Modeling relationships from themes in text and covariates with an outcome

A Bayesian supervised topic model with covariates

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Text Data in Psychology

- Text is an increasingly popular data source
    - Social media (Schwartz et al., 2013)
    - Open-ended questions (Popping, 2015)
    - Medical health records (Obeid et al., 2019)
- Various overviews exist on existing text mining algorithms for psychological research (Finch et al., 2018; Iliev et al., 2015; Kjell et al., 2019; Rohrer et al., 2017)
- These algorithms are often designed for large data sets
- Current challenge is to adapt these algorithms to psychological research

Modeling Text as Data

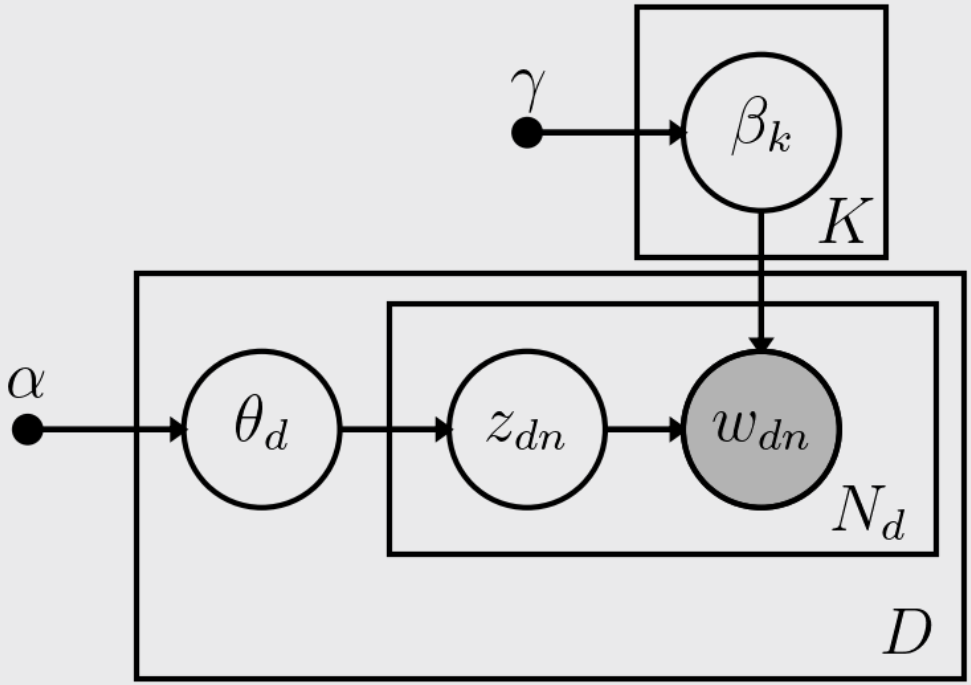
Top Down

- Dictionary methods
    - LIWC (Tausczik et al., 2010)
    - Sentiment analysis
- Dictionaries may not be valid for given data

Bottom Up

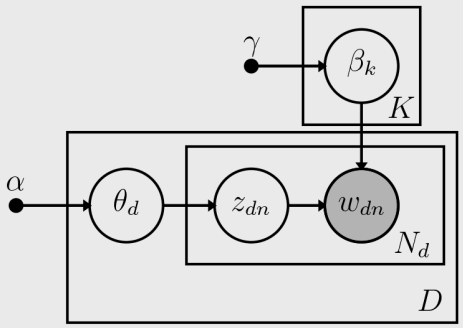
- Qualitative analysis
    - Gold standard
    - Time-consuming and expensive
    - Hard to reuse
- Quantitative models
    - Faster and cheaper
    - Reusable

Topic Modeling



Latent Dirichlet Allocation (LDA)

Seminal topic model (Blei et al., 2003)



$$L(\vec{\Theta}, \vec{B}) = \prod_{d=1}^{D} \prod_{n=1}^{N_d} \beta_{z_{dn}, w_{dn}} \theta_{d, z_{dn}}$$

Topics:

$$\vec{\beta}_k = \Pr\left[w_{dn} = m | z_{dn} = k\right]$$
$$\vec{\beta}_k \sim \mathrm{Dir}(\vec{\gamma})$$

