hurricane_posterior

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Model

$$Y_i(t+6) = \beta_{0,i} + \beta_{1,i}Y_i(t) + \beta_{2,i}\Delta_{i,1}(t) + \beta_{3,i}\Delta_{i,2}(t) + \beta_{4,i}\Delta_{i,3}(t) + \mathbf{X}_i\gamma + \epsilon_i(t)$$

$$\begin{bmatrix}\beta_{0,i}\\ \beta_{1,i}\\ \beta_{2,i}\\ \beta_{3,i}\\ \beta_{4,i}\end{bmatrix} \sim MVN(\begin{bmatrix}\mu_{0,i}\\ \mu_{1,i}\\ \mu_{2,i}\\ \mu_{3,i}\\ \mu_{4,i}\end{bmatrix}, \Sigma)$$

$$\epsilon_i \sim N(0, \sigma^2)$$

Priors

1. $$\begin{bmatrix}\mu_{0,i}\\ \mu_{1,i}\\ \mu_{2,i}\\ \mu_{3,i}\\ \mu_{4,i}\end{bmatrix} \sim MVN(\begin{bmatrix}0\\ 0\\ 0\\ 0\\ 0\end{bmatrix}, V)$$

$$f_{\mu_i}(\mu_i) \propto det(V)^{\frac{-1}{2}} e^{\frac{-1}{2}\mu_i^\intercal V^{-1}\mu_i} \propto e^{\frac{-1}{2}\mu_i^\intercal V^{-1}\mu_i}$$

2. $$\Sigma \sim W^{-1}(S, \nu = 5)$$

$$f_{\Sigma^{-1}}(\Sigma) \propto |\Sigma^{-1}|^{n+1} e^{\frac{-1}{2}tr(\Sigma^{-1})}$$

where n is the dimension of dataset… this formula might be wrong meh

determinant n dim of of sigma

Wishart

Due to property of Wishart distribution,

$$\Sigma^{-1} \sim W(S^{-1}, \nu = 5)$$

$$f_{\Sigma^{-1}}(\Sigma^{-1}) = |\Sigma^{-1}|^{\frac{\nu-d-1}{2}} exp(-\frac{tr(S\Sigma^{-1})}{2}) \propto |\Sigma^{-1}|^{\frac{\nu-5-1}{2}} exp(-\frac{tr(S\Sigma^{-1})}{2})$$

3.

$$\gamma \sim MVN(\begin{bmatrix}0\\0\\0\end{bmatrix}, 0.005^2 I_3)$$

$$f_\gamma(\gamma) = (3 * 0.005^2)^{-1/2} exp(-\frac{\gamma^\intercal 0.005^2 I_3 \gamma}{2}) \propto exp(-\frac{400\gamma^\intercal\gamma}{2})$$

4.

$$\sigma \sim Half - Cauchy(0, 10)$$

$$f_\sigma(\sigma) = \frac{2 * 10}{\pi(\sigma^2 + 10^2)}$$

By transformation theorem

$$f_{\sigma^2}(\sigma^2) = \frac{2 * 10}{\pi(\sigma^2 + 10^2)}|\frac{\sigma}{2}|$$

Likelihood

Because random effects coefficients β_i is normal, $Y_i|\beta_i$ also follows a normal distribution by property of normal distribution.

For each hurricane Y_i

$$\begin{aligned} Y_i|\beta_i, \mu_i, \sigma^2, \Sigma, \gamma \sim & MVN(\beta_{0,i} + \beta_{1,i}Y_i(t) + \beta_{2,i}\Delta_{i,1}(t) + \beta_{3,i}\Delta_{i,2}(t) + \beta_{4,i}\Delta_{i,3}(t) + \mathbf{X}_i\gamma, \sigma^2 I_i) \\ = & MVN(D_i\beta_i + X_i\gamma, \sigma^2 I_{n_i}) \end{aligned}$$

where

$$Y_i = \begin{bmatrix} Y_i(t=6) \\ Y_i(t=7) \\ \vdots \\ Y_i(t=t_j+6) \\ \vdots \\ Y_i(t=n_i+5) \end{bmatrix}_{n_i \times 1}$$

