THE ISBA BULLETIN

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The official bulletin of the International Society for Bayesian Analysis

A MESSAGE FROM THE PRESIDENT

- Sylvia Frühwirth-Schnatter -
president@bayesian.org

It is truly an honor for me to serve the Bayesian community as ISBA President for 2020. At a time when ISBA did not exist yet, at my very first Valencia Meeting in Altea in 1988, the international Bayesian community became my scientific home and many of its members became my scientific advisors, peers, and friends.

Since ISBA was founded in 1992, 25 past Presidents and hundreds of past officers and ISBA board members have shaped ISBA and created a scientific home and a network for an ever-growing community of researchers interested in and devoted to Bayesian inference. ISBA is extremely grateful to all those who contribute valuable time and effort to serve the society. I would like to start by thanking Raquel Prado for her dedicated service to our Society as 2019 ISBA President and I am looking forward to work with her as Past-President.

Special thanks to Marina Vannucci, 2019 Past-President, for her incredible devotion and outstanding work for ISBA during the past three years when ISBA had to face extraordinary challenges caused by unacceptable events at ISBA Meetings. Marina in coalition with 2017 ISBA President Kerrie Mengersen and former ISBA Executive Secretary Amy Herring reacted strongly and unanimously to these challenges by putting in place the SafeISBA Task Team which transitioned into the Professional Conduct Committee in 2019. The Code of Conduct developed the SafeISBA Task Team is a strong commitment of our Society to provide an atmosphere of personal respect, free exchange of ideas and intellectual growth at any ISBA Meeting.

Many thanks to Bobby Gramacy for his service as ISBA Treasurer during the past three years and for doing an outstanding job in keeping our finances in order. Many thanks also to the four retiring board members Natalia Bochkina, Cathrine Forbes, James Scott and Luca Tardella and to all retiring section and chapter officers.

A very warm welcome to all new members of ISBA's leadership, to Igor Prünster as President-Elect, to Marian Farah as the new ISBA Treasurer, and to the four new board members Francois Caron, Miguel de Carvalho, Nial Friel and Laura Ventura. A warm welcome also to all newly appointed section and chapter officers. We are very fortunate that Feng Liang who stepped up in 2019 as ISBA Executive Secretary will serve two more years. In 2019, a new Editorial team of ISBA was established and I would like to thank Michele Guindani as Editor-in-Chief of Bayesian Analysis, Maria DeYoreo as Editor of the ISBA Bulletin, and Daniel Williamson as ISBA Web Editor for continuing their service and for bringing in many new ideas. Michele, for instance, has initiated a Webinar series to highlight and discuss outstanding contributions to Bayesian Analysis. I very much look forward to working with all of you.

In this issue

Another very important part of ISBA's leadership is the Program Council. During the past year, Li Ma as Chair, David Rosell as Past-Chair and Athanasios Kottas as Vice-Chair worked very hard to organize and prepare the 2020 ISBA World Meeting in Kunming, China, together with the Scientific and the Local Organizing Committees. I would like to thank David Rosell for his dedicated service in the Program Council over three years and I warmly welcome Botond Szabo as the new Vice-Chair of the Program Council.

2020 started with a wonderful Bayes Comp 2020 Meeting that took place from January 7-10 in the Reitz Union at the University of Florida, Gainesville. The Scientific Committee (co-chaired by Eric Moulines and Christian Robert) and the Local Organizing Committee (chaired by Jim Hobert) did a great job in organizing a most stimulating conference that provides outstanding insights into frontier tools in Bayesian computing and their application in many disciplines. It was a great pleasure for me to meet and to exchange so many ideas with Bayesians from all over the world.

When we said our farewells in Florida, many of us were excited to meet soon at the ISBA World Meeting in Kunming, China in June 2020. Back in early January, nobody expected what was lying ahead of us. When we gradually became aware of the threat imposed by the Covid-19-virus, the leadership of ISBA had to face a very difficult decision concerning the 2020 ISBA World Meeting in Kunming. After careful evaluation of the situation, we finally decided in mid-February to postpone the World Meeting by exactly one year and to hold ISBA 2020 in Kunming from June 28-July 2, 2021. Several other ISBA co-sponsered or endorsed meetings, supposed to happen in convenient proximity to the ISBA World Meeting, were rescheduled as well. A big thank to the local organizers of ISBA 2020 for making this postponement possible. Special thanks to Li Ma for all the time and energy he invested in reaching out to the local organizers and to the organizers of the satellite meetings to make sure that ISBA2020-in-2021 will be the outstanding meeting it was supposed to be this year. Li's service to ISBA is truly outstanding.

Looking back, this sunny week in Florida in the middle of the winter feels like a dream and I still cannot grasp how the world has changed in the few weeks since this meeting due to the Covid-19 pan-epidemic. Many countries are in lockdown, borders closed, scientific meetings cancelled and researchers no longer free to travel or even meet in person. Some countries like Italy are facing the biggest challenge since World War II. My heart and thoughts go out to everyone effected by the crisis. In a situation like this, we also need to look forward. The drastic measures governments have taken in the past weeks impose constraints and limitations on many of us. However, as we can observe in China, social distancing is an effective strategy to defeat the virus. The pan epidemic will be over sooner or later and our lives will return to normal. We will be free again to meet and interact in person and to travel as we used to do. For this not too far future, Igor and I envision a meeting in particular for the younger Bayesians among you and we are confident that this vision will come true. Meanwhile, stay safe and healthy.

