

Supplementary Code 5: Code to Respond to Reviewers

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Introduction

The aim of this document is to respond to the reviewers comments. The comments are:

- 1) I would like to see whether indeed mothers are statistically more likely to stop having children after a twin birth (perhaps I missed that analysis and it was indeed presented)?
- 2) Directly test the odds that a mother terminate reproduction after a twin birth? In other words, use statistics to assess post-twinning reproductive outcomes compared to post-singleton reproductive outcomes.
- 3) Plot the real data as a cloud of points behind these lines- it is important to see the actual dataset in analyses like these.
- 4) Look at the analyses when limiting to opposite-sex offspring?
- 5) Based on analyses of Finnish data from 1953-1964 Eriksson and Fellman show that illegitimate maternities have a higher twinning rate than legitimate ones when maternal age and birth order are taken into account. They speculate that unmarried mothers are women who tend to become pregnant more easily than others owing to the effect of certain factors, e.g. a higher ovulation rate and to have relatively better physical qualifications for going through a twin pregnancy than mothers in general. It seems not unlikely that such mothers may remain single of the twin pregnancy, especially in earlier times?

```
#cleanup memory  
gcstuff <- gc(verbose=FALSE); rm(gcstuff);
```

```
#get last birth adding function  
source("../R/last_birth.R")
```

```
#simplified twinR summary tables  
source("../R/twinR_summary.R")
```

```
#fix twinR compute predictions to do prediction with no lambda as well  
source("../R/twinR_predictions.R")
```

```
#simple convenience functions  
source("../R/utils.R")
```

```
## Identify number of CPU cores available for parallel computing,  
## note: using a large number may lead RAM to max out, so you may have to adjust  
## that according to your infrastructure:
```

```
nb_cores <- min(c(50L, parallel::detectCores() - 1))
```

```
## Set option in spaMM:  
spaMM::spaMM.options(nb_cores = nb_cores)
```

```
## Registered S3 methods overwritten by 'registry':  
##   method          from  
##   print.registry_field proxy  
##   print.registry_entry proxy
```

Data Import

The Estonian dataset has been formatted to include the same columns as *the data_births_all* dataset from the **twinR** package. The only difference is that the columns *pop* and *monthly* are excluded as these are constant.

```
#some labels  
estLab <- "Estonian"  
westLab <- "9 other European"
```

```
#Import and preprocess Estonian Data
```

```
data_births_monthly_EE <- readRDS("./data/data_births_all_EE.rds")
```

```
#the twinR package expects population to be present  
data_births_monthly_EE$pop <- "Estonia"
```

```
## Expand the birth level data for the fit of statistical models:  
data_births_monthly_EE <- twinR::expand_data(data_births_monthly_EE)
```

```
data_births_monthly_EE <- add_last_birth(data_births_monthly_EE)
```

```
data_births_monthly_EE_not_last <- data_births_monthly_EE[!data_births_monthly_EE$last,]
```

```
#make the aggregates  
dmm_EE <- twinR::aggregate_data(data_births_monthly_EE)  
dmm_EE$prob_twin <- dmm_EE$twin_total / dmm_EE$births_total  
  
dmm_EE_nl <- twinR::aggregate_data(data_births_monthly_EE_not_last)  
dmm_EE_nl$prob_twin <- dmm_EE_nl$twin_total / dmm_EE_nl$births_total
```

```
##Import and pre-process twinR package data
```

```
## Filter the raw data to only keep data with monthly resolution:  
data_births_monthly <- twinR::filter_data(twinR::data_births_all)
```

```
## Expand the birth level data for the fit of statistical models:  
data_births_monthly <- twinR::expand_data(data_births_monthly)
```

```
data_births_monthly <- add_last_birth(data_births_monthly)  
data_births_monthly_not_last <- data_births_monthly[!data_births_monthly$last,]
```

```

dmm_orig <- twinR::aggregate_data(data_births_monthly)
dmm_orig$prob_twin <- dmm_orig$twin_total /dmm_orig$births_total

dmm_orig_nl <- twinR::aggregate_data(data_births_monthly_not_last)
dmm_orig_nl$prob_twin <- dmm_orig_nl$twin_total /dmm_orig_nl$births_total

#compared to twinR original add data on :
#-age at first birth (AFB)
#-quantiles range mother birth year
#-quantiles range offspring birth year
#-mean + SE total births
all_tbls <- rbind(build_data_summary.table(data_births_monthly),
                  build_data_summary.table(data_births_monthly_not_last),
                  build_data_summary.table(data_births_monthly_EE),
                  build_data_summary.table(data_births_monthly_EE_not_last))