Topic proportions:

$$\vec{\theta}_d = \Pr\left[z_{dn} = k\right]$$
$$\vec{\theta}_d \sim \mathrm{Dir}(\vec{\alpha})$$

Topic assignments:

$$\left(z_{dn} | \vec{\theta}_d\right) \sim \mathrm{Cat}(\vec{\theta}_d)$$

Words:

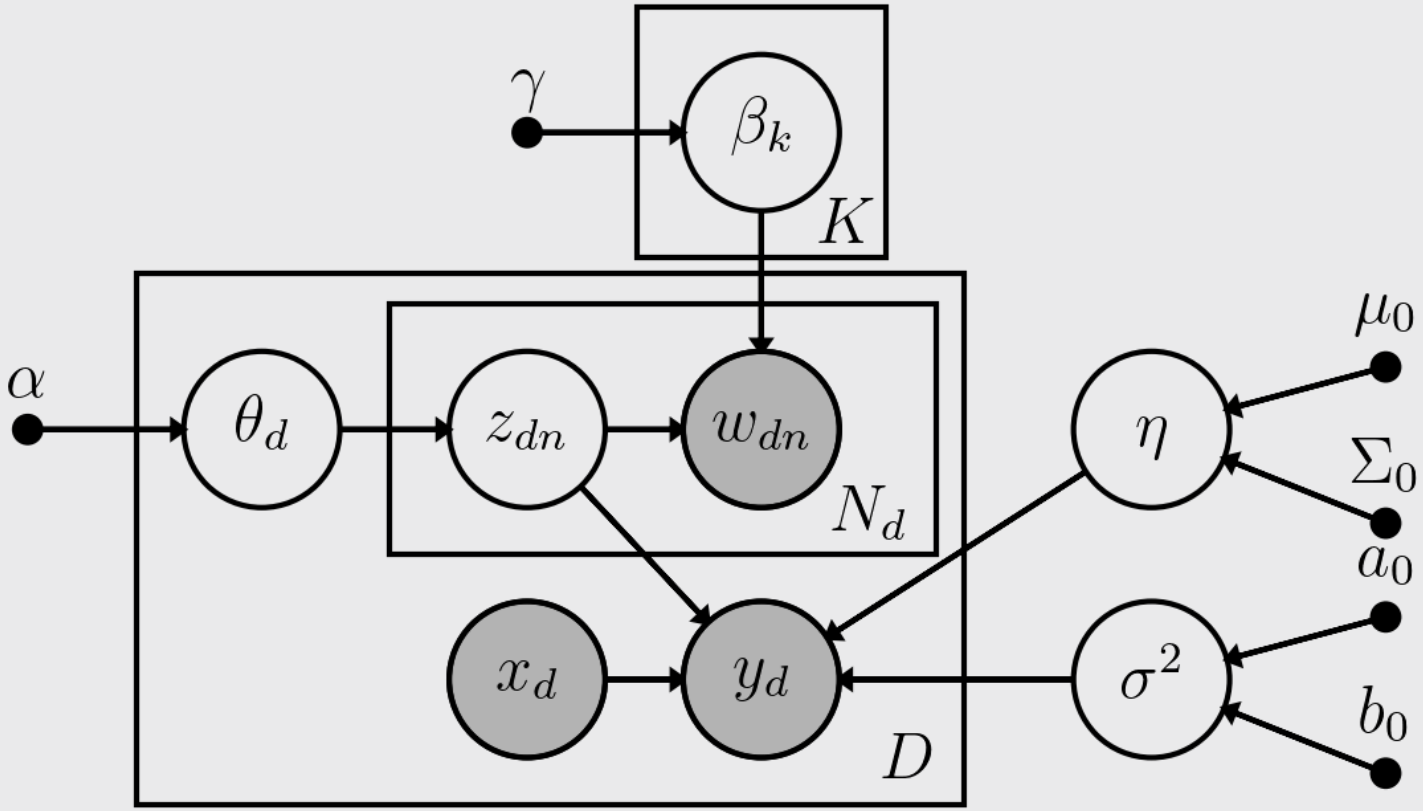
$$\left(w_{dn} | z_{dn} = k, \vec{\beta}_k\right) \sim \mathrm{Cat}(\vec{\beta}_k)$$