– Sylvia Frühwirth-Schnatter

FROM THE EDITOR

- Maria DeYoreo -
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Welcome to the March 2020 issue of the *ISBA Bulletin*. This is the first bulletin that features columns from our new President, Sylvia Frühwirth-Schnatter, and our new Program Council chair, Athanasios Kottas. Welcome Sylvia and Athanasios, and thank you for your service to ISBA!

Unfortunately we have entered into a time of great uncertainty across the world with regards to the recent coronavirus pandemic. This is causing disruptions to everyday life, and stress and uncertainty as we all wonder about what the future holds. Many in our Bayesian community have undoubtedly been affected in some way by this virus, and many more will be, and we are wishing all in the Bayesian

community health and safety in this difficult time.

You will note that a number of conferences have been postponed or cancelled, notably the ISBA World Meetings, which will now take place 1 year later than planned. ISBA 2021 will be held at the same location in Kunming, China, during the week of June 28-July 2, 2021. We look forward to coming together in China in 2021 with this epidemic behind us.

FROM THE PROGRAM COUNCIL

- Athanasios Kottas -
program-council@bayesian.org

Welcome New Member. Botond Szabo has joined the Program Council as the new Vice Chair. Welcome Botond! We are grateful to David Rossell for his outstanding service in the past three years. Many thanks David!

ISBA 2021 World Meeting. After careful evaluation of the ongoing COVID-19 outbreak in China and around the world, and in consultation with the local organizers of the 2020 World Meeting, the leadership of ISBA decided to postpone the World Meeting by one year. ISBA 2021 will be held at the same location in Kunming, China, during the week of June 28-July 2, 2021, with short courses on June 27, 2021.

One of the satellite meetings of the ISBA 2021 World Meeting has been rescheduled. The "5th EAC-ISBA Conference: A Satellite Meeting of the 2021 ISBA World Meeting in Celebrating James O Berger's 70th Birthday' will be held at the same location (Dali, Yunnan, China) June 25-26, 2021. The organizers of BAYSM 2020 are working on rescheduling that meeting as well.

The program structure and the session schedule for the World Meeting will remain the same. The invited sessions and plenary talks have been determined and will not be affected. There will be a new call for Contributed Talks/Posters and Junior Researcher Travel Award applications with submissions to open on October 1, 2020 and a deadline of November 30, 2020. Please note that only submissions received during that time period will be considered. The submission forms will become available on the World Meeting website at https://bayesian.org/isba2020-home/. You can also find the latest updates on the website.

The Savage Award session (originally scheduled as part of ISBA 2020) will take place as an invited session of JSM 2020, to be held in Philadelphia, Pennsylvania, August 1-6, 2020. We are grateful to the JSM 2020 Program Committee for offering us an invited session slot. If you will be at JSM 2020, please plan to attend the Savage Award session!

Finally, please note that the changes involving the ISBA 2021 World Meeting do not affect the plans for the ISBA 2022 World Meeting, which will be held according to schedule in Montreal.

(Co-)Sponsorship/Endorsement Requests. If you are planning a meeting and would like to request financial sponsorship (or co-sponsorship) or non-financial endorsement from ISBA, please submit your request to the program council at program-council@bayesian.org. Detailed information on how to submit a request for either sponsorship or endorsement can be found at https://bayesian.org/events/request-sponsorshipendorsement/.

Upcoming ISBA-sponsored/endorsed events:

1. NSF-CBMS Conference on "Bayesian Forecasting and Dynamic Models", August 10-14, 2020, University of California, Santa Cruz, CA, USA.
2. European Seminar on Bayesian Econometrics (ESOBE) 2020, September 3-4, 2020, Madrid, Spain.
3. 11th BAYES-PHARMA Applied Bayesian Biostatistics Workshop (BAYES2020), September 20-22, 2020, Rockville, MD, USA.
4. ABC in Svalbard, April 12-13, 2021, Svalbard, Norway.

5. The 5th EAC-ISBA Conference: A Satellite Meeting of the 2021 ISBA World Meeting in Celebrating James O Berger's 70th Birthday, June 25-26 2021, Dali, Yunnan, China.
6. BAYSM 2020, Kunming, China. (To be rescheduled)

UPDATES FROM BA

From the BA Editor

- Michele Guindani-
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The March 2020 issue of Bayesian Analysis is now available online. The issue features ten articles and one Discussion paper, *"A Novel Algorithmic Approach to Bayesian Logic Regression"* by Aliaksandr Hubin, Geir Storvik, and Florian Frommlet. The manuscript is complemented by three detailed and stimulating invited discussions papers, by 1) Ingo Ruczinski, Charles Kooperberg, and Michael LeBlanc; 2)Malgorzata Bogdan , Blazej Miasojedow , and Jonas Wallin, and 3) Holger Schwender and Katja Ickstadt. In addition, Gregoire Clarté and Christian P. Robert discuss the prior modeling and the algorithmic aspects of the paper in a contributed discussion. The authors provide their perspective in an extensive rejoinder, where they address the points raised by the discussants, and further provide several extensions of the original model. Finally, they give a brief tutorial on their R-package EMJMCMC dealing with Bayesian logic regression.