```

Comment 1: Logistic regression

We can test the hypothesis that mothers are statistically more likely to stop having children after a twin birth by fitting a logistic regression model with the response variable being the binary variable *last* and the predictor variable being the binary variable *twin*.

```

#fit logistic regression Estonia
logit_fit_EE <- glm(last ~ twin,
                   data = data_births_monthly_EE,
                   family = binomial(link = "logit"))
summary_logit_fit_EE <- summary(logit_fit_EE)
summary_logit_fit_EE

##
## Call:
## glm(formula = last ~ twin, family = binomial(link = "logit"),
##      data = data_births_monthly_EE)
##
## Coefficients:
##              Estimate Std. Error  z value Pr(>|z|)
## (Intercept) -0.84910352  0.00340496 -249.3723 < 2.22e-16 ***
## twinTRUE     0.35559579  0.02600496  13.6741 < 2.22e-16 ***
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
## (Dispersion parameter for binomial family taken to be 1)
##
##      Null deviance: 510562.5  on 417417  degrees of freedom
## Residual deviance: 510381.5  on 417416  degrees of freedom
## AIC: 510385.5
##
## Number of Fisher Scoring iterations: 4

```

```

#fit logistic regression Other European
logit_fit <- glm(last ~ twin,
                 data = data_births_monthly,
                 family = binomial(link = "logit"))
summary_logit_fit_W <- summary(logit_fit)
summary_logit_fit_W

##
## Call:
## glm(formula = last ~ twin, family = binomial(link = "logit"),
##      data = data_births_monthly)
##
## Coefficients:
##              Estimate Std. Error   z value Pr(>|z|)
## (Intercept) -1.38754400  0.00775251 -178.98007 < 2.22e-16 ***
## twinTRUE      0.45172685  0.05349239   8.44469 < 2.22e-16 ***
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
## (Dispersion parameter for binomial family taken to be 1)
##
##      Null deviance: 106259.4  on 105832  degrees of freedom
## Residual deviance: 106192.8  on 105831  degrees of freedom
## AIC: 106196.8
##
## Number of Fisher Scoring iterations: 4

```

Comment 2: Proportion of twins

The same test gives us the odds of mothers having more children after a twin birth.

```

# Extract coefficients
coef <- coef(logit_fit_EE)

# Calculate odds ratios
odds_ratios <- exp(coef)

```

For the Estonian dataset the odds of a birth event being the last one for a mother are 1.427 times higher for a twin birth than for a singleton birth.

```

# Extract coefficients
coef <- coef(logit_fit)

# Calculate odds ratios
odds_ratios <- exp(coef)

```

For the other dataset the odds of a birth event being the last one for a mother are 1.571 times higher for a twin birth than for a singleton birth.

```

#compare the precentage of twin births between last births and not last births
cat("Estonian dataset:\n")

```

```
## Estonian dataset:
```

```
tble <- table(data_births_monthly_EE[c("twin", "last")])
tble
```

```
##           last
## twin    FALSE  TRUE
##  FALSE 287874 123152
##   TRUE   3969   2423
```

```
cat("\n")
```

```
#now calculate the % by hand
```

```
cat("Last twins: ", round(100 * tble[2,2] / sum(tble[,2]), 2), "%\n")
```

```
## Last twins:  1.93 %
```

```
cat("Prior twins: ", round(100 * tble[2,1] / sum(tble[,1]), 2), "%\n")
```

```
## Prior twins:  1.36 %
```

```
#compare the percentage of twin births between last births and not last births
```

```
cat("Western dataset:\n")
```

```
## Western dataset:
```

```
tblw <- table(data_births_monthly[c("twin", "last")])
tblw
```

```
##           last
## twin    FALSE  TRUE
##  FALSE 83276 20793
##   TRUE  1267   497
```

```
cat("\n")
```

```
#now calculate the % by hand
```

```
cat("Last twins: ", round(100 * tblw[2,2] / sum(tblw[,2]), 2), "%\n")
```

```
## Last twins:  2.33 %
```

```
cat("Prior twins: ", round(100 * tblw[2,1] / sum(tblw[,1]), 2), "%\n")
```

```
## Prior twins:  1.5 %
```