Fusing Topic Models and Regression

$$Y = \boxed{\phantom{\vec{\Theta}}}\eta + X\beta + \epsilon$$

- Two-stage approach (Packard et al., 2020; Rohrer et al., 2017)
  - Use estimated $\vec{\Theta}$ to predict Y
  - Could include other manifest predictors $\vec{X}$
- One-stage approach
  - Supervised topic model (SLDA; Blei et al., 2010)
  - Does not include $\vec{X}$
- We propose the SLDAX model
  - One-stage approach
  - Allow topics and manifest predictors of Y

SLDAX


γ
β_k
K
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y_d
σ^2
b_0
D

Gibbs Sampler for $Y|\cdot \sim \mathrm{N}(\cdot)$

- $f\left(z_{d,n}=k|\cdot\right) \propto \exp\left\{-\frac{1}{2\sigma^2}\left(y_d-\left(\vec{\bar{z}}_d,\vec{x}_d\right)'\vec{\eta}\right)^2\right\}\times \left(n_{dk}^{(-n)}+\alpha\right)\left(\frac{n_{kv}^{(-n)}+\gamma}{n_k^{(-n)}+V\gamma}\right)$
- $f\left(\sigma^2|\cdot\right)=\mathrm{IG}\left(\frac{a_0+D}{2},\frac{1}{2}\left(b_0+\sum_d\left[y_d-\left(\vec{\bar{z}}_d,\vec{x}_d\right)'\vec{\eta}\right]^2\right)\right)$
- $f\left(\vec{\eta}|\cdot\right)=\mathrm{N}\left(\vec{\eta}_1,\vec{\Sigma}_1\right)$
  - $\vec{\Sigma}_1=\left(\vec{\Sigma}_0^{-1}+\sigma^{-2}\left(\vec{\bar{Z}},\vec{X}\right)'\left(\vec{\bar{Z}},\vec{X}\right)\right)^{-1}$
  - $\vec{\eta}_1=\vec{\Sigma}_1\left(\vec{\Sigma}_0^{-1}\vec{\mu}_0+\sigma^{-2}\left(\vec{\bar{Z}},\vec{X}\right)'\vec{y}\right)$

MH-in-Gibbs for $Y|\cdot \sim \text{Ber}(\cdot)$

- $f\left(z_{dn}=k|\cdot\right) \propto \frac{\exp\left\{y_d\left(\vec{\bar{z}}_d,\vec{x}_d\right)'\vec{\eta}\right\}}{1+\exp\left\{\left(\vec{\bar{z}}_d,\vec{x}_d\right)'\vec{\eta}\right\}}\left(n_{dk}^{(-n)}+\alpha\right)\left(\frac{n_{kv}^{(-n)}+\gamma}{n_{k}^{(-n)}+V\gamma}\right)$
- $f\left(\vec{\eta}|\cdot\right) \propto \prod_d \left[\frac{\exp\left\{y_d\left(\vec{\bar{z}}_d,\vec{x}_d\right)'\vec{\eta}\right\}}{1+\exp\left\{\left(\vec{\bar{z}}_d,\vec{x}_d\right)'\vec{\eta}\right\}}\right] \times \exp\left\{-\frac{1}{2}(\vec{\eta}-\vec{\mu}_0)'\vec{\Sigma}_0^{-1}(\vec{\eta}-\vec{\mu}_0)\right\}$
  - Use Metropolis-Hastings algorithm to sample
  - Independent proposal distributions
    - $\eta_j \sim \text{N}\left(\mu_j,\tau_j\right)$
    - Tune τ_j during burn-in

Software

- **psychtm** R package in *early* development
- Features
  - LDA, SLDA, SLDAX MCMC algorithms implemented in **C++**
    - Normal and dichotomous outcomes supported
  - Estimation and visualization of $\vec{\Theta}$ and $\vec{B}$
  - Model selection by WAIC (Watanabe, 2010)
- Available from Github

```
devtools::install_github("ktw5691/psychtm")
```

Simulation Study

Goal

- Compare SLDAX with two-stage approach (LDA + OLS regression)
  - SLDAX from our R package **`psychtm`**
  - LDA model from R package **`topicmodels`**
- Conditions
  - # topics K: 2 and 5
  - # documents D: 200, 800, and 1500
  - Mean # words $\bar{N}_d$: 15, 80, and 150
  - Vocabulary V: 500 and 1000

