Getting a Step Ahead: Using the Regularized Horseshoe Prior to Regularize

Cross-Loadings in Bayesian CFA

Research Proposal

Michael Koch (6412157)

Methodology and Statistics for the Behavioral, Biomedical, and Social Sciences

Supervisor: Dr. Sara van Erp

Email: j.m.b.koch@students.uu.nl

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Confirmatory Factor Analysis (CFA) is an essential tool for modeling measurement structures. Usually, all cross-loadings, factor loadings that relate items to factors that they theoretically do not belong to, are fixed to zero to identify the model. This often leads to poor model fit, and forces researchers to free some cross-loadings again to improve fit, a practice that is flawed for a variety of reasons, among which risking capitalization on chance (Muthen & Asparouhov, 2012). As solution, Muthen and Asparouhov (2012) proposed that rather than fixing *all* cross-loadings to zero, one should should assume that *most* cross-loadings are zero. Formally, this is achieved by setting the so-called *Small Variance Normal Prior* for the cross-loadings, which is a normal distribution with mean zero and a very small variance (e.g.: $\sigma^2 = 0.01$, $\sigma^2 = 0.001$). This prior has a large peak at zero, and very thin tails (see Figure 1). Hence, it attaches large prior mass to cross-loadings of or near zero, while attaching almost no prior mass to cross-loadings further from zero. Consequently, all cross-loadings in the model are shrunken. The larger the prior's variance, the more admissive the model is in the amount of deviation from zero it allows.

An issue with Muthen and Asparouhov (2012)'s approach is that not only the cross-loadings close to zero that are considered irrelevant are shrunken to zero, as desired, but also the ones further from zero are shrunken towards zero, which introduces bias. The method thus requires a two-step approach. First, the model is estimated with shrinkage. Then the model is re-estimated, with cross-loadings that have been shrunken to zero in the previous step fixed to zero, and the remaining cross-loadings estimated without shrinkage. This process is tedious and computationally expensive. Therefore, alternative priors need to be identified that can outperform the Small Variance Normal Prior *in a single step*.

Lu, Chow, and Loken (2016) pointed out that the approach by Muthen and Asparouhov (2012) can be viewed as a form of *Regularization*, where cross-loadings that are relevant in modeling a factor structure are selected. The literature on regularization in regression (see Van Erp, Oberski, & Mulder, 2019 for an overview) can thus provide

alternative priors. The *Regularized Horseshoe Prior* (Piironen & Vehtari, 2017), appears as particularly promising. This prior still has a sharp peak at zero resulting in shrinkage to zero of small coefficients (see Figure 1). However, it has much heavier tails, resulting in practically no shrinkage of larger coefficients. This prior is thus the best of both worlds, by only shrinking irrelevant parameters to zero, within one step (Piironen & Vehtari, 2017).

While the Regularized Horseshoe Prior has been shown to perform well in the selection of relevant predictors in regression (Piironen & Vehtari, 2017; Van Erp et al., 2019), no previous research has validated its performance in selecting relevant cross-loadings in CFA. To fill this gap, the aim of this study is to compare the Regularized Horseshoe Prior to the Small Variance Normal Prior in their performance in selecting the true factor structure in CFA.

Analytic Strategy

A Monte Carlo simulation study is conducted using stan (Stan Development Team, 2021). As main outcomes, we consider the bias in the estimated cross-loadings, and the trade-off in true positives vs. false positives in correctly identifying non-zero cross-loadings as non-zero (ROC curves). Hereby, the main criterion in selecting cross-loadings as non-zero is whether their 95% HPD interval contains zero (Zhang, Pan, & Ip, 2021).

We include two factor structures, one with a single, and one with three non-zero cross-loadings. Each model consists of three factors a three items. Factors are scaled by setting their means to zero and their variances to one. The correlations between all factors is set to 0.5, and the residual variance of all items to 0.3. We vary between three sample sizes (100, 200, 300), and three magnitudes of the cross-loadings (0.1, 0.2, 0.3).