We welcome public contributions to the Discussion of the manuscript: *"A Unified Framework for De-Duplication and Population Size Estimation"* by Andrea Tancredi, Rebecca Steorts, and Brunero Liseo, which will be featured as a **Discussion Paper in the June 2020 issue** of the journal. You can find the manuscript in the Advance publication section of the journal website. The contributions should be no more than two pages in length, using the BA latex style. The contributions should be submitted to the journal using the Electronic Journal Management System (EJMS) submission page, before **April 24th, 2020**.

j-ISBA

- Brenda Betancourt -

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The beginning of the year brought a significant portion of our Bayesian community to Gainesville, Florida for a very successful 2020 BayesComp conference! As it is tradition, the junior researchers had a strong presence with oral and poster presentations including a j-ISBA contributed session that highlighted recent work on Monte Carlo methodology in complex Bayesian settings. The session included talks on inference with finite-dimensional discrete random structures (Tommaso Rigon, Bocconi University), MCMC simulation from distributions on the set of orthogonal matrices (Michael Jauch, Duke University) and a novel sampling scheme for multimodal distributions called the annealed lead point sampler (ALPS – Nicholas Tawn, University of Warwick). We also held an informal j-ISBA mixer that allowed us to interact in a more relaxed environment after an exciting day of talks!

Unfortunately, for safety reasons associated with coronavirus, the upcoming summer conferences have been cancelled including the official j-ISBA meeting (BAYSM 2020). Stay tuned for updates on rescheduling plans for this conference. We encourage everyone to join our Section (only $5 with your ISBA subscription), and keep in touch with us and the community through our Facebook group, Twitter account or blog (https://jisbablog.wordpress.com/)!

NEWS FROM THE WORLD

-Francesco Denti-
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Conference Report

The **2020 BayesComp** conference held at the University of Florida was a great success with a diverse group of our Bayesian community in attendance. The conference brought 208 attendees to Gainesville which included around 80 speakers for 25 invited sessions and three plenary talks. With 150 faculty registrations and 58 students the conference had a good mix of researchers at different career stages. We also had 55 poster presentations from students and junior researchers, as well as 104 attendees to our social dinner! We would like to thank Jim Hobert and Christian Robert for leading the organization of such an engaging conference. Special thanks to the local administrative UF team, lead by Alethea Geiger, for handling all the logistics and making the event run smoothly. We would also like to thank the wonderful group of volunteers who were key in pulling this conference together: Bryant Davis, Zhumengmeng Jin, Michael Kim, Eleni Dilma and Grant Buckland. We hope everyone had a great experience during the conference and in Gainesville!

Brenda Betancourt

Meetings and conferences

ISBA World Meeting - Important Updates
https://bayesian.org/isba2020-home/

After careful evaluation of the ongoing Coronavirus situation in China and around the world, the leadership of ISBA has determined that it will be challenging to hold the 2020 World Meeting in Kunming, China this June. After a consultation with the local organizer, the board has decided to **postpone the World Meeting by one year**, to the week of June 28-July 2, 2021 with short courses on June 27, 2021.
ISBA 2021 will be held at the same location in Kunming, China. The program structure and the session schedule for the World Meeting will remain the same. The organizers for two satellite meetings – **5th EAC-ISBA meeting** and **BAYSM2020** – are working on plans for moving those meetings accordingly.

On behalf of the **EnviBayes** board, we are excited for several upcoming events for EnviBayes members in 2020.

- EnviBayes JSM. We are planning an informal social event for EnviBayes members who will be attending JSM in Philadelphia. Stay tuned for more information as plans are made.
- ENVR/EnviBayes Workshop. We invite all EnviBayes members to attend the ENVR 2020 workshop in Provo, Utah USA on October 8-10, 2020. Organizers have already put together a great collection of short courses and invited sessions. More information can be found at https://community.amstat.org/envr/events/envr2020workshop.

Two **JASP summer workshops** have been announced: they will be take place in Amsterdam next August. There will be one workshop focused on Bayesian cognitive modeling and one dedicated to Bayesian hypothesis testing in JASP. The Bayesian cognitive modeling course will also feature Stan.

For both the workshops, a call for posters is open.
https://jasp-stats.org/2019/12/23/two-workshops-on-bayesian-statistics/

- **Tenth Annual JAGS and Stan Workshop: Bayesian Modeling for Cognitive Science** - August 17 – 21, 2020, in Room A 2.11, Roeterseilandcampus, Amsterdam (NL).
  In this workshop, plenary lectures provide the theoretical background of Bayesian inference, and practical computer exercises teach you how to apply the popular JAGS and Stan software to a wide range of different statistical models.
- **Theory and Practice of Bayesian Hypothesis Testing: A JASP Workshop** - August 24 – 25, 2020, Room JK B.11, Roeterseilandcampus, Amsterdam (NL).
  The main purpose of this workshop is to familiarize participants with key Bayesian concepts in hypothesis testing. Concrete examples illustrate how to compute, report, and interpret Bayesian hypothesis tests for popular statistical models such as correlation, regression, t-test, ANOVA, and contingency tables.

NIMBLE short course, June 3-4, 2020 at UC Berkeley A two-day training workshop on NIMBLE will be held on June 3-4, 2020 in Berkeley, California. NIMBLE is a system for building and sharing analysis methods for statistical models, especially for hierarchical models and computationally-intensive methods.
https://r-nimble.org/nimble-short-course-june-3-4-2020-at-uc-berkeley

The workshop will assume attendees have a basic understanding of hierarchical/Bayesian models and MCMC, the BUGS (or JAGS) model language, and some familiarity with R. The workshop will cover the basic concepts and workflows for using NIMBLE and converting BUGS or JAGS models to work in NIMBLE, provide an overview of different MCMC sampling strategies and how to use them in NIMBLE, and much more. To register, please go here: https://na.eventscloud.com/528790. The organizers have also reserved a block of rooms on campus. To reserve a room, go here: https://na.eventscloud.com/528792.