Simulation Study

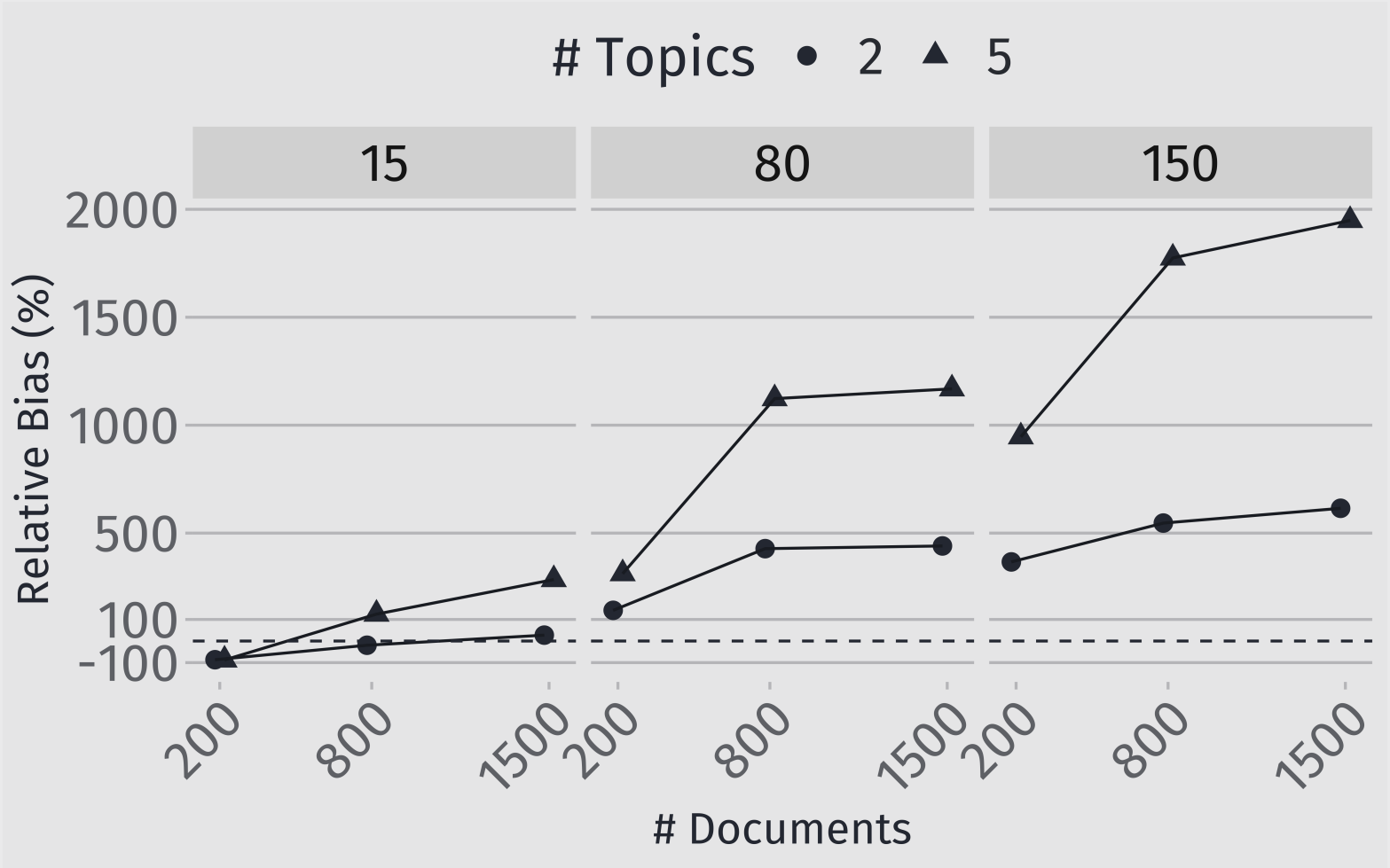
Data Generation

- SLDAX model
  - $X \sim \mathrm{N}(0, 1)$ w/ R^2 = .15
  - $Y \sim \mathrm{N}(\cdot)$
  - K topics w/ joint R^2 = .35

