Sample Code

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Maternal mortality

This analysis relates to estimating the maternal mortality for countries worldwide. A maternal death is defined by the World Health Organization as "the death of a woman while pregnant or within 42 days of termination of pregnancy, irrespective of the duration and site of the pregnancy, from any cause related to or aggravated by the pregnancy or its management but not from accidental or incidental causes". The indicator we are interested in is the (non-AIDS) maternal mortality ratio (MMR) which is defined as the number of non-AIDS maternal deaths divided by the number of live births.

The first data file relevant to this question is `mmr_data`, which contains information on, for a range of countries over a range of years:

- Observations of the proportion of non-AIDS deaths that are maternal (PM^{NA})
- Data source, most commonly from Vital Registration systems (VR)
- The Gross Domestic Product (GDP)
- The General Fertility Rate (GFR)
- The average number of skilled attendants at birth (SAB)
- The geographical region of the country
- The total number of women, births, deaths to women of reproductive age (WRA), and the estimated proportion of all WRA deaths that are due to HIV/AIDS

The `mmr_data` file will be used for fitting. Note that data on PM^{NA} is not available for every country.

The `mmr_pred` file contains information on GDP, GFR, SAB, total number of births, deaths and women, and proportion of deaths that are due to HIV/AIDS, for every country at different time points (every five years from mid 1985 to mid 2015). Information in this file is used for producing estimates of MMR for countries without data, and for producing estimates centered at a particular time point.

Consider the following model:

$$y_i | \eta_{c[i]}^{\text{country}}, \eta_{r[i]}^{\text{region}} \sim N\left(\beta_0 + \eta_{c[i]}^{\text{country}} + \eta_{r[i]}^{\text{region}} + \beta_1 x_{i,1} + \beta_2 x_{i,2} + \beta_3 x_{i,3}, \sigma_y^2\right)$$

$$\eta_c^{\text{country}} \sim N\left(0, \left(\sigma_\eta^{\text{country}}\right)^2\right), \text{ for } c = 1, 2, \ldots, C$$

$$\eta_r^{\text{region}} \sim N\left(0, \left(\sigma_\eta^{\text{region}}\right)^2\right), \text{ for } r = 1, 2, \ldots, R$$

where

- y_i is the ith observed $\log PM^{NA}$ in country $c[i]$ in region $r[i]$
- C is total number of countries and R is total number of regions
- $x_{i,1}$ is $\log(\text{GDP})$
- $x_{i,2}$ is $\log(\text{GFR})$
- $x_{i,3}$ is SAB

We will turn this model into a Bayesian model by specifying appropriate prior distributions for the hyper-parameters. We can specify weakly informative priors on all the parameters, i.e., for the βs

$$\beta \sim N(0,1)$$

and for $\sigma_y, \sigma_\eta^{\text{country}}$ and $\sigma_\eta^{\text{region}}$

$$\sigma \sim N^+(0,1)$$

where the plus indicates Half Normal.

We can fit the Bayesian model in Stan. The Stan model code is provided in `mmr.stan` and the fitted model is available in `mmr_model.Rdata`.

```r
# read in the data
mmr_data <- read_csv(here("data","mmr_data.csv"))
mmr_pred<-read_csv(here("data","mmr_pred.csv"))


# obtain the values and indexes required for model
mmr_pred$country_code <- as.numeric(factor(mmr_pred$iso))
country_codes <- mmr_pred %>%
  select(iso,country_code)%>%
  distinct() # a list of all unique iso codes
C <- max(mmr_pred$country_code) # number of iso codes (countries)

mmr_pred$region_code <- as.numeric(factor(mmr_pred$region))
region_codes <- mmr_pred %>%
  select(region,region_code) %>%
  distinct() # a list of all unique regions
R <- max(mmr_pred$region_code) # number of regions


mmr_data <- left_join(mmr_data, country_codes) # country of the ith observation
mmr_data <-  left_join(mmr_data, region_codes) # region of the ith observation


# get data in stan format
stan_data <- list(N = nrow(mmr_data), # data for fitting
                  C = C,
                  R = R,
                  country = mmr_data$country_code,
                  region = mmr_data$region_code,
                  y = log(mmr_data$PM_na),
```

```
                 x1 = log(mmr_data$GDP),
                 x2 = log(mmr_data$GFR),
                 x3 = mmr_data$SAB,
                 pred_N = nrow(mmr_pred), # data for prediction
                 new_country = mmr_pred$country_code,
                 new_region = mmr_pred$region_code,
                 new_x1 = log(mmr_pred$GDP),
                 new_x2 = log(mmr_pred$GFR),
                 new_x3 = mmr_pred$SAB)
```

```
# load MCMC samples from fitted stan model
load(file = "ext_fit.Rdata")
```

