0.11 | **-1.83** | 0.11 |
| FerreroYogu | 0.03 | 0.13 | -0.12 | 0.13 |
| Kinder | 0.22 | 0.14 | -0.07 | 0.19 |
| Lindt | 0.03 | 0.12 | -0.22 | 0.14 |
| Merci | **-0.36** | 0.09 | **-0.22** | 0.09 |
| Nestle | **-0.50** | 0.09 | **-0.49** | 0.11 |
| Ritter | 0.10 | 0.08 | 0.07 | 0.08 |
| Sarotti | **-0.82** | 0.10 | **-0.98** | 0.12 |
| Schogetten | **-0.47** | 0.08 | **-0.39** | 0.07 |
| Suchard | **-0.84** | 0.14 | **-1.22** | 0.19 |
| Tobler | **-0.23** | 0.10 | **-0.34** | 0.14 |
| Trumpf | **-0.64** | 0.12 | **-0.87** | 0.20 |
| **Chocolate** | | | | |
| black | **-0.85** | 0.15 | **-0.39** | 0.11 |
| dark | **-0.61** | 0.11 | **-0.42** | 0.10 |
| white | **-0.54** | 0.09 | **-0.55** | 0.10 |
| **Fruit and Nut** | | | | |
| nut | **-0.18** | 0.06 | **-0.19** | 0.07 |
| berry | **-0.27** | 0.08 | **-0.21** | 0.08 |
| fruit | **-0.53** | 0.12 | **-0.53** | 0.16 |
| grape | -0.01 | 0.06 | **-0.19** | 0.07 |
| **Filling** | | | | |
| blackwhite | **-0.40** | 0.09 | **-0.44** | 0.12 |
| caramel | **-0.46** | 0.08 | **-0.19** | 0.08 |
| chocchunk | **-0.35** | 0.08 | **-0.18** | 0.08 |
| coffee | **-0.54** | 0.08 | **-0.36** | 0.13 |
| cookie | **-0.27** | 0.07 | **-0.24** | 0.07 |
| crisp | **-0.39** | 0.09 | **-0.55** | 0.11 |
| marzipan | **-0.38** | 0.10 | -0.24 | 0.12 |
| milkcreme | **-0.45** | 0.06 | **-0.16** | 0.07 |
| nougat | -0.12 | 0.07 | -0.15 | 0.08 |
| special | **-0.18** | 0.06 | -0.03 | 0.08 |
| yog | **-0.53** | 0.07 | **-0.29** | 0.08 |
| lnE | **2.73** | 0.10 | **2.00** | 0.06 |
| lng | **-1.25** | 0.06 | **-1.10** | 0.06 |
| lnsig | **-0.99** | 0.04 | **-0.76** | 0.04 |



# Empirical Application

## Applying the proposed model

# Applying the proposed and competing models

Respondents were shown 8 tasks with 8 alternatives, then 8 tasks with 18 alternatives

We estimate a pooled model and then allow $\beta_0$, $\gamma$, $E$ to differ between the 8 and 18 alternative tasks, while 'part-worths' are assumed to be identical across the 8 and 18 alternative settings

Finally, we estimate the proposed model with location adjustment

# Model fits

| | In-sample | Out of sample | | |
|---|---|---|---|---|
| model | LMD | mse | mae | rae |
| pooled | -11384.75 | 0.143 | 0.134 | 0.799 |
| b | -11161.54 | 0.145 | 0.130 | 0.771 |
| bg | -11205.18 | 0.147 | 0.131 | 0.777 |
| bgE | -10954.32 | 0.147 | 0.131 | 0.777 |
| proposed | -11164.97 | 0.140 | 0.129 | 0.770 |

