

# Week 10: Temporal data

26/03/23

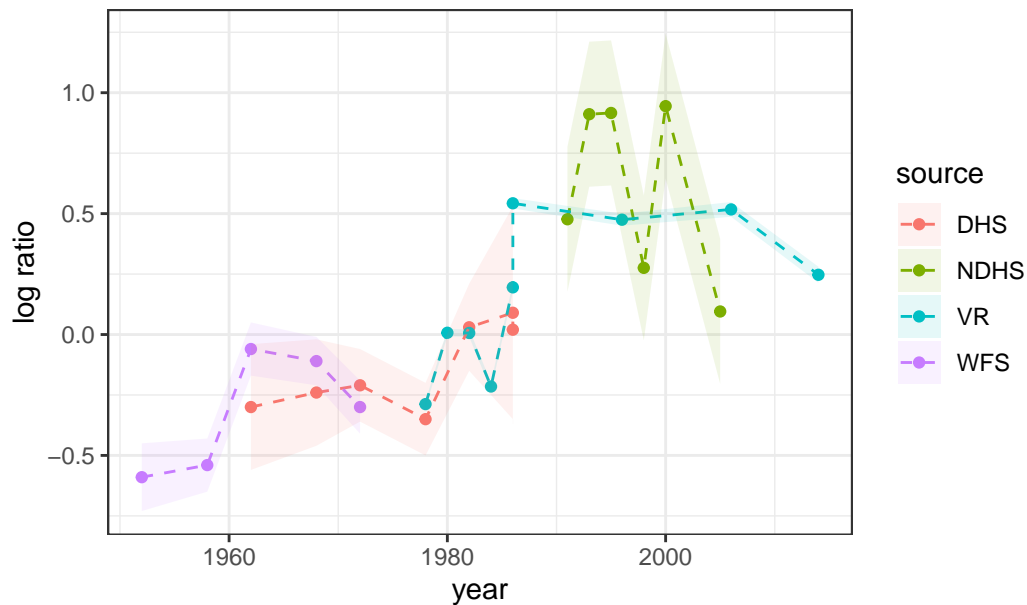
## Child mortality in Sri Lanka

In this lab you will be fitting a couple of different models to the data about child mortality in Sri Lanka, which was used in the lecture. Here's the data and the plot from the lecture:

```
library(tidyverse)
library(here)
library(rstan)
library(tidybayes)

lka <- read_csv(here("Labs/Lab8/lka.csv"))
ggplot(lka, aes(year, logit_ratio)) +
  geom_point(aes( color = source)) +
  geom_line(aes( color = source), lty = 2) +
  geom_ribbon(aes(ymin = logit_ratio - se,
                 ymax = logit_ratio + se,
                 fill = source), alpha = 0.1) +
  theme_bw()+
  labs(title = "Ratio of neonatal to other child mortality (logged), Sri Lanka", y = "log
```

Ratio of neonatal to other child mortality (logged), Sri Lanka



## Fitting a linear model

Let's firstly fit a linear model in time to these data. Here's the code to do this:

```
observed_years <- lka$year
years <- min(observed_years):max(observed_years)
nyears <- length(years)

stan_data <- list(y = lka$logit_ratio, year_i = observed_years - years[1]+1,
                 T = nyears, years = years, N = length(observed_years),
                 mid_year = mean(years), se = lka$se)

mod <- stan(data = stan_data,
            file = here("Labs/Lab8/lka_linear_me.stan"))
```

SAMPLING FOR MODEL 'anon\_model' NOW (CHAIN 1).

Chain 1:

Chain 1: Gradient evaluation took 3.8e-05 seconds

Chain 1: 1000 transitions using 10 leapfrog steps per transition would take 0.38 seconds.

Chain 1: Adjust your expectations accordingly!

```

Chain 1:
Chain 1:
Chain 1: Iteration:    1 / 2000 [  0%] (Warmup)
Chain 1: Iteration:   200 / 2000 [ 10%] (Warmup)
Chain 1: Iteration:   400 / 2000 [ 20%] (Warmup)
Chain 1: Iteration:   600 / 2000 [ 30%] (Warmup)
Chain 1: Iteration:   800 / 2000 [ 40%] (Warmup)
Chain 1: Iteration:  1000 / 2000 [ 50%] (Warmup)
Chain 1: Iteration: 1001 / 2000 [ 50%] (Sampling)
Chain 1: Iteration: 1200 / 2000 [ 60%] (Sampling)
Chain 1: Iteration: 1400 / 2000 [ 70%] (Sampling)
Chain 1: Iteration: 1600 / 2000 [ 80%] (Sampling)
Chain 1: Iteration: 1800 / 2000 [ 90%] (Sampling)
Chain 1: Iteration: 2000 / 2000 [100%] (Sampling)
Chain 1:
Chain 1: Elapsed Time: 0.049 seconds (Warm-up)
Chain 1:                0.028 seconds (Sampling)
Chain 1:                0.077 seconds (Total)
Chain 1:

```

SAMPLING FOR MODEL 'anon\_model' NOW (CHAIN 2).

```

Chain 2:
Chain 2: Gradient evaluation took 6e-06 seconds
Chain 2: 1000 transitions using 10 leapfrog steps per transition would take 0.06 seconds.
Chain 2: Adjust your expectations accordingly!
Chain 2:
Chain 2:
Chain 2: Iteration:    1 / 2000 [  0%] (Warmup)
Chain 2: Iteration:   200 / 2000 [ 10%] (Warmup)
Chain 2: Iteration:   400 / 2000 [ 20%] (Warmup)
Chain 2: Iteration:   600 / 2000 [ 30%] (Warmup)
Chain 2: Iteration:   800 / 2000 [ 40%] (Warmup)
Chain 2: Iteration:  1000 / 2000 [ 50%] (Warmup)
Chain 2: Iteration: 1001 / 2000 [ 50%] (Sampling)
Chain 2: Iteration: 1200 / 2000 [ 60%] (Sampling)
Chain 2: Iteration: 1400 / 2000 [ 70%] (Sampling)
Chain 2: Iteration: 1600 / 2000 [ 80%] (Sampling)
Chain 2: Iteration: 1800 / 2000 [ 90%] (Sampling)
Chain 2: Iteration: 2000 / 2000 [100%] (Sampling)
Chain 2:
Chain 2: Elapsed Time: 0.03 seconds (Warm-up)
Chain 2:                0.027 seconds (Sampling)
Chain 2:                0.057 seconds (Total)

```

Chain 2:

SAMPLING FOR MODEL 'anon\_model' NOW (CHAIN 3).

Chain 3:

Chain 3: Gradient evaluation took 4e-06 seconds

Chain 3: 1000 transitions using 10 leapfrog steps per transition would take 0.04 seconds.

Chain 3: Adjust your expectations accordingly!