Following Muthen and Asparouhov (2012) we consider three values for the hyperparameter of the Small Variance Normal Prior ($\sigma^2 = 0.001, 0.01, 0.1$). The Regularized Horseshoe Prior has five hyperparameters, and varying all of them broadly

would lead to an unfeasible number of conditions. We will therefore conduct a pilot study on a single simulated dataset to identify combinations of hyperparameters that are worth to consider in the main study.

All models will be sampled using the No-U-Turn-Sampler (Betancourt, 2018; Homan & Gelman, 2014). We aim to identify a suitable chain length in the pilot study.

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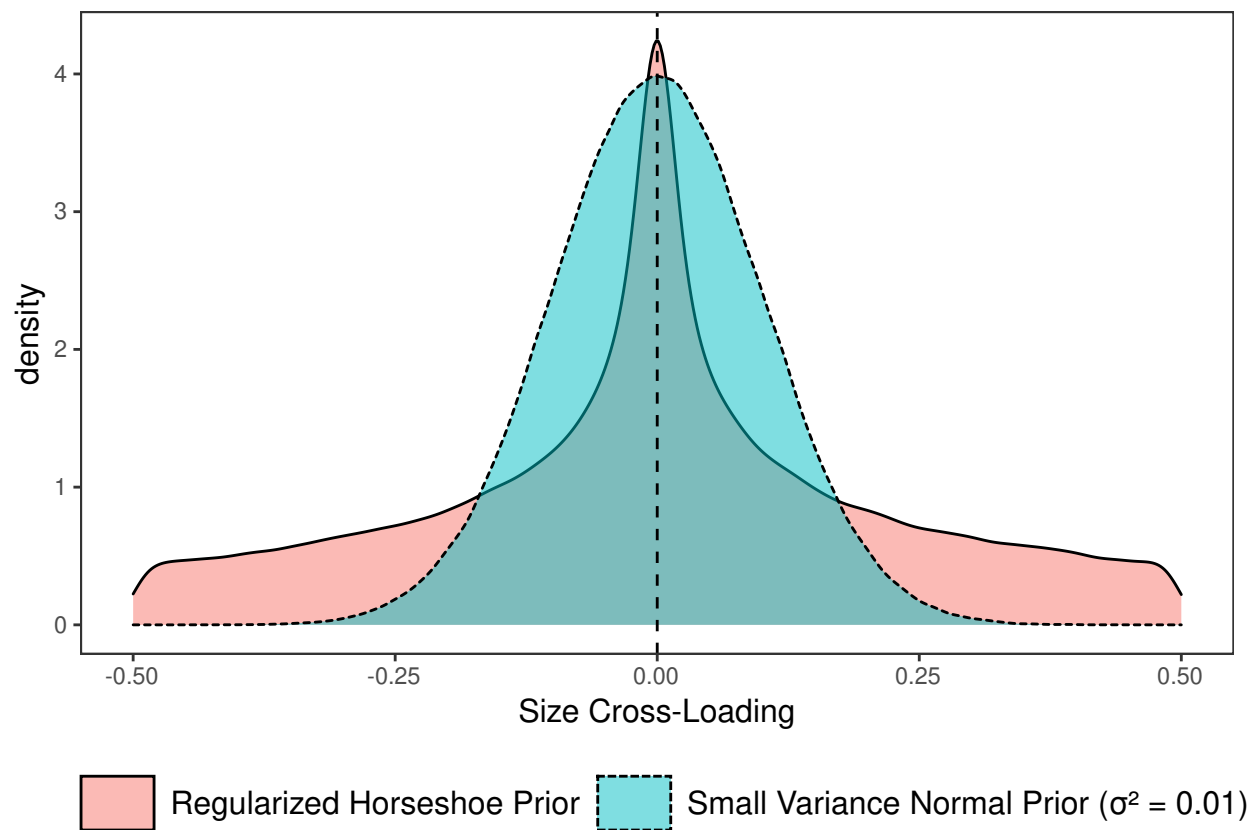
Figure 1. Density Plots of the Regularization Priors of Interest