In-sample fit favors more flexible models

Overall, out-of-sample fit is very similar

# Estimates: Using 18 vs 8 alternatives

| | pooled | | b | | bg | | bgE | | proposed | |
|---|---|---|---|---|---|---|---|---|---|---|
| $\bar{\theta}$ posterior | mean | sd | mean | sd | mean | sd | mean | sd | mean | sd |
| baseline | **-3.16** | 0.12 | **-2.92** | 0.12 | **-2.92** | 0.13 | **-2.55** | 0.12 | **-2.55** | 0.15 |
| baseline2 | | | **-3.22** | 0.11 | **-3.25** | 0.12 | **-3.46** | 0.13 | | |
| **Brand** (reference=Milka) | | | | | | | | | | |
| Alpia | **-0.65** | 0.11 | **-0.82** | 0.09 | **-0.80** | 0.11 | **-0.79** | 0.09 | **-0.70** | 0.10 |
| Feodora | **-2.22** | 0.19 | **-2.42** | 0.17 | **-2.45** | 0.20 | **-2.56** | 0.17 | **-2.07** | 0.21 |
| FerreroYogu | -0.10 | 0.17 | -0.04 | 0.16 | -0.10 | 0.18 | 0.10 | 0.14 | 0.04 | 0.21 |
| Kinder | 0.32 | 0.16 | 0.23 | 0.17 | **0.52** | 0.18 | **0.72** | 0.19 | 0.25 | 0.16 |
| Lindt | -0.24 | 0.17 | **-0.45** | 0.17 | **-0.37** | 0.22 | **-0.44** | 0.20 | -0.24 | 0.19 |
| Merci | **-0.46** | 0.12 | **-0.56** | 0.14 | **-0.52** | 0.15 | **-0.48** | 0.13 | **-0.41** | 0.14 |
| Nestle | **-0.71** | 0.20 | **-0.46** | 0.13 | **-0.60** | 0.16 | **-0.43** | 0.20 | **-0.46** | 0.15 |
| Ritter | -0.06 | 0.11 | -0.08 | 0.11 | -0.09 | 0.12 | -0.06 | 0.12 | -0.03 | 0.11 |
| Sarotti | **-1.24** | 0.15 | **-1.22** | 0.13 | **-1.32** | 0.13 | **-1.38** | 0.13 | **-1.13** | 0.13 |
| Schogetten | **-0.54** | 0.09 | **-0.59** | 0.09 | **-0.54** | 0.10 | **-0.57** | 0.10 | **-0.49** | 0.09 |
| Suchard | **-1.78** | 0.27 | **-1.26** | 0.23 | **-1.46** | 0.23 | **-1.52** | 0.21 | **-1.27** | 0.16 |
| Tobler | **-0.50** | 0.16 | **-0.50** | 0.16 | **-0.44** | 0.14 | **-0.47** | 0.15 | **-0.53** | 0.15 |
| Trumpf | **-0.67** | 0.16 | **-0.87** | 0.19 | **-0.83** | 0.23 | **-0.56** | 0.16 | **-0.82** | 0.23 |
| **Chocolate** (reference=milk) | | | | | | | | | | |
| black | -0.34 | 0.20 | -0.23 | 0.19 | -0.33 | 0.19 | -0.09 | 0.16 | -0.29 | 0.18 |
| dark | **-0.61** | 0.16 | **-0.67** | 0.15 | **-0.79** | 0.15 | **-0.73** | 0.15 | **-0.66** | 0.13 |
| white | **-0.80** | 0.14 | **-0.80** | 0.17 | **-0.83** | 0.13 | **-0.87** | 0.12 | **-0.78** | 0.12 |
| **Fruit and Nut** | | | | | | | | | | |
| nut | -0.12 | 0.09 | -0.13 | 0.08 | **-0.19** | 0.09 | -0.18 | 0.10 | -0.14 | 0.08 |
| berry | **-0.36** | 0.13 | **-0.25** | 0.11 | **-0.32** | 0.12 | **-0.31** | 0.12 | **-0.30** | 0.11 |
| fruit | **-0.89** | 0.14 | **-0.77** | 0.14 | **-0.68** | 0.21 | **-0.73** | 0.20 | **-1.15** | 0.13 |
| grape | -0.13 | 0.08 | -0.08 | 0.08 | -0.10 | 0.09 | -0.07 | 0.09 | -0.08 | 0.08 |
| **Filling** | | | | | | | | | | |
| blackwhite | **-0.52** | 0.13 | **-0.55** | 0.15 | **-0.62** | 0.15 | **-0.53** | 0.11 | **-0.57** | 0.17 |
| caramel | **-0.29** | 0.10 | **-0.27** | 0.11 | **-0.29** | 0.12 | **-0.35** | 0.11 | **-0.33** | 0.11 |
| chocchunk | **-0.49** | 0.14 | **-0.48** | 0.10 | **-0.53** | 0.12 | **-0.42** | 0.15 | **-0.58** | 0.13 |
| coffee | **-0.51** | 0.11 | **-0.49** | 0.12 | **-0.54** | 0.14 | **-0.65** | 0.14 | **-0.61** | 0.14 |
| cookie | **-0.36** | 0.10 | **-0.40** | 0.11 | **-0.43** | 0.11 | **-0.51** | 0.13 | **-0.40** | 0.11 |
| crisp | **-0.30** | 0.12 | **-0.45** | 0.16 | **-0.40** | 0.10 | **-0.55** | 0.10 | **-0.42** | 0.12 |
| marzipan | **-0.41** | 0.13 | **-0.49** | 0.10 | **-0.47** | 0.12 | **-0.46** | 0.14 | **-0.43** | 0.13 |
| milkcreme | **-0.32** | 0.09 | **-0.34** | 0.10 | **-0.40** | 0.09 | **-0.43** | 0.10 | **-0.34** | 0.09 |
| nougat | -0.04 | 0.10 | -0.03 | 0.09 | -0.08 | 0.09 | -0.03 | 0.09 | -0.06 | 0.09 |
| special | **-0.29** | 0.10 | **-0.29** | 0.10 | **-0.37** | 0.09 | **-0.39** | 0.11 | **-0.28** | 0.09 |
| yog | **-0.47** | 0.10 | **-0.55** | 0.11 | **-0.61** | 0.10 | **-0.64** | 0.10 | **-0.57** | 0.11 |
| lnE | **1.91** | 0.07 | **1.86** | 0.07 | **1.84** | 0.07 | **1.49** | 0.06 | **1.94** | 0.07 |
| lnE2 | | | | | | | **1.90** | 0.08 | | |
| lng | **-1.06** | 0.07 | **-1.04** | 0.07 | **-0.91** | 0.07 | **-1.11** | 0.09 | **-1.10** | 0.07 |
| lng2 | | | | | **-1.05** | 0.07 | **-0.98** | 0.07 | | |
| lnsig | **-0.62** | 0.04 | **-0.61** | 0.05 | **-0.57** | 0.04 | **-0.50** | 0.05 | **-0.67** | 0.04 |
| lndelta | | | | | | | | | **-3.62** | 0.27 |