Chain 3:

Chain 3:

Chain 3: Iteration: 1 / 2000 [ 0%] (Warmup)

Chain 3: Iteration: 200 / 2000 [ 10%] (Warmup)

Chain 3: Iteration: 400 / 2000 [ 20%] (Warmup)

Chain 3: Iteration: 600 / 2000 [ 30%] (Warmup)

Chain 3: Iteration: 800 / 2000 [ 40%] (Warmup)

Chain 3: Iteration: 1000 / 2000 [ 50%] (Warmup)

Chain 3: Iteration: 1001 / 2000 [ 50%] (Sampling)

Chain 3: Iteration: 1200 / 2000 [ 60%] (Sampling)

Chain 3: Iteration: 1400 / 2000 [ 70%] (Sampling)

Chain 3: Iteration: 1600 / 2000 [ 80%] (Sampling)

Chain 3: Iteration: 1800 / 2000 [ 90%] (Sampling)

Chain 3: Iteration: 2000 / 2000 [100%] (Sampling)

Chain 3:

Chain 3: Elapsed Time: 0.031 seconds (Warm-up)

Chain 3: 0.028 seconds (Sampling)

Chain 3: 0.059 seconds (Total)

Chain 3:

SAMPLING FOR MODEL 'anon\_model' NOW (CHAIN 4).

Chain 4:

Chain 4: Gradient evaluation took 5e-06 seconds

Chain 4: 1000 transitions using 10 leapfrog steps per transition would take 0.05 seconds.

Chain 4: Adjust your expectations accordingly!

Chain 4:

Chain 4:

Chain 4: Iteration: 1 / 2000 [ 0%] (Warmup)

Chain 4: Iteration: 200 / 2000 [ 10%] (Warmup)

Chain 4: Iteration: 400 / 2000 [ 20%] (Warmup)

Chain 4: Iteration: 600 / 2000 [ 30%] (Warmup)

Chain 4: Iteration: 800 / 2000 [ 40%] (Warmup)

Chain 4: Iteration: 1000 / 2000 [ 50%] (Warmup)

Chain 4: Iteration: 1001 / 2000 [ 50%] (Sampling)

Chain 4: Iteration: 1200 / 2000 [ 60%] (Sampling)

Chain 4: Iteration: 1400 / 2000 [ 70%] (Sampling)

```
Chain 4: Iteration: 1600 / 2000 [ 80%] (Sampling)
Chain 4: Iteration: 1800 / 2000 [ 90%] (Sampling)
Chain 4: Iteration: 2000 / 2000 [100%] (Sampling)
Chain 4:
Chain 4: Elapsed Time: 0.037 seconds (Warm-up)
Chain 4:           0.029 seconds (Sampling)
Chain 4:           0.066 seconds (Total)
Chain 4:
```

Extract the results:

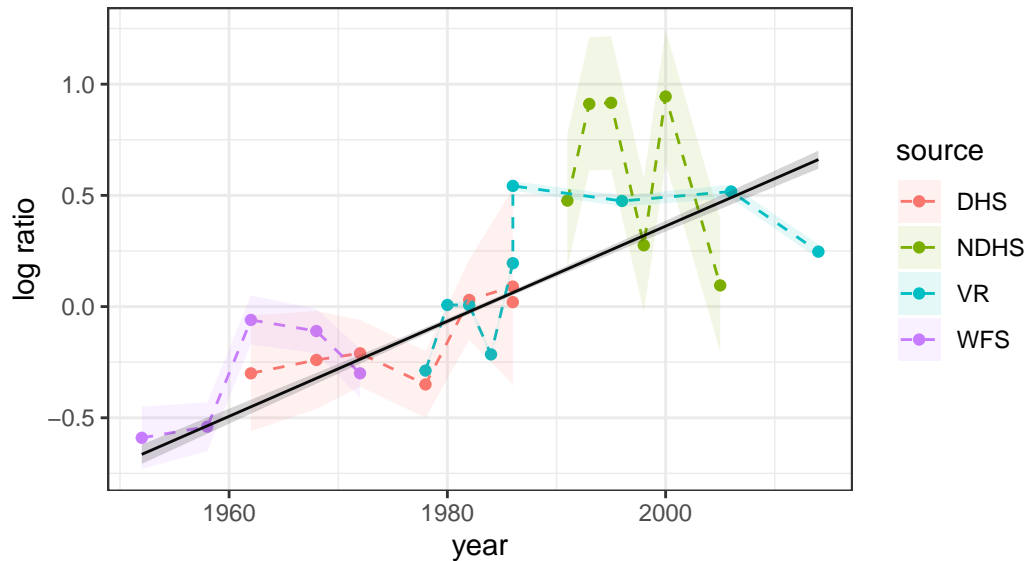
```
res1 <- mod %>%
  gather_draws(mu[t]) %>%
  median_qi() %>%
  mutate(year = years[t])
```

Plot the results:

```
ggplot(lka, aes(year, logit_ratio)) +
  geom_point(aes( color = source)) +
  geom_line(aes( color = source), lty = 2) +
  geom_ribbon(aes(ymin = logit_ratio - se,
                 ymax = logit_ratio + se,
                 fill = source), alpha = 0.1) +
  theme_bw()+
  geom_line(data = res1, aes(year, .value)) +
  geom_ribbon(data = res1, aes(y = .value, ymin = .lower, ymax = .upper), alpha = 0.2)+
  theme_bw()+
  labs(title = "Ratio of neonatal to other child mortality (logged), Sri Lanka",
       y = "log ratio", subtitle = "Linear fit shown in black")
```

## Ratio of neonatal to other child mortality (logged), Sri Lanka

Linear fit shown in black



### Question 1

Project the linear model above out to 2023 by adding a **generated quantities** block in Stan (do the projections based on the expected value  $\mu$ ). Plot the resulting projections on a graph similar to that above.

```
stan_data <- list(y = lka$logit_ratio, year_i = observed_years - years[1]+1,
                 T = nyears, years = years, N = length(observed_years),
                 mid_year = mean(years), se = lka$se, P = 9)

mod2 <- stan(data = stan_data,
             file = here("Labs/Lab8/Lab10_1.stan"))
```

SAMPLING FOR MODEL 'anon\_model' NOW (CHAIN 1).

Chain 1:

Chain 1: Gradient evaluation took 2e-05 seconds

Chain 1: 1000 transitions using 10 leapfrog steps per transition would take 0.2 seconds.

Chain 1: Adjust your expectations accordingly!

Chain 1:

Chain 1:

```

Chain 1: Iteration:    1 / 2000 [  0%] (Warmup)
Chain 1: Iteration:   200 / 2000 [ 10%] (Warmup)
Chain 1: Iteration:   400 / 2000 [ 20%] (Warmup)
Chain 1: Iteration:   600 / 2000 [ 30%] (Warmup)
Chain 1: Iteration:   800 / 2000 [ 40%] (Warmup)
Chain 1: Iteration:  1000 / 2000 [ 50%] (Warmup)
Chain 1: Iteration:  1001 / 2000 [ 50%] (Sampling)
Chain 1: Iteration:  1200 / 2000 [ 60%] (Sampling)
Chain 1: Iteration:  1400 / 2000 [ 70%] (Sampling)
Chain 1: Iteration:  1600 / 2000 [ 80%] (Sampling)
Chain 1: Iteration:  1800 / 2000 [ 90%] (Sampling)
Chain 1: Iteration:  2000 / 2000 [100%] (Sampling)
Chain 1:
Chain 1: Elapsed Time: 0.031 seconds (Warm-up)
Chain 1:                0.027 seconds (Sampling)
Chain 1:                0.058 seconds (Total)
Chain 1:

```

SAMPLING FOR MODEL 'anon\_model' NOW (CHAIN 2).

```

Chain 2:
Chain 2: Gradient evaluation took 6e-06 seconds
Chain 2: 1000 transitions using 10 leapfrog steps per transition would take 0.06 seconds.
Chain 2: Adjust your expectations accordingly!
Chain 2:
Chain 2:
Chain 2: Iteration:    1 / 2000 [  0%] (Warmup)
Chain 2: Iteration:   200 / 2000 [ 10%] (Warmup)
Chain 2: Iteration:   400 / 2000 [ 20%] (Warmup)
Chain 2: Iteration:   600 / 2000 [ 30%] (Warmup)
Chain 2: Iteration:   800 / 2000 [ 40%] (Warmup)
Chain 2: Iteration:  1000 / 2000 [ 50%] (Warmup)
Chain 2: Iteration:  1001 / 2000 [ 50%] (Sampling)
Chain 2: Iteration:  1200 / 2000 [ 60%] (Sampling)
Chain 2: Iteration:  1400 / 2000 [ 70%] (Sampling)
Chain 2: Iteration:  1600 / 2000 [ 80%] (Sampling)
Chain 2: Iteration:  1800 / 2000 [ 90%] (Sampling)
Chain 2: Iteration:  2000 / 2000 [100%] (Sampling)
Chain 2:
Chain 2: Elapsed Time: 0.031 seconds (Warm-up)
Chain 2:                0.027 seconds (Sampling)
Chain 2:                0.058 seconds (Total)
Chain 2:

```

SAMPLING FOR MODEL 'anon\_model' NOW (CHAIN 3).

Chain 3:

Chain 3: Gradient evaluation took 5e-06 seconds

Chain 3: 1000 transitions using 10 leapfrog steps per transition would take 0.05 seconds.

Chain 3: Adjust your expectations accordingly!

Chain 3:

Chain 3:

Chain 3: Iteration: 1 / 2000 [ 0%] (Warmup)

Chain 3: Iteration: 200 / 2000 [ 10%] (Warmup)

Chain 3: Iteration: 400 / 2000 [ 20%] (Warmup)

Chain 3: Iteration: 600 / 2000 [ 30%] (Warmup)

Chain 3: Iteration: 800 / 2000 [ 40%] (Warmup)

Chain 3: Iteration: 1000 / 2000 [ 50%] (Warmup)

Chain 3: Iteration: 1001 / 2000 [ 50%] (Sampling)

Chain 3: Iteration: 1200 / 2000 [ 60%] (Sampling)

Chain 3: Iteration: 1400 / 2000 [ 70%] (Sampling)

Chain 3: Iteration: 1600 / 2000 [ 80%] (Sampling)

Chain 3: Iteration: 1800 / 2000 [ 90%] (Sampling)

Chain 3: Iteration: 2000 / 2000 [100%] (Sampling)

Chain 3:

Chain 3: Elapsed Time: 0.029 seconds (Warm-up)

Chain 3: 0.028 seconds (Sampling)

Chain 3: 0.057 seconds (Total)

Chain 3:

SAMPLING FOR MODEL 'anon\_model' NOW (CHAIN 4).

Chain 4:

Chain 4: Gradient evaluation took 4e-06 seconds

Chain 4: 1000 transitions using 10 leapfrog steps per transition would take 0.04 seconds.

Chain 4: Adjust your expectations accordingly!

Chain 4:

Chain 4:

Chain 4: Iteration: 1 / 2000 [ 0%] (Warmup)

Chain 4: Iteration: 200 / 2000 [ 10%] (Warmup)

Chain 4: Iteration: 400 / 2000 [ 20%] (Warmup)

Chain 4: Iteration: 600 / 2000 [ 30%] (Warmup)

Chain 4: Iteration: 800 / 2000 [ 40%] (Warmup)

Chain 4: Iteration: 1000 / 2000 [ 50%] (Warmup)

Chain 4: Iteration: 1001 / 2000 [ 50%] (Sampling)

Chain 4: Iteration: 1200 / 2000 [ 60%] (Sampling)

Chain 4: Iteration: 1400 / 2000 [ 70%] (Sampling)

Chain 4: Iteration: 1600 / 2000 [ 80%] (Sampling)

Chain 4: Iteration: 1800 / 2000 [ 90%] (Sampling)



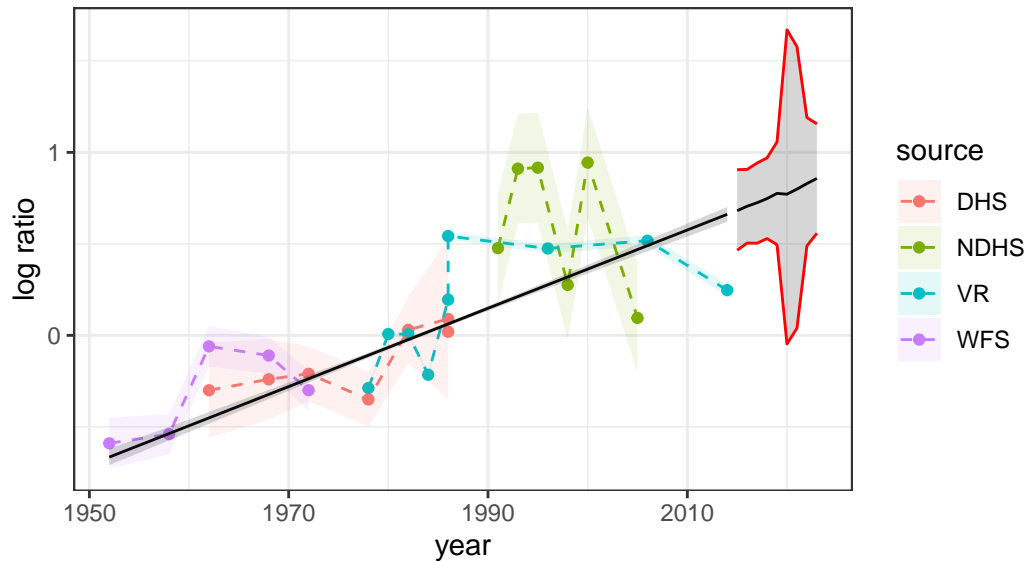
```
Chain 4: Iteration: 2000 / 2000 [100%] (Sampling)
Chain 4:
Chain 4: Elapsed Time: 0.032 seconds (Warm-up)
Chain 4:           0.025 seconds (Sampling)
Chain 4:           0.057 seconds (Total)
Chain 4:
```

```
res2 <- mod2 %>%
  gather_draws(mu[t]) %>%
  median_qi() %>%
  mutate(year=years[t])

res_p2 <- mod2 %>%
  gather_draws(mu_p[p]) %>%
  median_qi() %>%
  mutate(year=years[nyears]+ p)

ggplot(lka, aes(year, logit_ratio)) +
  geom_point(aes( color = source)) +
  geom_line(aes( color = source), lty = 2) +
  geom_ribbon(aes(ymin = logit_ratio - se,
                 ymax = logit_ratio + se,
                 fill = source), alpha = 0.1) +
  theme_bw()+
  geom_line(data = res2, aes(year, .value)) +
  geom_ribbon(data = res2, aes(y = .value, ymin = .lower, ymax = .upper), alpha = 0.2)+
  geom_line(data = res_p2, aes(year, .value)) +
  geom_ribbon(data = res_p2, aes(y = .value, ymin = .lower, ymax = .upper), alpha = 0.2, c
  theme_bw()+
  labs(title = "Ratio of neonatal to other child mortality (logged), Sri Lanka",
       y = "log ratio", subtitle = "Linear fit shown in black")
```

Ratio of neonatal to other child mortality (logged), Sri Lanka  
Linear fit shown in black



## Random walks

### Question 2

Code up and estimate a first order random walk model to fit to the Sri Lankan data, taking into account measurement error, and project out to 2023.

```
stan_data <- list(y = lka$logit_ratio, year_i = observed_years - years[1]+1,
                 T = nyears, years = years, N = length(observed_years),
                 mid_year = mean(years), se = lka$se, P = 9)

mod3 <- stan(data = stan_data,
             file = here("Labs/Lab8/Lab10_2.stan"))
```

SAMPLING FOR MODEL 'anon\_model' NOW (CHAIN 1).