We can use the MCMC samples to construct 95% credible intervals for the proportion of non-AIDS
deaths that are maternal for 5-year periods from 1985.5 to 2015.5. We will do this for one country
with data, Argentina, and one country without any observed data, the Bahamas.

```
# get predictions and CIs of PM_na
mmr_pred$y_pred = exp(apply(ext_fit$y_pred, 2, mean))
mmr_pred$y_lower = exp(apply(ext_fit$y_pred, 2, quantile, probs = 0.025))
mmr_pred$y_upper = exp(apply(ext_fit$y_pred, 2, quantile, probs = 0.975))
```

```
# plot the results
mmr_pred %>%
  filter(Country=="Bahamas") %>%
  ggplot(aes(x=mid.date, y=y_pred)) +
    geom_point(size=2, color="steelblue") +
    geom_errorbar(aes(ymin=y_lower, ymax=y_upper), width=1, color="steelblue") +
    labs(title="Proportion of non-AIDS deaths that are maternal, Bahamas",
        y="Proportion", x="Period (5-year period centered at mid-year)") +
    scale_x_continuous(breaks=c(1985, 1990, 1995, 2000, 2005, 2010, 2015))
```

Proportion of non–AIDS deaths that are maternal, Bahamas
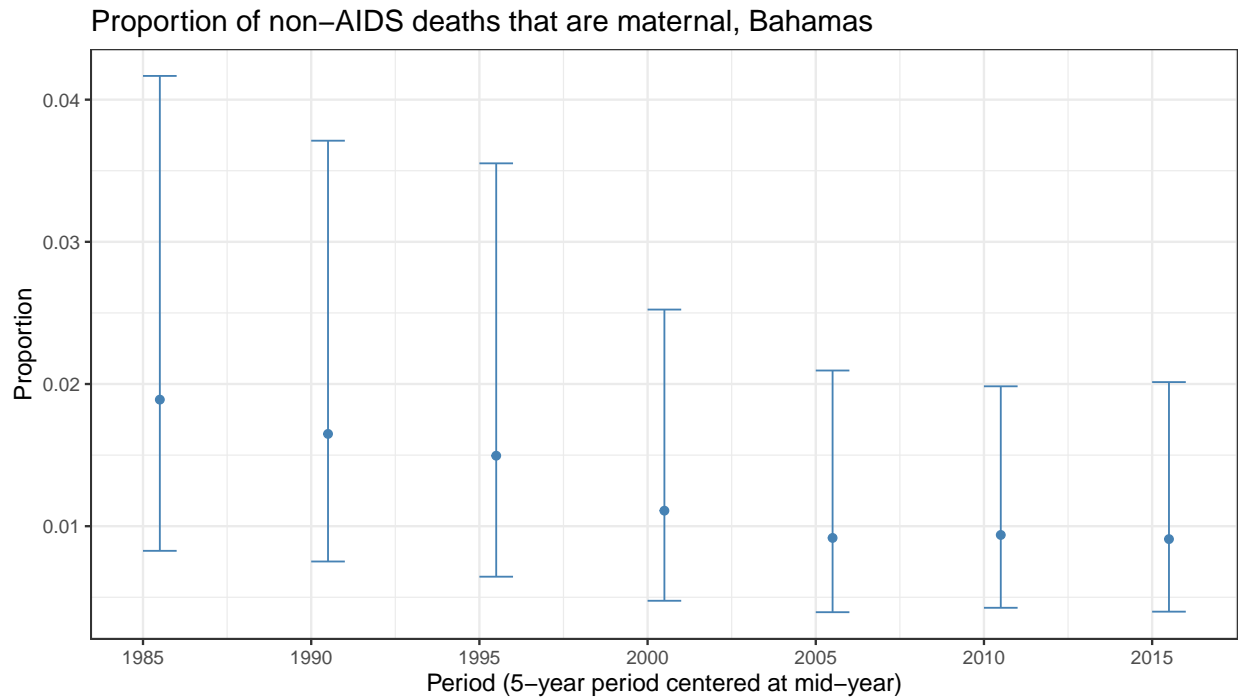

```
mmr_pred %>%
  filter(Country=="Argentina") %>%
  ggplot(aes(x=mid.date,y=y_pred,color="Prediction")) +
    geom_point(size=2) +
    geom_errorbar(aes(ymin=y_lower, ymax=y_upper), width=1) +
    geom_point(data=mmr_data %>%
                 filter(Country=="Argentina"),
               aes(x=mid.date, y=PM_na, color="Observed"), size=2) +
    labs(title="Proportion of non-AIDS deaths that are maternal, Argentina",
      y="Proportion", x="Period (5-year period centered at mid-year)") +
    scale_x_continuous(breaks=c(1985, 1990, 1995, 2000, 2005, 2010, 2015)) +
    scale_color_manual(values=c('firebrick','steelblue')) +
    theme(legend.title=element_blank())
```