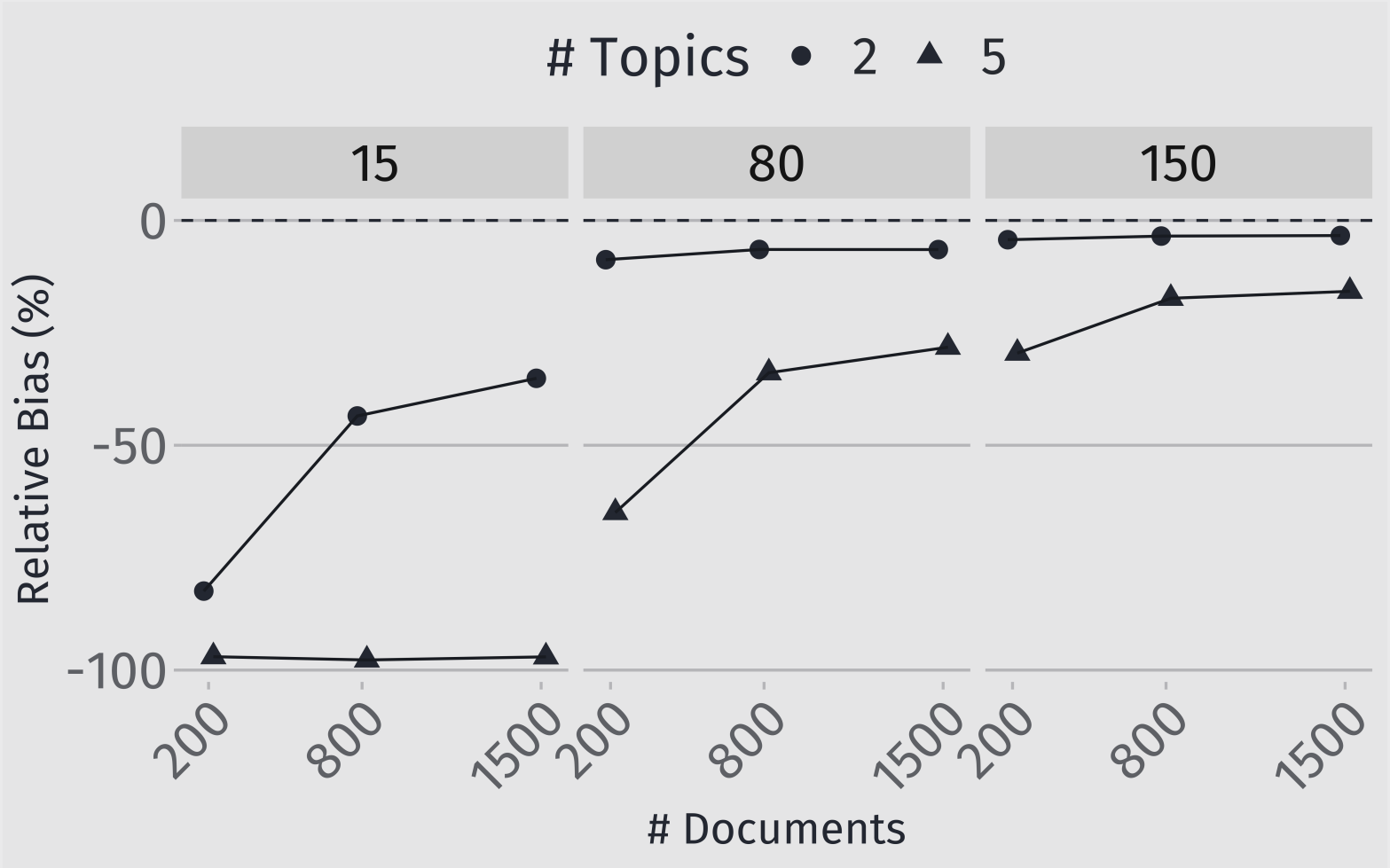
Estimation

- SLDAX with flat priors
- Two-stage
  1. LDA: estimated w/ variational EM (same hyper-parameters)
  2. OLS regression