And don't forget:

The **Applied Bayesian Statistics School in Bayesian Causal Inference** will be held at the Florence Center for Data Science, University of Florence, Italy, on 8-12 June 2020. The Lecturer is Professor Fan Li (Duke University).
http://www.mi.imati.cnr.it/conferences/abs20/index.html

Joint Statistical Meetings will take place next August, in Philadelphia, U.S.A. Between January 22 - April 2, 2020 you can make and online submission of JSM Meeting & Event Requests.
https://ww2.amstat.org/meetings/jsm/2020/conferenceinfo.cfm

The **Bayes-pharma - Applied Bayesian Biostatistics Workshop** will be held in the United States. This new edition will be held on September 20-22 in Rockville, MD, USA. Call for abstracts is now open.

Send your abstract (Title + Authors + Max 300 words) at info@bayes-pharma.org before May 1, 2020. You will be notified of the acceptance of your abstract around the beginning of June. Priority will be given to practical case studies showing implementation from the objective to the programming to the communication to scientists and authorities.
https://www.bayes-pharma.org/

The **European Seminar on Bayesian Econometrics (ESOBE)** will take place next year, September 3-4, 2020 in Madrid, Spain.
https://esobe.org/

SOFTWARE HIGHLIGHT

SHRINKTVP – TIME-VARYING PARAMETER MODELS WITH SHRINKAGE IN R

Peter Knaus, Angela Bitto-Nemling, Annalisa Cadonna and Sylvia Frühwirth-Schnatter
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1 Introduction

Time-varying parameter (TVP) models are widely used in time series analysis, because of their flexibility and ability to capture gradual changes in the model parameters over time. The popularity of TVP models in macroeconomics and finance is based on the fact that, in most applications, the influence of certain predictors on the outcome variables varies over time [see, for example, Primiceri, 2005, Dangl and Halling, 2012, Belmonte et al., 2014]. The TVP model in state space form can be formulated as follows

$$\begin{aligned} y_t &= x_t\beta_t + \epsilon_t, \qquad \epsilon_t \sim \mathcal{N}(0, \sigma_t^2), \\ \beta_t &= \beta_{t-1} + w_t, \qquad w_t \sim \mathcal{N}_d(0, Q), \end{aligned} \tag{1}$$

for $t = 1, \ldots, T$, where y_t is a univariate response variable and $x_t = (x_{t1}, \ldots, x_{td})$ is a d-dimensional row vector containing the regressors at time t, with x_{t1} corresponding to the intercept. For simplicity, we assume that $Q = \text{Diag}(\theta_1, \ldots, \theta_d)$ is a diagonal matrix, implying that the state innovations are conditionally independent. Moreover, we assume the initial value follows a normal distribution, i.e., $\beta_0 \sim \mathcal{N}_d(\beta, Q)$, with initial mean $\beta = (\beta_1, \ldots, \beta_d)$.

While flexible, the forecasting performance of such models is often poor, as the large number of parameters leads to overfitting if not properly regularized. A key contribution in overcoming this issue was made by Frühwirth-Schnatter and Wagner [2010], who recast (1) into the *non-centered parameterization*, which looks as follows

$$\begin{aligned} y_t &= x_t\beta + x_t\text{Diag}(\sqrt{\theta}_1, \ldots, \sqrt{\theta}_d)\tilde{\beta}_t + \epsilon_t, \quad \epsilon_t \sim \mathcal{N}(0, \sigma_t^2), \\ \tilde{\beta}_t &= \tilde{\beta}_{t-1} + \tilde{u}_t, \qquad \tilde{u}_t \sim \mathcal{N}_d(0, I_d), \end{aligned} \tag{2}$$

with $\tilde{\beta}_0 \sim \mathcal{N}(0, I_d)$, where I_d is the d-dimensional identity matrix. In this parameterization, three interesting special cases become more apparent. If both $\beta_j \neq 0$ and $\sqrt{\theta}_j \neq 0$ for a covariate, the respective state is left to move according to a random walk. If $\beta_j \neq 0$ and $\sqrt{\theta}_j = 0$, the state is pulled towards a constant, i.e. a parameter that does not change over time. Finally, if both $\beta_j = 0$ and $\sqrt{\theta}_j = 0$, then the state is pulled towards a constant at zero, effectively excluded from the model. These three cases are visualized in Figure 1.