Proportion of non–AIDS deaths that are maternal, Argentina
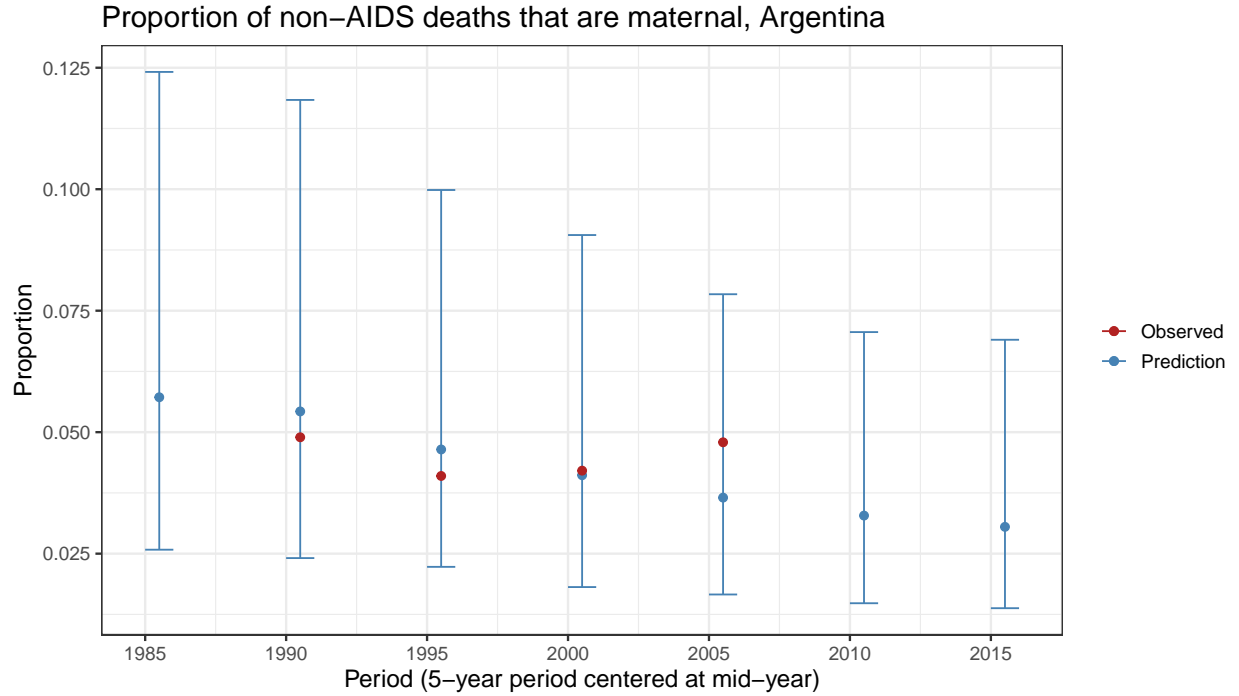

```r
# results tables
mmr_pred %>%
  filter(Country=="Bahamas") %>%
  select(mid.date, y_pred, y_lower, y_upper) %>%
  kable("latex",
        col.names=c("Period","Estimate","2.5%","97.5%"),
        digits=4,
        booktabs=TRUE,
        caption="Proportion of non-AIDS deaths that are maternal, Bahamas") %>%
  add_header_above(c("","Proportion"=3)) %>%
  kable_styling(latex_options="HOLD_position")
```

Table 1: Proportion of non-AIDS deaths that are maternal, Bahamas

	Proportion		
Period	Estimate	2.5%	97.5%
1985.5	0.0189	0.0083	0.0417
1990.5	0.0165	0.0075	0.0371
1995.5	0.0150	0.0064	0.0355
2000.5	0.0111	0.0048	0.0252
2005.5	0.0092	0.0040	0.0210
2010.5	0.0094	0.0043	0.0198
2015.5	0.0091	0.0040	0.0201

```
mmr_pred %>%
  filter(Country=="Argentina")%>%
  select(mid.date,y_pred,y_lower,y_upper) %>%
  kable("latex",
        col.names=c("Period","Estimate","2.5%","97.5%"),
        digits=4,
        booktabs=TRUE,
        caption="Proportion of non-AIDS deaths that are maternal, Argentina") %>%
  add_header_above(c("","Proportion"=3))%>%
  kable_styling(latex_options="HOLD_position")
```

Table 2: Proportion of non-AIDS deaths that are maternal, Argentina

Period	Proportion		
	Estimate	2.5%	97.5%
1985.5	0.0572	0.0258	0.1241
1990.5	0.0543	0.0241	0.1184
1995.5	0.0464	0.0223	0.0998
2000.5	0.0411	0.0181	0.0906
2005.5	0.0365	0.0166	0.0784
2010.5	0.0328	0.0148	0.0706
2015.5	0.0305	0.0138	0.0690