Two-Stage Estimation Bias for $\eta_{\bar{z}}$



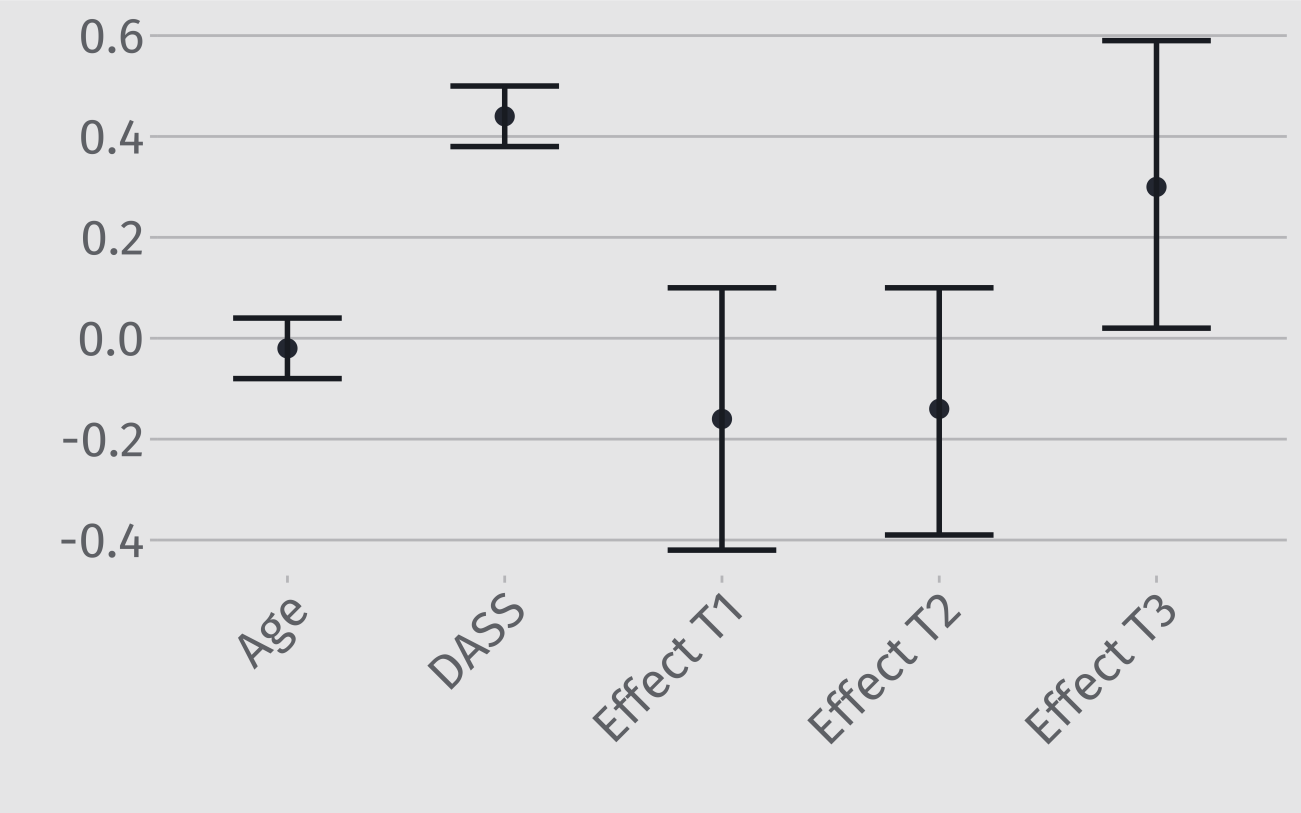
SLDAX Estimation Bias for $\eta_{\bar{z}}$