$$\begin{aligned} D_i(t) = & \begin{bmatrix} 1 & Y_i(t) & \Delta_{i,1}(t) & \Delta_{i,2}(t) & \Delta_{i,3}(t) \end{bmatrix} \\ = & \begin{bmatrix} 1 & Y_i(t=0) & \Delta_{i,1}(t=0) & \Delta_{i,2}(t=0) & \Delta_{i,3}(t=0) \\ 1 & Y_i(t=1) & \Delta_{i,1}(t=1) & \Delta_{i,2}(t=1) & \Delta_{i,3}(t=1) \\ \cdots \\ 1 & Y_i(t=t_j) & \Delta_{i,1}(t=t_j) & \Delta_{i,2}(t=t_j) & \Delta_{i,3}(t=t_j) \\ \cdots \\ 1 & Y_i(t=n_i-1) & \Delta_{n,1}(t=n_i-1) & \Delta_{n,2}(t=n_i-1) & \Delta_{n,3}(t=n_i-1) \end{bmatrix}_{n_i \times 5} \end{aligned}$$

$$\beta_i = \begin{bmatrix} \beta_{0,i} \\ \beta_{1,i} \\ \beta_{2,i} \\ \beta_{3,i} \\ \beta_{4,i} \end{bmatrix}$$

$$X_i = \begin{bmatrix} x_{i,1} & x_{i,2} & x_{i,3} \end{bmatrix}_{1\times 3}$$
$$\gamma = \begin{bmatrix} \gamma_1 \\ \gamma_2 \\ \gamma_3 \end{bmatrix}_{3\times 1}$$

Likelihood for the ith hurricane is

$$f(Y_i|\beta_i, \mu_i, \sigma^2, \Sigma, \gamma) = det(\sigma^2 I_{n_i})^{-1/2} exp(-\frac{(Y_i - D_i\beta_i - X_i\gamma)^\intercal (Y_i - D_i\beta_i - X_i\gamma)}{2\sigma^2})$$

To calculate the joint likelihood for $Y = \begin{bmatrix} Y_1 & Y_2 \dots Y_i \dots Y_H \end{bmatrix}^\intercal$, we denote total number of observations for all hurricanes as $N = \sum_{i=0}^{H} n_i$ where n_i is the total number of observation for the ith hurricane and H is the total number of hurricanes.

All random effects coefficients β_i in

$$\begin{aligned} B &= \begin{bmatrix} \beta_1 & \beta_2 \dots & \beta_i & \dots \beta_H \end{bmatrix} \\ &= \begin{bmatrix} \beta_{0,1} & \beta_{0,2} & \dots & \beta_{0,i} & \dots & \beta_{0,H} \\ \beta_{1,1} & \beta_{1,2} & \dots & \beta_{1,i} & \dots & \beta_{1,H} \\ \beta_{2,1} & \beta_{2,2} & \dots & \beta_{2,i} & \dots & \beta_{2,H} \\ \beta_{3,1} & \beta_{3,2} & \dots & \beta_{3,i} & \dots & \beta_{3,H} \\ \beta_{4,1} & \beta_{4,2} & \dots & \beta_{4,i} & \dots & \beta_{4,H} \end{bmatrix}_{5\times H} \end{aligned}$$

Design matrix for random effects for all hurricanes are in D. $D = \begin{bmatrix} D_1(t) \\ D_2(t) \\ \vdots \\ D_i(t) \\ \vdots \\ D_H(t) \end{bmatrix}_{N\times 5}$

Due to independence of each hurricane, the joint likelihood is

$$\begin{aligned} L_Y(B, \mu, \sigma^2, \Sigma, \gamma) &= \prod_{i=1}^{H} L_{Y_i}(\beta_i, \mu, \sigma^2, \Sigma, \gamma) \\ &= \prod_{i=1}^{H} det(\sigma^2 I_{n_i})^{-1/2} exp(-\frac{(Y_i - D_i\beta_i - X_i\gamma)^\intercal (Y_i - D_i\beta_i - X_i\gamma)}{2\sigma^2}) \\ &= \frac{1}{\sigma^N} exp(-\frac{(Y - DB - X\gamma)^\intercal (Y - DB - X\gamma)}{2\sigma^2}) \end{aligned}$$