Chain 1:

Chain 1: Gradient evaluation took 3e-05 seconds

Chain 1: 1000 transitions using 10 leapfrog steps per transition would take 0.3 seconds.

Chain 1: Adjust your expectations accordingly!

Chain 1:

```

Chain 1:
Chain 1: Iteration:    1 / 2000 [  0%] (Warmup)
Chain 1: Iteration:   200 / 2000 [ 10%] (Warmup)
Chain 1: Iteration:   400 / 2000 [ 20%] (Warmup)
Chain 1: Iteration:   600 / 2000 [ 30%] (Warmup)
Chain 1: Iteration:   800 / 2000 [ 40%] (Warmup)
Chain 1: Iteration:  1000 / 2000 [ 50%] (Warmup)
Chain 1: Iteration:  1001 / 2000 [ 50%] (Sampling)
Chain 1: Iteration:  1200 / 2000 [ 60%] (Sampling)
Chain 1: Iteration:  1400 / 2000 [ 70%] (Sampling)
Chain 1: Iteration:  1600 / 2000 [ 80%] (Sampling)
Chain 1: Iteration:  1800 / 2000 [ 90%] (Sampling)
Chain 1: Iteration:  2000 / 2000 [100%] (Sampling)
Chain 1:
Chain 1: Elapsed Time: 0.182 seconds (Warm-up)
Chain 1:                0.131 seconds (Sampling)
Chain 1:                0.313 seconds (Total)
Chain 1:

```

SAMPLING FOR MODEL 'anon\_model' NOW (CHAIN 2).

```

Chain 2:
Chain 2: Gradient evaluation took 8e-06 seconds
Chain 2: 1000 transitions using 10 leapfrog steps per transition would take 0.08 seconds.
Chain 2: Adjust your expectations accordingly!
Chain 2:
Chain 2:
Chain 2: Iteration:    1 / 2000 [  0%] (Warmup)
Chain 2: Iteration:   200 / 2000 [ 10%] (Warmup)
Chain 2: Iteration:   400 / 2000 [ 20%] (Warmup)
Chain 2: Iteration:   600 / 2000 [ 30%] (Warmup)
Chain 2: Iteration:   800 / 2000 [ 40%] (Warmup)
Chain 2: Iteration:  1000 / 2000 [ 50%] (Warmup)
Chain 2: Iteration:  1001 / 2000 [ 50%] (Sampling)
Chain 2: Iteration:  1200 / 2000 [ 60%] (Sampling)
Chain 2: Iteration:  1400 / 2000 [ 70%] (Sampling)
Chain 2: Iteration:  1600 / 2000 [ 80%] (Sampling)
Chain 2: Iteration:  1800 / 2000 [ 90%] (Sampling)
Chain 2: Iteration:  2000 / 2000 [100%] (Sampling)
Chain 2:
Chain 2: Elapsed Time: 0.194 seconds (Warm-up)
Chain 2:                0.154 seconds (Sampling)
Chain 2:                0.348 seconds (Total)
Chain 2:

```

SAMPLING FOR MODEL 'anon\_model' NOW (CHAIN 3).

Chain 3:

Chain 3: Gradient evaluation took 6e-06 seconds

Chain 3: 1000 transitions using 10 leapfrog steps per transition would take 0.06 seconds.

Chain 3: Adjust your expectations accordingly!

Chain 3:

Chain 3:

Chain 3: Iteration: 1 / 2000 [ 0%] (Warmup)

Chain 3: Iteration: 200 / 2000 [ 10%] (Warmup)

Chain 3: Iteration: 400 / 2000 [ 20%] (Warmup)

Chain 3: Iteration: 600 / 2000 [ 30%] (Warmup)

Chain 3: Iteration: 800 / 2000 [ 40%] (Warmup)

Chain 3: Iteration: 1000 / 2000 [ 50%] (Warmup)

Chain 3: Iteration: 1001 / 2000 [ 50%] (Sampling)

Chain 3: Iteration: 1200 / 2000 [ 60%] (Sampling)

Chain 3: Iteration: 1400 / 2000 [ 70%] (Sampling)

Chain 3: Iteration: 1600 / 2000 [ 80%] (Sampling)

Chain 3: Iteration: 1800 / 2000 [ 90%] (Sampling)

Chain 3: Iteration: 2000 / 2000 [100%] (Sampling)

Chain 3:

Chain 3: Elapsed Time: 0.196 seconds (Warm-up)

Chain 3: 0.151 seconds (Sampling)

Chain 3: 0.347 seconds (Total)

Chain 3:

SAMPLING FOR MODEL 'anon\_model' NOW (CHAIN 4).

Chain 4:

Chain 4: Gradient evaluation took 7e-06 seconds

Chain 4: 1000 transitions using 10 leapfrog steps per transition would take 0.07 seconds.

Chain 4: Adjust your expectations accordingly!

Chain 4:

Chain 4:

Chain 4: Iteration: 1 / 2000 [ 0%] (Warmup)

Chain 4: Iteration: 200 / 2000 [ 10%] (Warmup)

Chain 4: Iteration: 400 / 2000 [ 20%] (Warmup)

Chain 4: Iteration: 600 / 2000 [ 30%] (Warmup)

Chain 4: Iteration: 800 / 2000 [ 40%] (Warmup)

Chain 4: Iteration: 1000 / 2000 [ 50%] (Warmup)

Chain 4: Iteration: 1001 / 2000 [ 50%] (Sampling)

Chain 4: Iteration: 1200 / 2000 [ 60%] (Sampling)

Chain 4: Iteration: 1400 / 2000 [ 70%] (Sampling)

Chain 4: Iteration: 1600 / 2000 [ 80%] (Sampling)