2 Prior distributions

Conditional on the non-centered states $\tilde{\beta}_t$, the representation of the model in (2) is akin to a regular linear regression problem. This enables the use of well established shrinkage priors designed for variable selection to be used for variance selection, as they can now easily be placed on $\sqrt{\theta}_j$. `shrinkTVP`

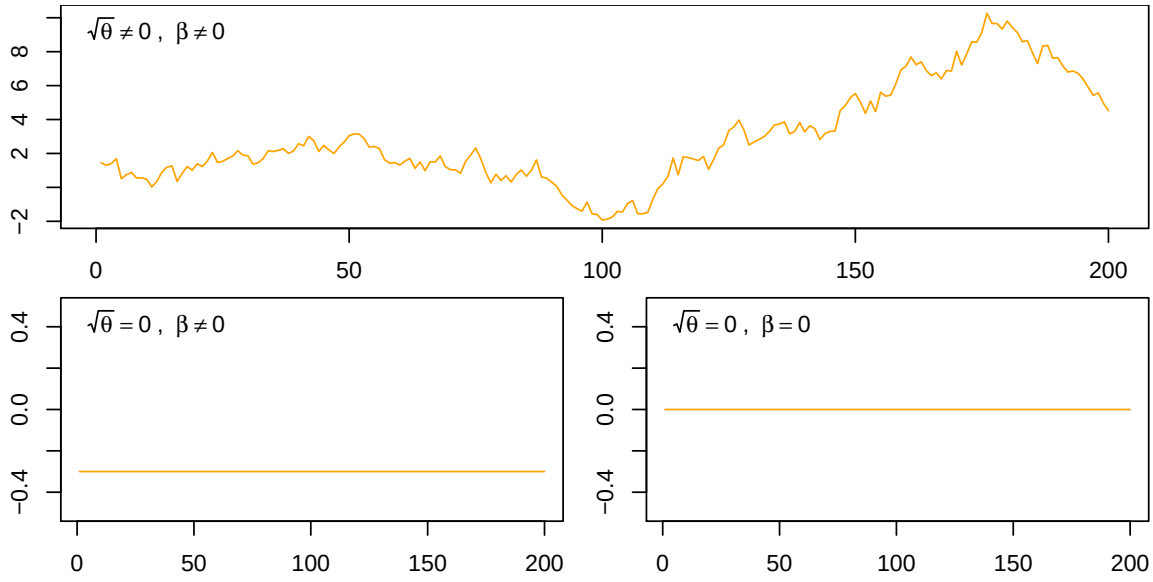

Figure 1: Sample evolution of states for different values of $\sqrt{\theta}_j$ and β_j.

follows the work done by Bitto and Frühwirth-Schnatter [2019] and places conditionally independent normal-gamma priors [Griffin and Brown, 2010] on the square root of the variances of the states, i.e. $\sqrt{\theta}_j$, and on the means of the initial value, i.e. β_j, which looks as follows:

$$\sqrt{\theta}_j|\xi_j^2 \sim \mathcal{N}\left(0, \xi_j^2\right), \qquad \xi_j^2|a^\xi, \kappa^2 \sim \mathcal{G}\left(a^\xi, \frac{a^\xi \kappa^2}{2}\right), \tag{3}$$

$$\beta_j|\tau_j^2 \sim \mathcal{N}\left(0, \tau_j^2\right), \qquad \tau_j^2|a^\tau, \lambda^2 \sim \mathcal{G}\left(a^\tau, \frac{a^\tau \lambda^2}{2}\right). \tag{4}$$

The parameters κ^2, λ^2, a^ξ, a^τ can be learned from the data through appropriate prior distributions. As priors for these so-called global shrinkage parameters, we use

$$\kappa^2 \sim \mathcal{G}\left(d_1, d_2\right), \qquad \lambda^2 \sim \mathcal{G}\left(e_1, e_2\right). \tag{5}$$

Moreover, in order to learn a^ξ and a^τ, we generalize the approach taken in Bitto and Frühwirth-Schnatter [2019] and use the following gamma distributions as priors:

$$a^\xi \sim \mathcal{G}\left(\nu^\xi, \nu^\xi b^\xi\right), \qquad a^\tau \sim \mathcal{G}\left(\nu^\tau, \nu^\tau b^\tau\right). \tag{6}$$

Finally, the variance of the observation equation σ_t^2 can either be modeled homoscedastically or via a stochastic volatility process [Taylor, 1982]. In the case of homoscedasticity, a hierarchical prior is employed, where the scale of an inverse gamma prior for σ^2 follows a gamma distribution, that is,

$$\sigma^2|C_0 \sim \mathcal{G}^{-1}\left(c_0, C_0\right), \qquad C_0 \sim \mathcal{G}\left(g_0, G_0\right), \tag{7}$$

with hyperparameters c_0, g_0, and G_0.

In the case that the variance is modeled via stochastic volatility, the algorithm and priors from Kastner and Frühwirth-Schnatter [2014] are used, accessed through the package `stochvol` [Kastner, 2016].

3 Algorithm

From a high level perspective, `shrinkTVP` implements a Metropolis-Hastings within Gibbs algorithm, with the sampling for a^ξ and a^τ done via Metropolis-Hastings. As mixing for such models can often be