Posterior

By Baye's Rule

$$f(B, \mu, \sigma^2, \Sigma, \gamma|Y) \propto f(Y|B, \mu, \sigma^2, \Sigma, \gamma) \times f(B|\mu, \Sigma) \times f(\mu) \times f(\Sigma) \times f(\sigma^2) \times f(\gamma)$$

where

$$\begin{aligned} \mu &= \begin{bmatrix} \mu_1 & \mu_2 \dots & \mu_i & \dots \mu_H \end{bmatrix} \\ &= \begin{bmatrix} \mu_{0,1} & \mu_{0,2} & \dots & \mu_{0,i} & \dots & \mu_{0,H} \\ \mu_{1,1} & \mu_{1,2} & \dots & \mu_{1,i} & \dots & \mu_{1,H} \\ \mu_{2,1} & \mu_{2,2} & \dots & \mu_{2,i} & \dots & \mu_{2,H} \\ \mu_{3,1} & \mu_{3,2} & \dots & \mu_{3,i} & \dots & \mu_{3,H} \\ \mu_{4,1} & \mu_{4,2} & \dots & \mu_{4,i} & \dots & \mu_{4,H} \end{bmatrix}_{5\times H} \end{aligned}$$

$$
\begin{aligned}
f(B|\mu,\Sigma) &= \prod_{i=1}^{H} f(\beta_i|\mu_i,\Sigma) \\
&= \prod_{i=1}^{H} det(\Sigma)^{-1/2} exp(-\frac{(\beta_i-\mu_i)^\intercal \Sigma^{-1}(\beta_i-\mu_i)}{2}) \\
&= det(A)^{H/2} \prod_{i=1}^{H} exp(-\frac{(\beta_i-\mu_i)^\intercal A(\beta_i-\mu_i)}{2})
\end{aligned}
$$

where $A = \Sigma^{-1}$

$$
\begin{aligned}
f(\mu) &= \prod_{i=1}^{H} f_{\mu_i}(\mu_i) \\
&= \prod_{i=1}^{H} det(V)^{\frac{-1}{2}} exp(-\frac{\mu_i^\intercal V^{-1}\mu_i}{2}) \\
&= det(V)^{\frac{-H}{2}} \prod_{i=1}^{H} exp(-\frac{\mu_i^\intercal V^{-1}\mu_i}{2})
\end{aligned}
$$

We'll only use $f_{\Sigma^{-1}}$ because only Σ^{-1} shows up in the likelihood equation. We denote $A = \Sigma^{-1}$ in the posterior.

$$
\begin{aligned}
f_{\Sigma^{-1}}(\Sigma^{-1}) &\propto |\Sigma^{-1}|^{\frac{\nu-5-1}{2}} exp(-\frac{tr(S\Sigma^{-1})}{2}) \\
f_{\sigma^2}(\sigma^2) &= \frac{2*10}{\pi(\sigma^2+10^2)}|\frac{\sigma}{2}| \\
f_\gamma(\gamma) &= exp(-\frac{400\gamma^\intercal\gamma}{2})
\end{aligned}
$$

Final posterior

$$
\begin{aligned}
f(B,\mu,\sigma^2,\Sigma,\gamma|Y) \propto& f(Y|B,\mu,\sigma^2,\Sigma,\gamma) \times f(B|\mu,\Sigma) \times f(\mu) \times f(\Sigma^{-1}) \times f(\sigma^2) \times f(\gamma) \\
=& f(Y|B,\mu,\sigma^2,\Sigma,\gamma) \times f(B|\mu,A) \times f(\mu) \times f(A) \times f(\sigma^2) \times f(\gamma) \\
=& \frac{1}{\sigma^N} exp(-\frac{(Y-DB-X\gamma)^\intercal (Y-DB-X\gamma)}{2\sigma^2}) \times \\
& det(A)^{H/2} \prod_{i=1}^{H} exp(-\frac{(\beta_i-\mu_i)^\intercal A(\beta_i-\mu_i)}{2}) \times \\
& det(V)^{\frac{-H}{2}} \prod_{i=1}^{H} exp(-\frac{\mu_i^\intercal V^{-1}\mu_i}{2}) \times \\
& |A|^{\frac{\nu-5-1}{2}} exp(-\frac{tr(SA)}{2}) \times \\
& \frac{2*10}{\pi(\sigma^2+10^2)}|\frac{\sigma}{2}| \times \\
& exp(-\frac{400\gamma^\intercal\gamma}{2})
\end{aligned}
$$