Test the Population Interaction We check if the population has an effect in a reversed model where the predictor variable is the binary variable *last* and the response variable is the binary variable *twin*.

```

#fit logistic regression Estonia
logit_fit_EE <- glm(twin ~ last,
                   data = data_births_monthly_EE,
                   family = binomial(link = "logit"))
summary_logit_fit_EE <- summary(logit_fit_EE)
summary_logit_fit_EE

##
## Call:
## glm(formula = twin ~ last, family = binomial(link = "logit"),
##      data = data_births_monthly_EE)
##
## Coefficients:
##              Estimate Std. Error   z value    Pr(>|z|)
## (Intercept) -4.2840087   0.0159821 -268.0512 < 2.22e-16 ***
## lastTRUE     0.3555958   0.0260050   13.6741 < 2.22e-16 ***
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
## (Dispersion parameter for binomial family taken to be 1)
##
##      Null deviance: 66110.47  on 417417  degrees of freedom
## Residual deviance: 65929.38  on 417416  degrees of freedom
## AIC: 65933.38
##
## Number of Fisher Scoring iterations: 7

```

```

#fit logistic regression Other European
logit_fit <- glm(twin ~ last,
                 data = data_births_monthly,
                 family = binomial(link = "logit"))
summary_logit_fit_W <- summary(logit_fit)
summary_logit_fit_W

##
## Call:
## glm(formula = twin ~ last, family = binomial(link = "logit"),
##      data = data_births_monthly)
##
## Coefficients:
##              Estimate Std. Error   z value    Pr(>|z|)
## (Intercept) -4.1855085   0.0283068 -147.86238 < 2.22e-16 ***
## lastTRUE     0.4517268   0.0534924   8.44469 < 2.22e-16 ***
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
## (Dispersion parameter for binomial family taken to be 1)
##
##      Null deviance: 17943.05  on 105832  degrees of freedom
## Residual deviance: 17876.42  on 105831  degrees of freedom
## AIC: 17880.42
##
## Number of Fisher Scoring iterations: 7

```

```
data_births_monthly$monthly <- NULL
#data_births_monthly$pop <- "Western"
dbmFull <- rbind(data_births_monthly_EE[colnames(data_births_monthly)],
                 data_births_monthly)
dbmFull$popEE <- dbmFull$pop == "Estonia"
```

```
#fit logistic regression
logit_fit_full <- glm(twin ~ last + popEE + popEE:last,
                     data = dbmFull,
                     family = binomial(link = "logit"))
summary_logit_fit_full <- summary(logit_fit_full)
summary_logit_fit_full
```

```
##
## Call:
## glm(formula = twin ~ last + popEE + popEE:last, family = binomial(link = "logit"),
##      data = dbmFull)
##
## Coefficients:
##              Estimate Std. Error   z value Pr(>|z|)
## (Intercept)   -4.1855085  0.0283068 -147.86238 < 2.22e-16 ***
## lastTRUE       0.4517268  0.0534924   8.44469 < 2.22e-16 ***
## popEETRUE     -0.0985002  0.0325069  -3.03013  0.0024445 **
## lastTRUE:popEETRUE -0.0961311  0.0594785  -1.61623  0.1060444
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
## (Dispersion parameter for binomial family taken to be 1)
##
## Null deviance: 84063.45 on 523250 degrees of freedom
## Residual deviance: 83805.81 on 523247 degrees of freedom
## AIC: 83813.81
##
## Number of Fisher Scoring iterations: 7
```

```
#' Get Coefficient Table
#
#' This function returns a table with odds ratios and their confidence intervals.
#
#' @param summary A summary object from a glm model.
#' @param datasetname A character string specifying the name of the dataset.
#
#' @return A data frame with odds ratios and their confidence intervals.
get_coef_tbl <- function(summary, datasetname){
  tbl <- as.data.frame(summary$coefficients)
  tbl$dataset <- datasetname
  tbl$variable <- rownames(tbl)
  tbl$`Odds Ratio` <- exp(tbl$Estimate)
  tbl$`CI low` <- exp(tbl$Estimate - 1.96 * tbl$`Std. Error`)
  tbl$`CI high` <- exp(tbl$Estimate + 1.96 * tbl$`Std. Error`)
  rownames(tbl) <- NULL
  tbl <- tbl[,c(5,6,7:9)]
  return(tbl)
```

```

}

#print all coeficient tables in one table
#add dataset name to each table
coefEEtbl <- get_coef_tbl(summary_logit_fit_EE, "Estonia")
ceofWtbl <- get_coef_tbl(summary_logit_fit_W, "Western")
ceofFulltbl <- get_coef_tbl(summary_logit_fit_full, "Combined")

tbl <- rbind(coefEEtbl, ceofWtbl, ceofFulltbl)
knitr::kable(tbl, digits = 3, caption = "Odds ratios and confidence intervals for the logistic regression")