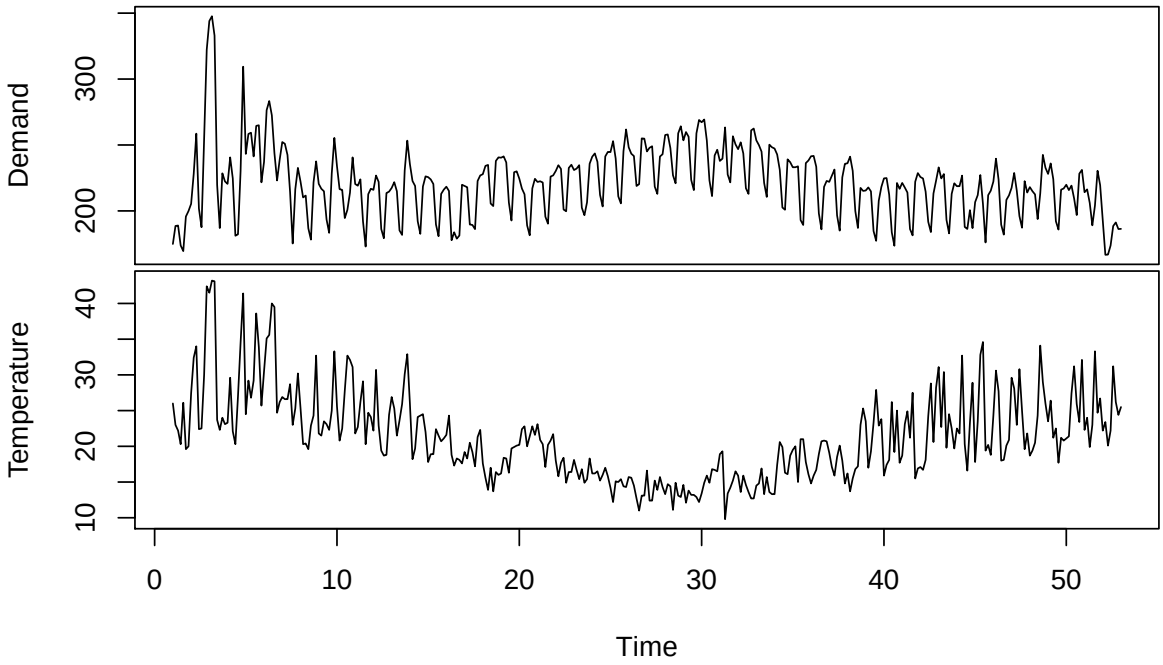

Figure 2: Top: Daily electricity demand in Gigawatts for Victoria, Australia, in 2014. Bottom: Maximum daily temperatures for Melbourne.

poor, `shrinkTVP` makes use of the ancillarity-sufficiency interweaving strategy (ASIS) introduced by Yu and Meng [2011] and collapses some of the steps within the algorithm to boost its performance. The heavy lifting is done in C++ and interfaced to R through the `Rcpp` package [Eddelbuettel and François, 2011], which significantly speeds up computation vis-à-vis pure R code, making the use of `shrinkTVP` feasible for larger datasets as well. For more insight into the mathematical details of the sampler, the reader is referred to Bitto and Frühwirth-Schnatter [2019].

4 A case study on energy consumption in Australia

To demonstrate some of the core functionality of `shrinkTVP`, we will examine a dataset from the `fpp2` package [Hyndman, 2018]. It contains data on daily energy demand in gigawatt in Victoria, Australia. The two explanatory variables are a dummy variable which takes value 1 on work days, and 0 otherwise and the maximum daily temperature. A visualization of the data (sans the dummy variable) can be found in Figure 2.

```
library("shrinkTVP")
energ <- fpp2::elecdaily
plot(energ[,c("Demand", "Temperature")], main = "",
     oma.multi = c(4,0,0,0) + 0.1, mar.multi = c(0,4,0,0) + 0.1)
```

The core sampling function of `shrinkTVP` is the function `shrinkTVP`, which is designed to offer a low barrier to entry to users, while also giving more advanced options to experienced users. The only mandatory argument is an object of class `formula`, which is used to specify the response and the independent variables in the model. In the example below, a model for the energy demand is specified, using the `WorkDay` dummy and the daily `Temperature` as explanatory variables and stochastic volatility for the error term. Note that, like `lm`, `shrinkTVP` automatically adds an intercept, unless otherwise requested.

```
train <- as.data.frame(energ[1:(nrow(energ) - 1),])
test <- as.data.frame(t(energ[nrow(energ),]))
model <- shrinkTVP(Demand ~ WorkDay + Temperature, train,
                   sv = TRUE, niter = 30000)
```

A slew of further options exist. As previously mentioned, levels of the hierarchy can be turned off entirely, and all hyperparameters can be modified. A sample piece of code demonstrating a few of these options can be found below. For more information on, please consult the `shrinkTVP` manual.

```
adv_model <- shrinkTVP(Demand ~ WorkDay + Temperature, train,
                       sv = TRUE, niter = 30000, nthin = 10,
                       learn_a_tau = FALSE, a_tau = 1,
                       hyperprior_param = list(nu_xi = 2),
                       sv_param = list(Bsigma_sv = 10))
```

The object output by `shrinkTVP` contains posterior draws as `coda` [Plummer et al., 2006] objects, hyperparameter values, data and some summary statistics, among other things. Methods for investigating parameter estimates, as well as evaluating model convergence, are also imlpemented. The `plot` method defaults to displaying the evolution of the time-varying parameters $\beta_j = (\beta_{j0}, \ldots, \beta_{jT})$, for $j = 1, \ldots, d$ over time $t = 0, \ldots, T$, as demonstrated below and visualized in Figure 3.

```
plot(model)
```

To look at other parameters and judge their convergence, the user can specify which parameters are to be plotted via the `pars` argument. If the parameter specified is non time-varying, `shrinkTVP` calls on `coda`'s plotting facilities and provides trace plots to assess convergence of the MCMC chain, as well as kernel density estimates of the posterior samples. Below, `plot` is called on the model to investigate the parameters $\sqrt{\theta}_1, \sqrt{\theta}_2, \sqrt{\theta}_3$. The output is visualized in Figure 4.

```
plot(model, pars = "theta_sr")
```