- Estimates of part-worths are consistent across models
- Need for location adjustment visible from difference in $\beta_0$ estimates; location shift will be larger with larger differences in choice set size

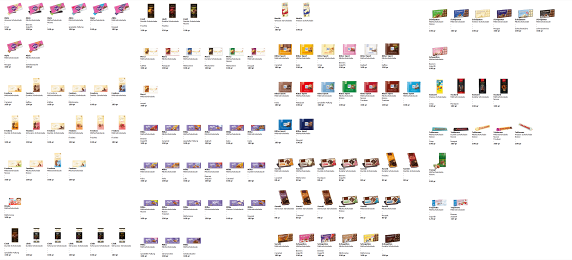
# Empirical Application

## Marketplace Predictions

# Marketplace Prediction

Product offerings based on typical supermarket, >100 SKUs, average prices

Predictions based on proposed and pooled models



# Extrapolating marketplace demand in t – actual: 240,000

Annual primary demand prediction, assuming 25m households, 3 shopping trips/week:

| model | mean | median | centile 5 | centile 95 | sd |
|---|---|---|---|---|---|
| b | 411,453 | 411,095 | 393,778 | 430,124 | 11,184 |
| bg | 414,355 | 414,066 | 395,323 | 434,303 | 11,905 |
| bgE | 440,239 | 440,491 | 414,383 | 466,117 | 15,852 |
| pooled | 435,315 | 434,782 | 415,240 | 456,749 | 12,740 |
| **proposed** | 257,076 | 255,315 | 227,662 | 294,244 | 19,944 |
| $\bar{x}$ - 18 alternatives | 206,100 | | | | |
| $\bar{x}$ - 8 alternatives | 150,300 | | | | |
| stated 'last purchase' | 217,617 | | | | |