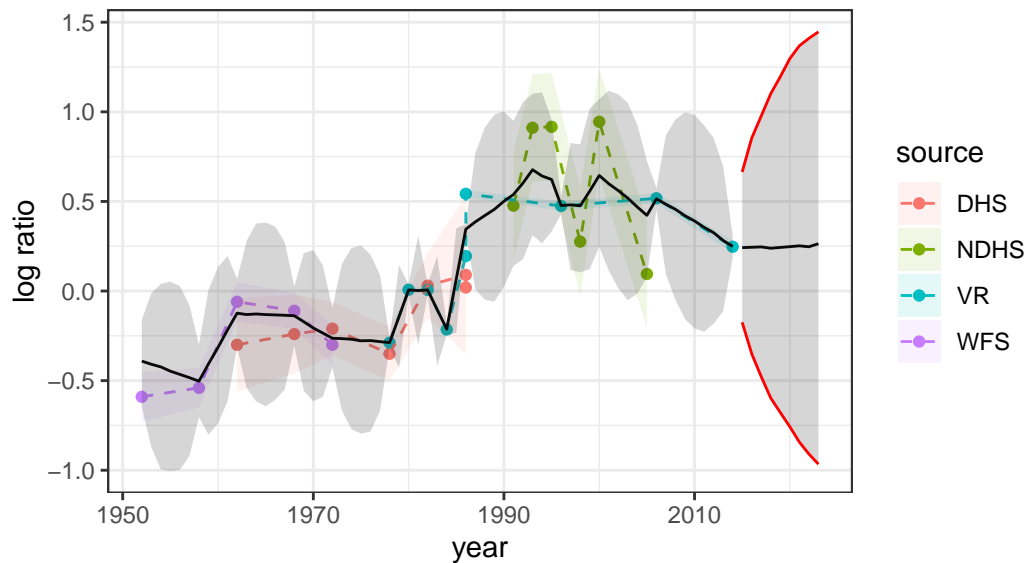
```
Chain 4: Iteration: 1800 / 2000 [ 90%] (Sampling)
Chain 4: Iteration: 2000 / 2000 [100%] (Sampling)
Chain 4:
Chain 4: Elapsed Time: 0.179 seconds (Warm-up)
Chain 4:           0.153 seconds (Sampling)
Chain 4:           0.332 seconds (Total)
Chain 4:
```

```
res3 <- mod3 %>%
  gather_draws(mu[t]) %>%
  median_qi() %>%
  mutate(year=years[t])

res_p3 <- mod3 %>%
  gather_draws(mu_p[p]) %>%
  median_qi() %>%
  mutate(year=years[nyears]+ p)

ggplot(lka, aes(year, logit_ratio)) +
  geom_point(aes( color = source)) +
  geom_line(aes( color = source), lty = 2) +
  geom_ribbon(aes(ymin = logit_ratio - se,
                 ymax = logit_ratio + se,
                 fill = source), alpha = 0.1) +
  theme_bw()+
  geom_line(data = res3, aes(year, .value)) +
  geom_ribbon(data = res3, aes(y = .value, ymin = .lower, ymax = .upper), alpha = 0.2)+
  geom_line(data = res_p3, aes(year, .value)) +
  geom_ribbon(data = res_p3, aes(y = .value, ymin = .lower, ymax = .upper), alpha = 0.2, c
  theme_bw()+
  labs(title = "Ratio of neonatal to other child mortality (logged), Sri Lanka",
       y = "log ratio", subtitle = "first order shown in black, projections in red")
```

Ratio of neonatal to other child mortality (logged), Sri Lanka  
first order shown in black, projections in red



### Question 3

Now alter your model above to estimate and project a second-order random walk model (RW2).

```
stan_data <- list(y = lka$logit_ratio, year_i = observed_years - years[1]+1,
                 T = nyears, years = years, N = length(observed_years),
                 mid_year = mean(years), se = lka$se, P = 9)

mod4 <- stan(data = stan_data,
             file = here("Labs/Lab8/Lab10_3.stan"))
```

SAMPLING FOR MODEL 'anon\_model' NOW (CHAIN 1).

Chain 1:

Chain 1: Gradient evaluation took 3.7e-05 seconds

Chain 1: 1000 transitions using 10 leapfrog steps per transition would take 0.37 seconds.

Chain 1: Adjust your expectations accordingly!

Chain 1:

Chain 1:

Chain 1: Iteration: 1 / 2000 [ 0%] (Warmup)

```

Chain 1: Iteration: 200 / 2000 [ 10%] (Warmup)
Chain 1: Iteration: 400 / 2000 [ 20%] (Warmup)
Chain 1: Iteration: 600 / 2000 [ 30%] (Warmup)
Chain 1: Iteration: 800 / 2000 [ 40%] (Warmup)
Chain 1: Iteration: 1000 / 2000 [ 50%] (Warmup)
Chain 1: Iteration: 1001 / 2000 [ 50%] (Sampling)
Chain 1: Iteration: 1200 / 2000 [ 60%] (Sampling)
Chain 1: Iteration: 1400 / 2000 [ 70%] (Sampling)
Chain 1: Iteration: 1600 / 2000 [ 80%] (Sampling)
Chain 1: Iteration: 1800 / 2000 [ 90%] (Sampling)
Chain 1: Iteration: 2000 / 2000 [100%] (Sampling)
Chain 1:
Chain 1: Elapsed Time: 0.523 seconds (Warm-up)
Chain 1:           0.398 seconds (Sampling)
Chain 1:           0.921 seconds (Total)
Chain 1:

```

SAMPLING FOR MODEL 'anon\_model' NOW (CHAIN 2).

```

Chain 2:
Chain 2: Gradient evaluation took 7e-06 seconds
Chain 2: 1000 transitions using 10 leapfrog steps per transition would take 0.07 seconds.
Chain 2: Adjust your expectations accordingly!
Chain 2:
Chain 2:
Chain 2: Iteration: 1 / 2000 [ 0%] (Warmup)
Chain 2: Iteration: 200 / 2000 [ 10%] (Warmup)
Chain 2: Iteration: 400 / 2000 [ 20%] (Warmup)
Chain 2: Iteration: 600 / 2000 [ 30%] (Warmup)
Chain 2: Iteration: 800 / 2000 [ 40%] (Warmup)
Chain 2: Iteration: 1000 / 2000 [ 50%] (Warmup)
Chain 2: Iteration: 1001 / 2000 [ 50%] (Sampling)
Chain 2: Iteration: 1200 / 2000 [ 60%] (Sampling)
Chain 2: Iteration: 1400 / 2000 [ 70%] (Sampling)
Chain 2: Iteration: 1600 / 2000 [ 80%] (Sampling)
Chain 2: Iteration: 1800 / 2000 [ 90%] (Sampling)
Chain 2: Iteration: 2000 / 2000 [100%] (Sampling)
Chain 2:
Chain 2: Elapsed Time: 0.544 seconds (Warm-up)
Chain 2:           0.422 seconds (Sampling)
Chain 2:           0.966 seconds (Total)
Chain 2:

```

SAMPLING FOR MODEL 'anon\_model' NOW (CHAIN 3).

```

Chain 3:
Chain 3: Gradient evaluation took 7e-06 seconds
Chain 3: 1000 transitions using 10 leapfrog steps per transition would take 0.07 seconds.
Chain 3: Adjust your expectations accordingly!
Chain 3:
Chain 3:
Chain 3: Iteration:    1 / 2000 [  0%]  (Warmup)
Chain 3: Iteration:   200 / 2000 [ 10%]  (Warmup)
Chain 3: Iteration:   400 / 2000 [ 20%]  (Warmup)
Chain 3: Iteration:   600 / 2000 [ 30%]  (Warmup)
Chain 3: Iteration:   800 / 2000 [ 40%]  (Warmup)
Chain 3: Iteration:  1000 / 2000 [ 50%]  (Warmup)
Chain 3: Iteration:  1001 / 2000 [ 50%]  (Sampling)
Chain 3: Iteration:  1200 / 2000 [ 60%]  (Sampling)
Chain 3: Iteration:  1400 / 2000 [ 70%]  (Sampling)
Chain 3: Iteration:  1600 / 2000 [ 80%]  (Sampling)
Chain 3: Iteration:  1800 / 2000 [ 90%]  (Sampling)
Chain 3: Iteration:  2000 / 2000 [100%]  (Sampling)
Chain 3:
Chain 3: Elapsed Time: 0.532 seconds (Warm-up)
Chain 3:                  0.46 seconds (Sampling)
Chain 3:                  0.992 seconds (Total)
Chain 3:

```

SAMPLING FOR MODEL 'anon\_model' NOW (CHAIN 4).

```

Chain 4:
Chain 4: Gradient evaluation took 8e-06 seconds
Chain 4: 1000 transitions using 10 leapfrog steps per transition would take 0.08 seconds.
Chain 4: Adjust your expectations accordingly!
Chain 4:
Chain 4:
Chain 4: Iteration:    1 / 2000 [  0%]  (Warmup)
Chain 4: Iteration:   200 / 2000 [ 10%]  (Warmup)
Chain 4: Iteration:   400 / 2000 [ 20%]  (Warmup)
Chain 4: Iteration:   600 / 2000 [ 30%]  (Warmup)
Chain 4: Iteration:   800 / 2000 [ 40%]  (Warmup)
Chain 4: Iteration:  1000 / 2000 [ 50%]  (Warmup)
Chain 4: Iteration:  1001 / 2000 [ 50%]  (Sampling)
Chain 4: Iteration:  1200 / 2000 [ 60%]  (Sampling)
Chain 4: Iteration:  1400 / 2000 [ 70%]  (Sampling)
Chain 4: Iteration:  1600 / 2000 [ 80%]  (Sampling)
Chain 4: Iteration:  1800 / 2000 [ 90%]  (Sampling)
Chain 4: Iteration:  2000 / 2000 [100%]  (Sampling)

```



```
Chain 4:
Chain 4: Elapsed Time: 0.534 seconds (Warm-up)
Chain 4:           0.485 seconds (Sampling)
Chain 4:           1.019 seconds (Total)
Chain 4:
```

```
res4 <- mod4 %>%
  gather_draws(mu[t]) %>%
  median_qi() %>%
  mutate(year=years[t])

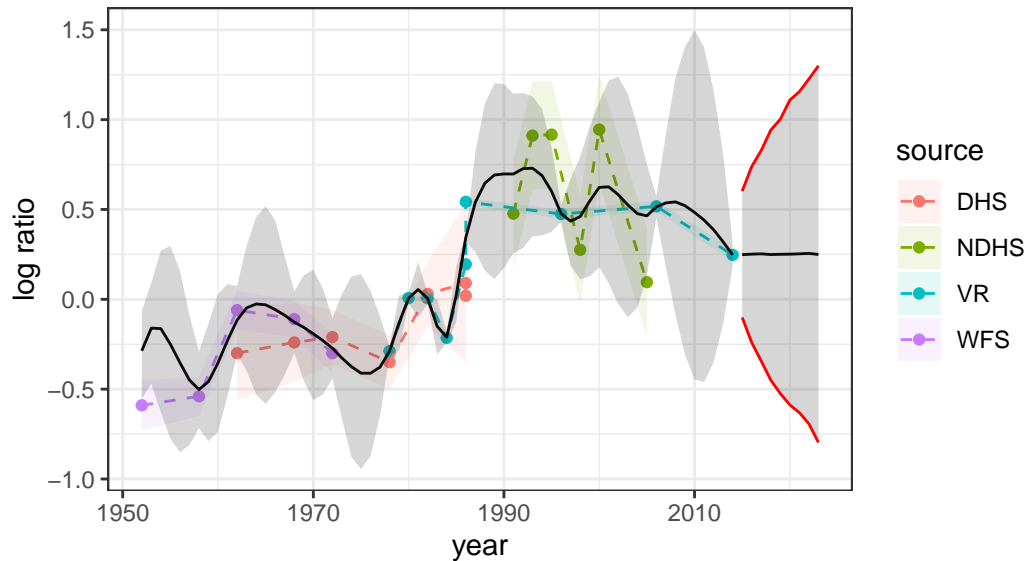
res_p4 <- mod4 %>%
  gather_draws(mu_p[p]) %>%
  median_qi() %>%
  mutate(year=years[nyears]+ p)

ggplot(lka, aes(year, logit_ratio)) +
  geom_point(aes( color = source)) +
  geom_line(aes( color = source), lty = 2) +
  geom_ribbon(aes(ymin = logit_ratio - se,
                  ymax = logit_ratio + se,
                  fill = source), alpha = 0.1) +

  theme_bw()+
  geom_line(data = res4, aes(year, .value)) +
  geom_ribbon(data = res4, aes(y = .value, ymin = .lower, ymax = .upper), alpha = 0.2)+
  geom_line(data = res_p4, aes(year, .value)) +
  geom_ribbon(data = res_p4, aes(y = .value, ymin = .lower, ymax = .upper), alpha = 0.2, c
  theme_bw()+
  labs(title = "Ratio of neonatal to other child mortality (logged), Sri Lanka",
       y = "log ratio", subtitle = "Second order shown in black, projections in red")
```

## Ratio of neonatal to other child mortality (logged), Sri Lanka

Second order shown in black, projections in red



### Question 4

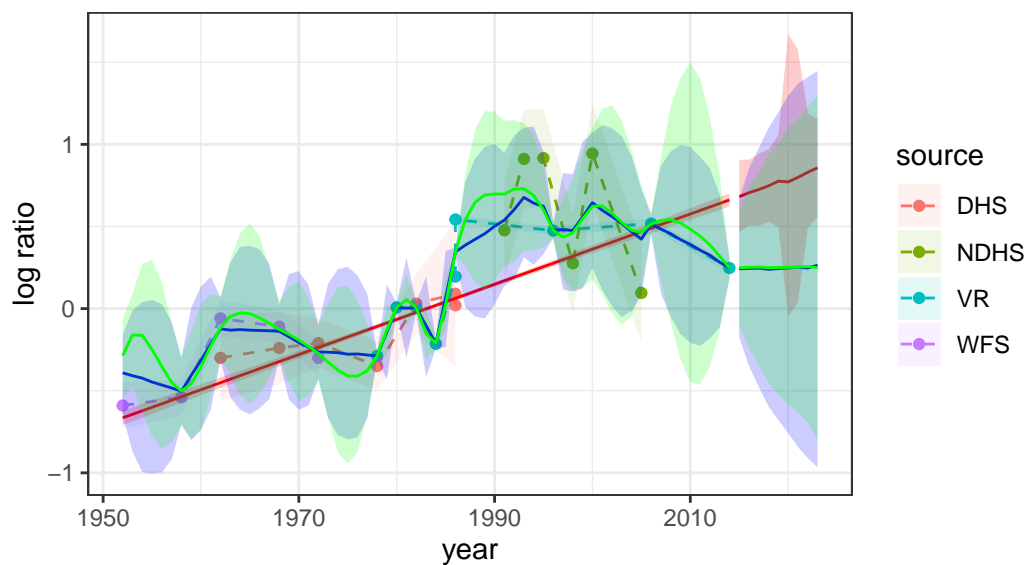
Run the first order and second order random walk models, including projections out to 2023. Compare these estimates with the linear fit by plotting everything on the same graph.

```
ggplot(lka, aes(year, logit_ratio)) +
  geom_point(aes( color = source)) +
  geom_line(aes( color = source), lty = 2) +
  geom_ribbon(aes(ymin = logit_ratio - se,
                  ymax = logit_ratio + se,
                  fill = source), alpha = 0.1) +
  geom_line(data = res2, aes(year, .value), color= "red") +
  geom_ribbon(data = res2, aes(y = .value, ymin = .lower, ymax = .upper), alpha = 0.2, fill = "red") +
  geom_line(data = res_p2, aes(year, .value), color= "red") +
  geom_ribbon(data = res_p2, aes(y = .value, ymin = .lower, ymax = .upper), alpha = 0.2, fill = "red") +

  geom_line(data = res3, aes(year, .value), color = "blue") +
  geom_ribbon(data = res3, aes(y = .value, ymin = .lower, ymax = .upper), alpha = 0.2, fill = "blue") +
  geom_line(data = res_p3, aes(year, .value), color = "blue") +
  geom_ribbon(data = res_p3, aes(y = .value, ymin = .lower, ymax = .upper), alpha = 0.2, fill = "blue")
```

```
geom_line(data = res4, aes(year, .value), color = "green") +
geom_ribbon(data = res4, aes(y = .value, ymin = .lower, ymax = .upper), alpha = 0.2, fill = "green") +
geom_line(data = res_p4, aes(year, .value), color = "green") +
geom_ribbon(data = res_p4, aes(y = .value, ymin = .lower, ymax = .upper), alpha = 0.2, fill = "green") +
theme_bw() +
labs(title = "Ratio of neonatal to other child mortality (logged), Sri Lanka",
      y = "log ratio", subtitle = "second-order RW(green), first-order RW(blue), linear fit(red) f")
```