Finally, `shrinkTVP` can also evaluate the one-step ahead predictive density via `eval_pred_dens`. It is vectorized over the input vector `x`, allowing it to be passed directly to functions such as `integrate` or `curve`, as done below. This allows users to create plots of the one-step ahead predictive density, such as in Figure 5, or compute probabilities for intervals.

```
curve(eval_pred_dens(x, model, test), from = 120, to = 260,
      ylab = bquote("p(" * y[t[0]+1] * "\uff5c" * y[1] * ","
                    * ldots * "," ~ y[t[0]] * "," ~ x[t[0]+1]
                    * ")"),
      xlab = expression(y[t[0]+1]),
      lwd = 2.5, col = "skyblue", axes = FALSE)
abline(v = test$Demand)
axis(1)
axis(2)
```

More information

The `shrinkTVP` package is available on the Comprehensive R Archive Network (CRAN) under https://CRAN.R-project.org/package=shrinkTVP.

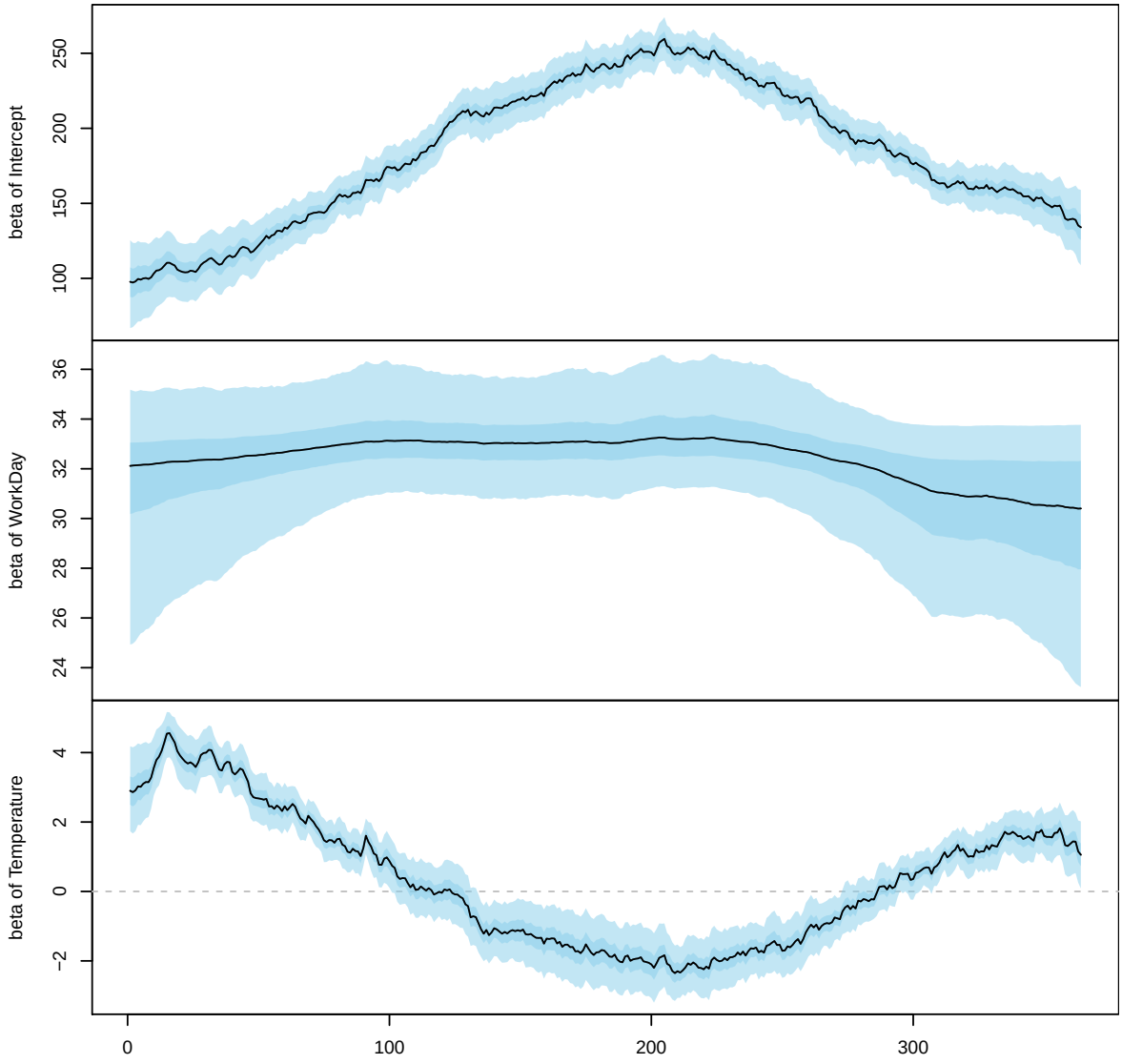

Figure 3: The evolution of the time-varying parameters $\beta_j = (\beta_{j0}, \ldots, \beta_{jT})$, for $j = 1, 2, 3$ over time $t = 0, \ldots, T$ for the energy consumption data set. The median is displayed as a black line, and the shaded areas indicate the pointwise 95% and 50% posterior credible intervals.