Actual annual demand: 240,000t

Models without location adjustment overpredict demand

Primary demand depends on choice-set size

# Brand-name level predictions – per trip

| | demand quantity | | | | demand share | | | |
|---|---|---|---|---|---|---|---|---|
| brand | only18 | only8 | pooled | proposed | only18 | only8 | pooled | proposed |
| Milka | 2.323 | 1.839 | 1.483 | 0.805 | 0.267 | 0.289 | 0.307 | 0.282 |
| Ritter | 1.674 | 1.167 | 0.845 | 0.485 | 0.193 | 0.184 | 0.175 | 0.170 |
| Lindt | 1.106 | 0.615 | 0.553 | 0.372 | 0.127 | 0.097 | 0.114 | 0.130 |
| Alpia | 1.170 | 0.708 | 0.606 | 0.356 | 0.134 | 0.111 | 0.125 | 0.125 |
| Schogetten | 0.739 | 0.575 | 0.392 | 0.237 | 0.085 | 0.090 | 0.081 | 0.083 |
| Tobler | 0.406 | 0.354 | 0.269 | 0.169 | 0.047 | 0.056 | 0.056 | 0.059 |
| Sarotti | 0.364 | 0.273 | 0.169 | 0.119 | 0.042 | 0.043 | 0.035 | 0.042 |
| FerreroYogu | 0.240 | 0.230 | 0.132 | 0.078 | 0.028 | 0.036 | 0.027 | 0.028 |
| Kinder | 0.162 | 0.088 | 0.119 | 0.072 | 0.019 | 0.014 | 0.025 | 0.025 |
| Merci | 0.208 | 0.217 | 0.108 | 0.060 | 0.024 | 0.034 | 0.022 | 0.021 |
| Nestle | 0.115 | 0.113 | 0.077 | 0.045 | 0.013 | 0.018 | 0.016 | 0.016 |
| Feodora | 0.092 | 0.079 | 0.041 | 0.026 | 0.011 | 0.013 | 0.008 | 0.009 |
| Suchard | 0.055 | 0.051 | 0.019 | 0.017 | 0.006 | 0.008 | 0.004 | 0.006 |
| Trumpf | 0.045 | 0.047 | 0.025 | 0.014 | 0.005 | 0.007 | 0.005 | 0.005 |

# Brand-name level sales prediction (actual: EUR 240m)

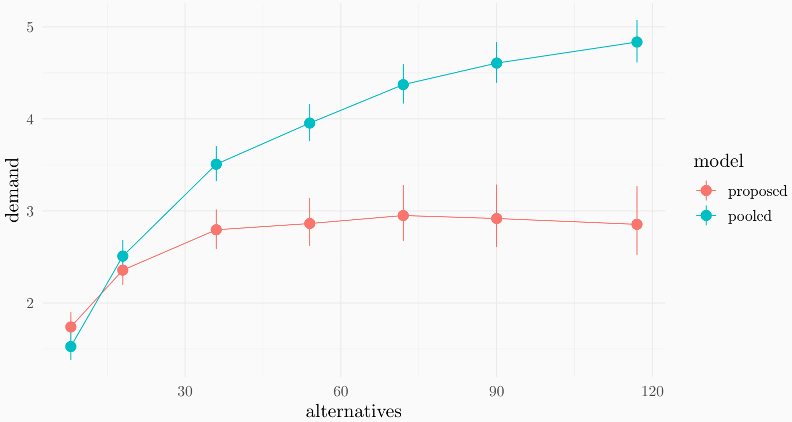
Ritter SPORT

Domestic Sales of Ritter Sport: EUR 240m (actual)

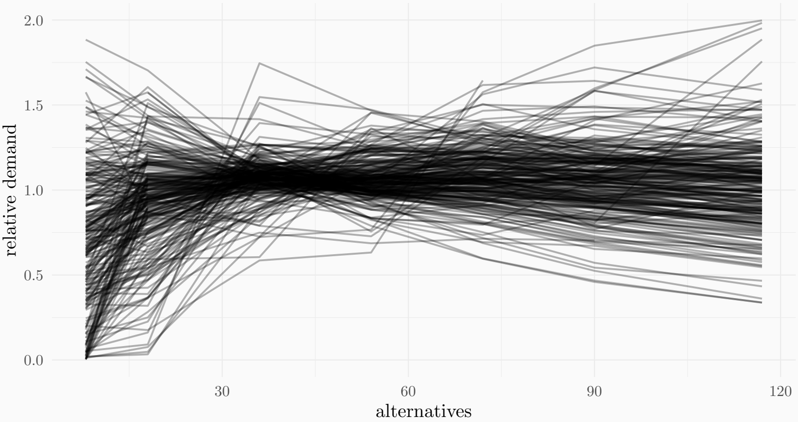
Prediction, assuming 50% sales margin, 25m households, 3 shopping trips/week:

| **model** | **mean** | **median** | **centile 5** | **centile 95** | **sd** |
|---|---|---|---|---|---|
| b | 352.89 | 351.62 | 295.51 | 416.79 | 37.52 |
| bg | 354.89 | 353.07 | 292.74 | 421.64 | 39.21 |
| bgE | 378.02 | 376.41 | 312.51 | 449.50 | 41.81 |
| pooled | 380.50 | 379.51 | 315.21 | 447.20 | 40.18 |
| **proposed** | 217.53 | 216.28 | 165.12 | 276.17 | 34.24 |