Ratio of neonatal to other child mortality (logged), Sri Lanka  
second-order RW(green), first-order RW(blue), linear fit(red)



## Question 5

Rerun the RW2 model excluding the VR data. Briefly comment on the differences between the two data situations.

```
# exclude VR
excluded_VR <- lka %>% filter(source != 'VR')
observed_years <- excluded_VR$year
years <- min(observed_years):max(observed_years)
nyears <- length(years)
```

```

stan_data <- list(y = excluded_VR$logit_ratio, year_i = observed_years - years[1]+1,
                 T = nyears, years = years, N = length(observed_years),
                 mid_year = round(mean(years)), se = excluded_VR$se, P = 18)

mod5 <- stan(data = stan_data,
             file = here("Labs/Lab8/Lab10_3.stan"))

```

SAMPLING FOR MODEL 'anon\_model' NOW (CHAIN 1).

Chain 1:

Chain 1: Gradient evaluation took 1e-05 seconds

Chain 1: 1000 transitions using 10 leapfrog steps per transition would take 0.1 seconds.

Chain 1: Adjust your expectations accordingly!

Chain 1:

Chain 1:

Chain 1: Iteration: 1 / 2000 [ 0%] (Warmup)

Chain 1: Iteration: 200 / 2000 [ 10%] (Warmup)

Chain 1: Iteration: 400 / 2000 [ 20%] (Warmup)

Chain 1: Iteration: 600 / 2000 [ 30%] (Warmup)

Chain 1: Iteration: 800 / 2000 [ 40%] (Warmup)

Chain 1: Iteration: 1000 / 2000 [ 50%] (Warmup)

Chain 1: Iteration: 1001 / 2000 [ 50%] (Sampling)

Chain 1: Iteration: 1200 / 2000 [ 60%] (Sampling)

Chain 1: Iteration: 1400 / 2000 [ 70%] (Sampling)

Chain 1: Iteration: 1600 / 2000 [ 80%] (Sampling)

Chain 1: Iteration: 1800 / 2000 [ 90%] (Sampling)

Chain 1: Iteration: 2000 / 2000 [100%] (Sampling)

Chain 1:

Chain 1: Elapsed Time: 0.985 seconds (Warm-up)

Chain 1: 0.569 seconds (Sampling)

Chain 1: 1.554 seconds (Total)

Chain 1:

SAMPLING FOR MODEL 'anon\_model' NOW (CHAIN 2).

Chain 2:

Chain 2: Gradient evaluation took 1e-05 seconds

Chain 2: 1000 transitions using 10 leapfrog steps per transition would take 0.1 seconds.

Chain 2: Adjust your expectations accordingly!

Chain 2:

Chain 2:

Chain 2: Iteration: 1 / 2000 [ 0%] (Warmup)

Chain 2: Iteration: 200 / 2000 [ 10%] (Warmup)

Chain 2: Iteration: 400 / 2000 [ 20%] (Warmup)  
Chain 2: Iteration: 600 / 2000 [ 30%] (Warmup)  
Chain 2: Iteration: 800 / 2000 [ 40%] (Warmup)  
Chain 2: Iteration: 1000 / 2000 [ 50%] (Warmup)  
Chain 2: Iteration: 1001 / 2000 [ 50%] (Sampling)  
Chain 2: Iteration: 1200 / 2000 [ 60%] (Sampling)  
Chain 2: Iteration: 1400 / 2000 [ 70%] (Sampling)  
Chain 2: Iteration: 1600 / 2000 [ 80%] (Sampling)  
Chain 2: Iteration: 1800 / 2000 [ 90%] (Sampling)  
Chain 2: Iteration: 2000 / 2000 [100%] (Sampling)

Chain 2:

Chain 2: Elapsed Time: 1.052 seconds (Warm-up)

Chain 2: 0.839 seconds (Sampling)

Chain 2: 1.891 seconds (Total)

Chain 2:

SAMPLING FOR MODEL 'anon\_model' NOW (CHAIN 3).

Chain 3:

Chain 3: Gradient evaluation took 1e-05 seconds

Chain 3: 1000 transitions using 10 leapfrog steps per transition would take 0.1 seconds.

Chain 3: Adjust your expectations accordingly!

Chain 3:

Chain 3:

Chain 3: Iteration: 1 / 2000 [ 0%] (Warmup)  
Chain 3: Iteration: 200 / 2000 [ 10%] (Warmup)  
Chain 3: Iteration: 400 / 2000 [ 20%] (Warmup)  
Chain 3: Iteration: 600 / 2000 [ 30%] (Warmup)  
Chain 3: Iteration: 800 / 2000 [ 40%] (Warmup)  
Chain 3: Iteration: 1000 / 2000 [ 50%] (Warmup)  
Chain 3: Iteration: 1001 / 2000 [ 50%] (Sampling)  
Chain 3: Iteration: 1200 / 2000 [ 60%] (Sampling)  
Chain 3: Iteration: 1400 / 2000 [ 70%] (Sampling)  
Chain 3: Iteration: 1600 / 2000 [ 80%] (Sampling)  
Chain 3: Iteration: 1800 / 2000 [ 90%] (Sampling)  
Chain 3: Iteration: 2000 / 2000 [100%] (Sampling)

Chain 3:

Chain 3: Elapsed Time: 0.827 seconds (Warm-up)

Chain 3: 1.768 seconds (Sampling)

Chain 3: 2.595 seconds (Total)

Chain 3:

SAMPLING FOR MODEL 'anon\_model' NOW (CHAIN 4).