Illustrative Example

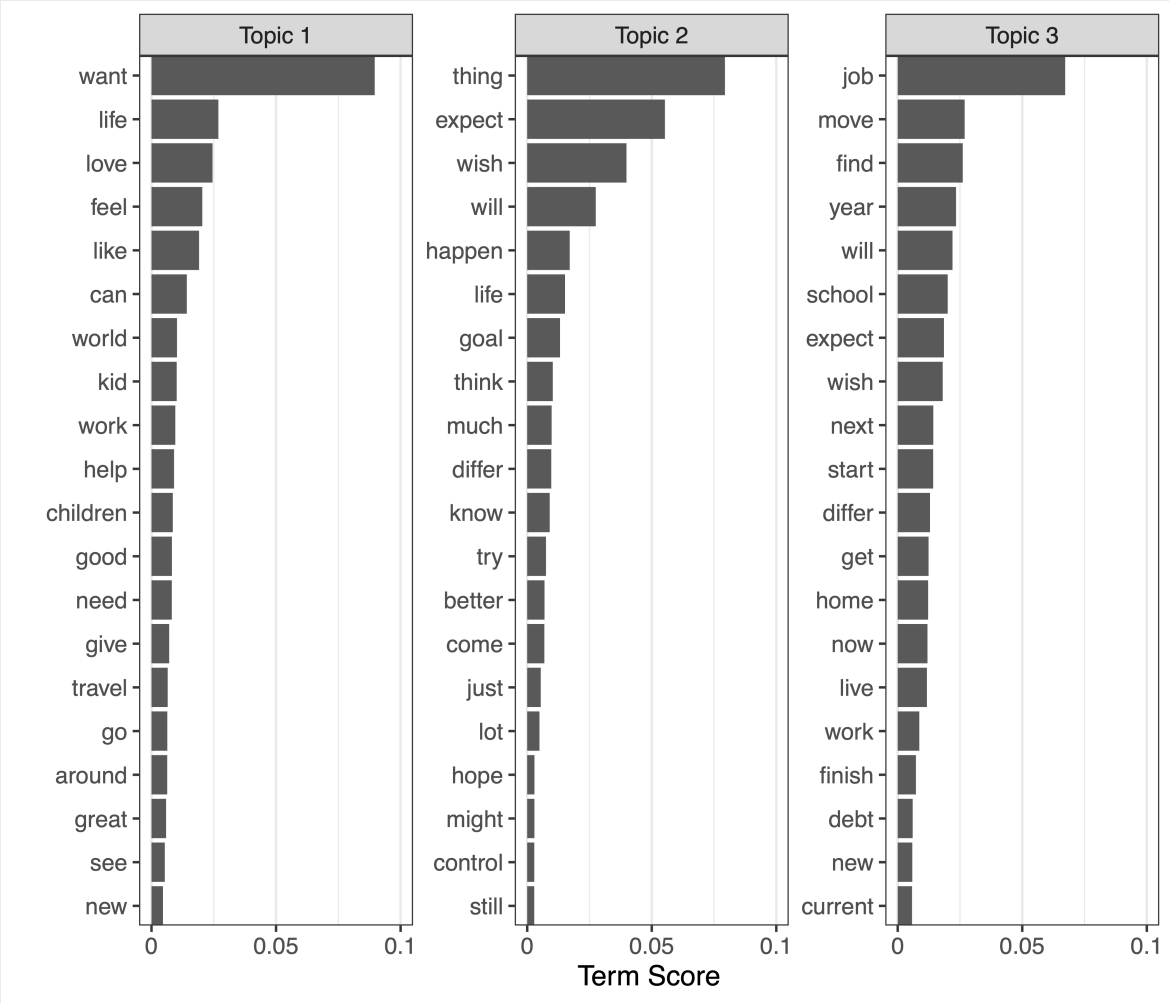
- 882 adults recruited on MTurk
- Y: Beck Hopelessness Scale (Beck et al., 1989)
- "What are your expectations for the future?"
  - *M* = 50 words, *SD* = 24, *Range* = 5 – 186
  - After stopword removal and stemming:
    - Median length was 18 words (*M* = 21, *SD* = 10, *Range* = 2 – 76)
    - Vocabulary of 3096 stems (98% of original vocabulary)
- Manifest predictors
  - Depression Anxiety Stress Scales (Lovibond et al., 1995)
  - Age (*M* = 33, *SD* = 10, *Range* = 18 – 79)

Regression Estimates



$$\text{Effect} = \hat{\eta}_k - K^{-1} \sum_{j \neq k}^{K} \hat{\eta}_j$$

Topic Estimates



Conclusions

- Hopelessness in responses associated with BHS
  - Convergent validity for topics
  - Text topics associated with BHS above and beyond DASS
- Topic effects may be attenuated based on simulation results
  - Large D, small $\bar{N}_d$
- Could predict on new data or update model using new data

Discussion

Key Findings

- We derived MCMC algorithms to estimate SLDAX models
- SLDAX models implemented in open-source **R** package
- The popular two-stage approach yields biased regression estimates
- SLDAX yields accurate estimates with shrinkage in small-data scenarios

Future Work

- SLDAX framework can be generalized
  - Integration with SEM
  - Longitudinal / EMA data
- Impact of text data quality on performance

Thanks!

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Slides:

ktylerwilcox.netlify.app/talk/2020-isdsa-sldax/

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