# Comparing assortment elasticity of demand



# Heterogeneity in assortment elasticity



# Conclusion

# Implications, Future Research, Limitations

Assortment size elasticity of demand matters

Proposed model can also be applied to purchase transaction data with dynamic assortment sizes

Screening rules

More variation in number of alternatives

Apply to sales data

Integer choices vs continuous quantities (not solvable in high dimension, since NP-hard)

# Backup

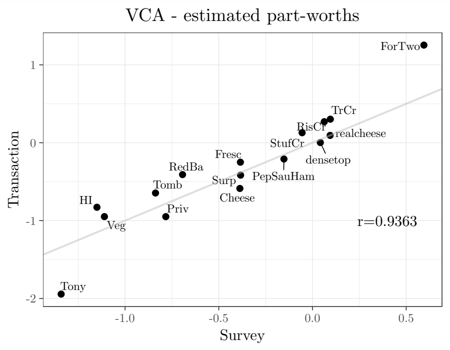
# Secondary demand analysis works

Despite challenges, secondary demand analysis works well

For instance, in packaged goods, people know what they like

Recap from volumetric demand study on frozen Pizza purchases

- Relative preferences are identical between Conjoint and Transaction data
- Choice experiments are capable of predicting market *shares*



# Jacobian

Transforming from random-utility error ($\varepsilon$) to the likelihood of the observed data ($x$), we need to consider the Jacobian $|J_{R_t}|$:

$$|J_{R_t}| = \prod_{i=1}^{R_t} \left( \frac{\gamma}{\gamma x_{i,t} + 1} \right) \left\{ \sum_{i=1}^{R_t} \frac{\gamma x_{i,t} + 1}{\gamma} \cdot \frac{p_i}{z_t} + 1 \right\}$$

# Priors & Estimation

$\theta_h = \{\beta_h, \ln\gamma_h, \ln E_h, \ln\sigma_h, \ln\delta_h\}$ is respondent $h$'s vector of parameters of length $M$ governing the individual-level demand model.

We assume:

$$\theta_h \sim \text{Normal}(\bar{\theta}, \Sigma)$$

Hyperparameters:

$$\bar{\theta} \sim Normal(0, 100 I_M)$$

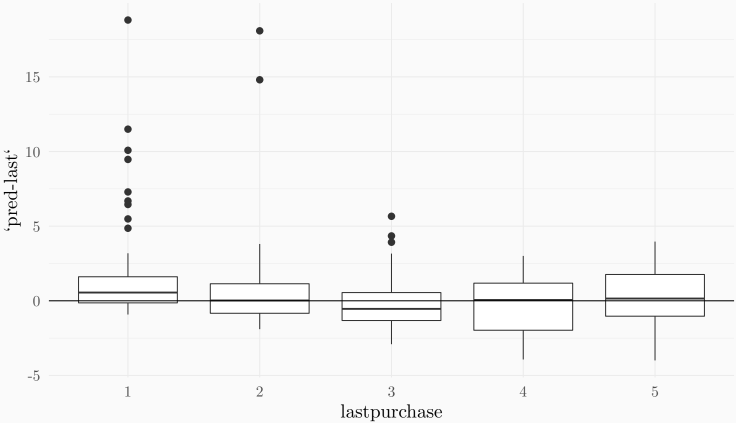
$$\Sigma \sim \mathrm{IW}(M+4, (M+4) I_M)$$

Estimation of this model is easy using standard Monte Carlo Markov Chain methods, including the Metropolis-Hastings algorithm

# Hold-Out fit statistics

$$
\begin{aligned}
\mathrm{MSE}(\mathbf{x}, \hat{\mathbf{x}}) &= \frac{\sum_{i=1}^{n} \left(\hat{\mathbf{x}}_i - \mathbf{x}_i\right)^2}{n} \\
\mathrm{MAE}(\mathbf{x}, \hat{\mathbf{x}}) &= \frac{\sum_{i=1}^{n} \left|\hat{\mathbf{x}}_i - \mathbf{x}_i\right|}{n} \\
\mathrm{RAE}(\mathbf{x}, \hat{\mathbf{x}}) &= \frac{\sum_{i=1}^{n} \left|\hat{\mathbf{x}}_i - \mathbf{x}_i\right|}{\sum_{i=1}^{n} \left|\bar{\mathbf{x}} - \mathbf{x}_i\right|}
\end{aligned}
$$

# Individual-level primary demand predictions



# Chocolate bars in Germany

Common packaged good

Variety

We do not expect choice anomalies: easy tasks, familiar brands and features

I like chocolate

# Median response times

Respondents are quick to adjust to changing choice-set size