Chain 4:

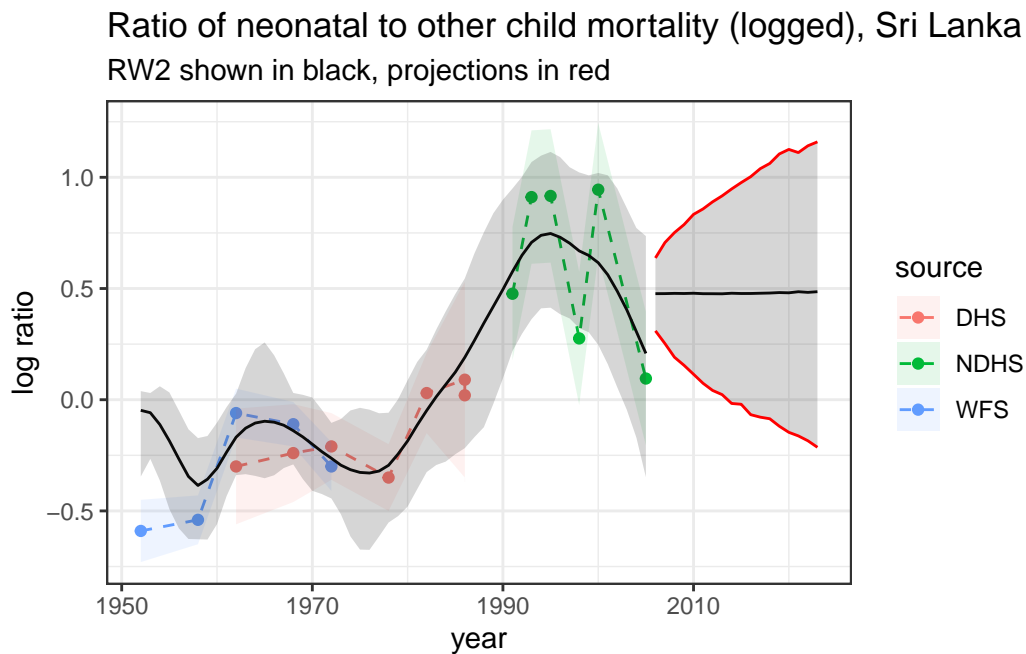
Chain 4: Gradient evaluation took 7e-06 seconds  
Chain 4: 1000 transitions using 10 leapfrog steps per transition would take 0.07 seconds.  
Chain 4: Adjust your expectations accordingly!  
Chain 4:  
Chain 4:  
Chain 4: Iteration: 1 / 2000 [ 0%] (Warmup)  
Chain 4: Iteration: 200 / 2000 [ 10%] (Warmup)  
Chain 4: Iteration: 400 / 2000 [ 20%] (Warmup)  
Chain 4: Iteration: 600 / 2000 [ 30%] (Warmup)  
Chain 4: Iteration: 800 / 2000 [ 40%] (Warmup)  
Chain 4: Iteration: 1000 / 2000 [ 50%] (Warmup)  
Chain 4: Iteration: 1001 / 2000 [ 50%] (Sampling)  
Chain 4: Iteration: 1200 / 2000 [ 60%] (Sampling)  
Chain 4: Iteration: 1400 / 2000 [ 70%] (Sampling)  
Chain 4: Iteration: 1600 / 2000 [ 80%] (Sampling)  
Chain 4: Iteration: 1800 / 2000 [ 90%] (Sampling)  
Chain 4: Iteration: 2000 / 2000 [100%] (Sampling)  
Chain 4:  
Chain 4: Elapsed Time: 0.716 seconds (Warm-up)  
Chain 4: 0.681 seconds (Sampling)  
Chain 4: 1.397 seconds (Total)  
Chain 4:

```
res5 <- mod5 %>%
  gather_draws(mu[t]) %>%
  median_qi() %>%
  mutate(year=years[t])

res_p5 <- mod5 %>%
  gather_draws(mu_p[p]) %>%
  median_qi() %>%
  mutate(year=years[nyears]+ p)

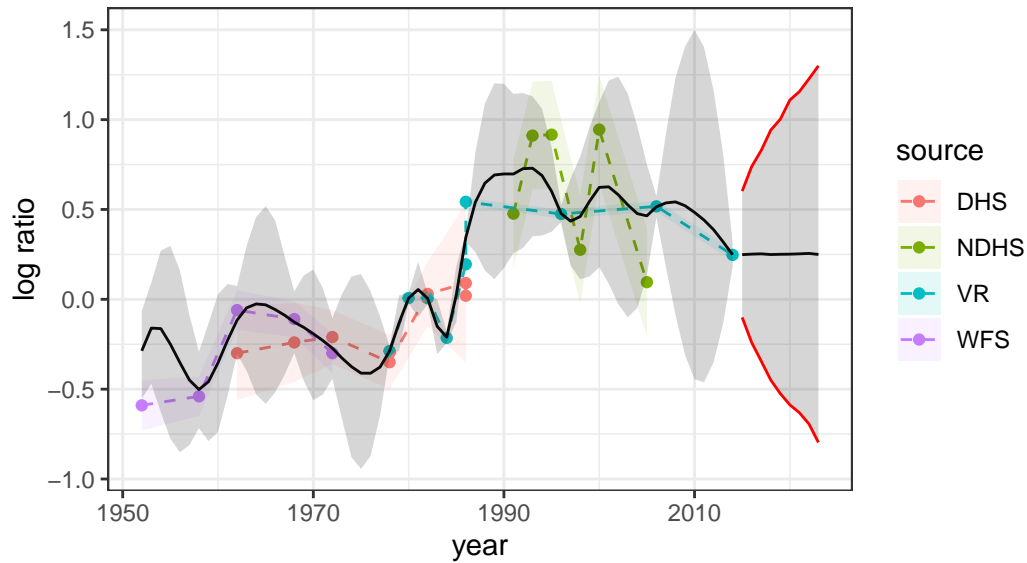
ggplot(excluded_VR, aes(year, logit_ratio)) +
  geom_point(aes( color = source)) +
  geom_line(aes( color = source), lty = 2) +
  geom_ribbon(aes(ymin = logit_ratio - se,
                  ymax = logit_ratio + se,
                  fill = source), alpha = 0.1) +
  theme_bw()+
  geom_line(data = res5, aes(year, .value)) +
```

```
geom_ribbon(data = res5, aes(y = .value, ymin = .lower, ymax = .upper), alpha = 0.2)+
geom_line(data = res_p5, aes(year, .value)) +
geom_ribbon(data = res_p5, aes(y = .value, ymin = .lower, ymax = .upper), alpha = 0.2, c
theme_bw()+
labs(title = "Ratio of neonatal to other child mortality (logged), Sri Lanka",
      y = "log ratio", subtitle = "RW2 shown in black, projections in red")
```



```
ggplot(lka, aes(year, logit_ratio)) +
  geom_point(aes( color = source)) +
  geom_line(aes( color = source), lty = 2) +
  geom_ribbon(aes(ymin = logit_ratio - se,
                 ymax = logit_ratio + se,
                 fill = source), alpha = 0.1) +
  theme_bw()+
  geom_line(data = res4, aes(year, .value)) +
  geom_ribbon(data = res4, aes(y = .value, ymin = .lower, ymax = .upper), alpha = 0.2)+
  geom_line(data = res_p4, aes(year, .value)) +
  geom_ribbon(data = res_p4, aes(y = .value, ymin = .lower, ymax = .upper), alpha = 0.2, c
  theme_bw()+
  labs(title = "Ratio of neonatal to other child mortality (logged), Sri Lanka",
        y = "log ratio", subtitle = "RW2 shown in black, projections in red")
```

Ratio of neonatal to other child mortality (logged), Sri Lanka  
RW2 shown in black, projections in red



Without data source VR, we don't have observations in year 2016. This means the prediction is not so good compared to when we have source VR available to us.

## Question 6

Briefly comment on which model you think is most appropriate, or an alternative model that would be more appropriate in this context.

Looking at the plot in Q4, second-order random walk may be the best model. Since it utilized more information, has similar prediction as first-order random walk model, but with lower standard error.