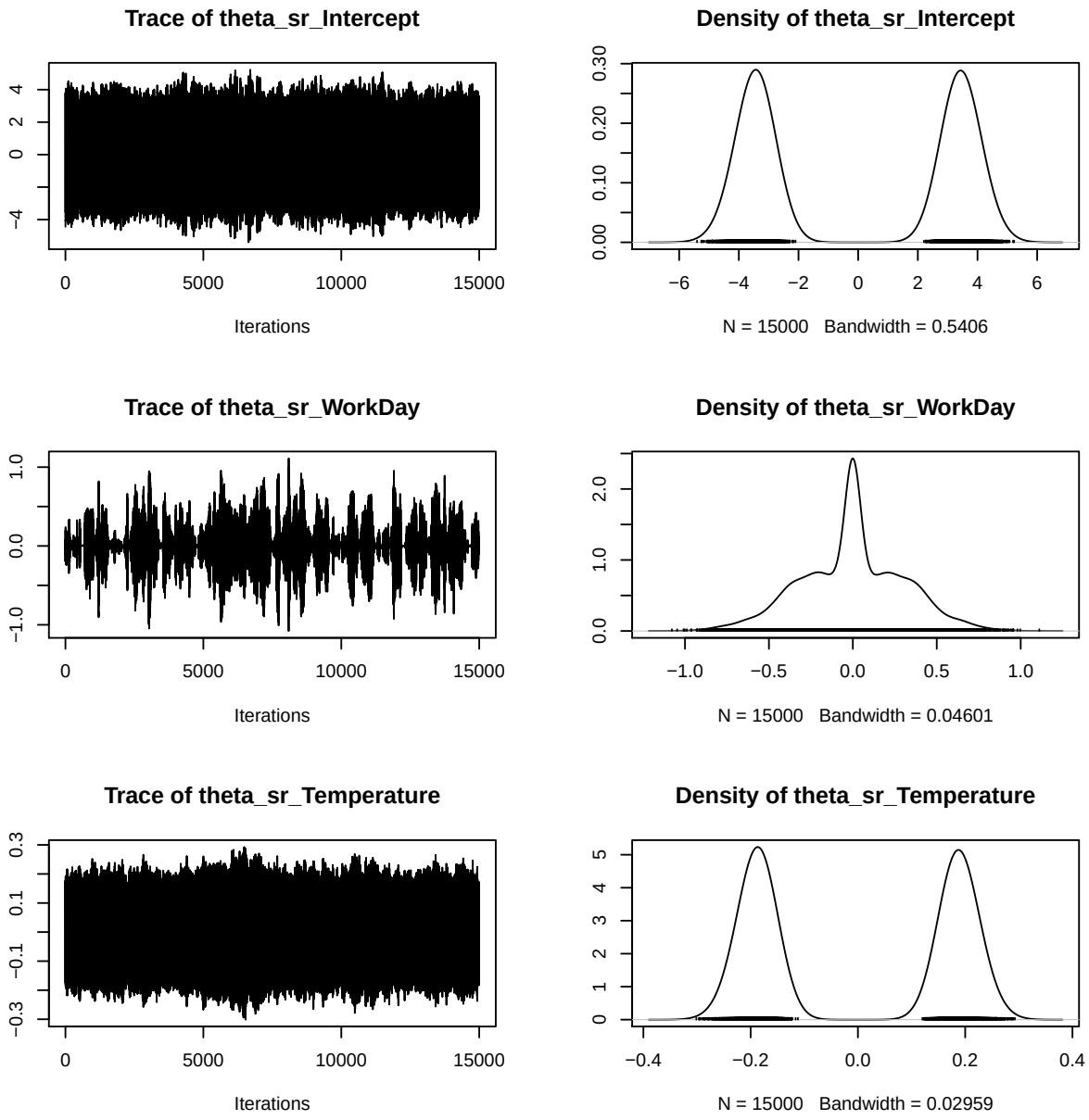

Figure 4: Trace plots (left column) and kernel density estimates of the posterior density (right column) for the parameters $\sqrt{\theta}_1, \sqrt{\theta}_3, \sqrt{\theta}_3$, for the energy consumption dataset.

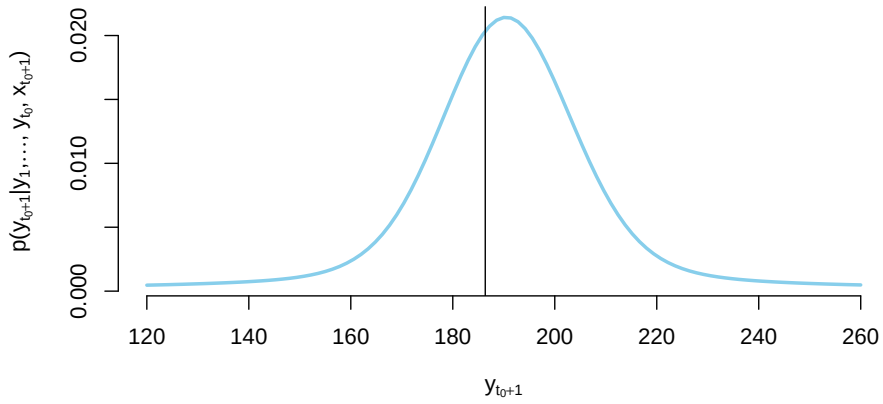

Figure 5: One-step ahead predictive density $p(y_{t_0+1}|y_1, ..., y_{t_0}, x_{t_0+1})$ for the energy consumption dataset. The black vertical line represents the true realisation of y_{t_0+1}.

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