```

Table 1: Odds ratios and confidence intervals for the logistic regression model with the response variable being the binary variable *twin* and the predictor variable being the binary variable *last*.

| dataset | variable | Odds Ratio | CI low | CI high |
|----------|--------------------|------------|--------|---------|
| Estonia | (Intercept) | 0.014 | 0.013 | 0.014 |
| Estonia | lastTRUE | 1.427 | 1.356 | 1.502 |
| Western | (Intercept) | 0.015 | 0.014 | 0.016 |
| Western | lastTRUE | 1.571 | 1.415 | 1.745 |
| Combined | (Intercept) | 0.015 | 0.014 | 0.016 |
| Combined | lastTRUE | 1.571 | 1.415 | 1.745 |
| Combined | popEETRUE | 0.906 | 0.850 | 0.966 |
| Combined | lastTRUE:popEETRUE | 0.908 | 0.808 | 1.021 |

```

#print the frequency table
frqTbl <- aggregate(maternal_id ~ twin + last + popEE,
                     data = dbmFull, FUN = length)

# Rename the variables inside the columns
frqTbl$twin <- ifelse(frqTbl$twin == TRUE, "twins", "singleton")
frqTbl$last <- ifelse(frqTbl$last == TRUE, "Yes", "No")
frqTbl$popEE <- ifelse(frqTbl$popEE == TRUE, "Estonia", "Western")

# Rename the column names
colnames(frqTbl) <- c("Birth", "Last Breeding", "Population", "Count")
knitr::kable(frqTbl, digits = 0, caption = "Frequency table of the data used for the logistic regression")

```

Table 2: Frequency table of the data used for the logistic regression model with the response variable being the binary variable *twin* and the predictor variable being the binary variable *last*.

| Birth | Last Breeding | Population | Count |
|-----------|---------------|------------|-------|
| singleton | No | Western | 83276 |
| twins | No | Western | 1267 |
| singleton | Yes | Western | 20793 |

| Birth | Last Breeding | Population | Count |
|-----------|---------------|------------|--------|
| twins | Yes | Western | 497 |
| singleton | No | Estonia | 287874 |
| twins | No | Estonia | 3969 |
| singleton | Yes | Estonia | 123152 |
| twins | Yes | Estonia | 2423 |

Comment 3: Original Data on Plots

The reviewers also asked to put the data on the Figure 1.

```
# import the function to do model fit and predictions
source("./R/fit_models.R")
```

```
## full data
```

```
## Estonia - mother level data
```

```
formula <- "cbind(twin_total, singleton_total) ~ 1 + births_total"
dmm_EE_fit <- fitPredictions(dmm_EE, formula, predict = T)
```

```
## Warning in fitPredictions(dmm_EE, formula, predict = T): Pre-computed fit returned from file:
## ./data/predictions/cbind(twin_total,singleton_total)~1+births_totaldmm_EE_fit.rds
## If you want to re-run this step delete the file or change the saveDir!
```

```
## Warning in get_predictions(predDataFname, fit, dataset, args, save): Pre-computed predictions returned from file:
## ./data/predictions/cbind(twin_total,singleton_total)~1+births_totaldmm_EEdata_fig.rds
## If you want to re-run this step delete the file or change the saveDir!
```

```
## TwinR - mother level data
```

```
formula <- "cbind(twin_total, singleton_total) ~ 1 + births_total + (1|pop)"
dmm_orig_fit <- fitPredictions(dmm_orig, formula, predict=T)
```

```
## Warning in fitPredictions(dmm_orig, formula, predict = T): Pre-computed fit returned from file:
## ./data/predictions/cbind(twin_total,singleton_total)~1+births_total+(1_x_pop)dmm_orig_fit.rds
## If you want to re-run this step delete the file or change the saveDir!
```

```
## Warning in get_predictions(predDataFname, fit, dataset, args, save): Pre-computed predictions returned from file:
## ./data/predictions/cbind(twin_total,singleton_total)~1+births_total+(1_x_pop)dmm_origdata_fig.rds
## If you want to re-run this step delete the file or change the saveDir!
```

```
library(ggplot2)
#some nice colors
bc <- c("azure4","purple4", "black", "navy", "darkgoldenrod2", "springgreen3", "gray")

#use new base theme that displays also grid lines
source("./R/twinR_theme.R")
```

Fig 1a: Estonian vs TwinR Full Data

```
fig2_EE_plot_data <- dmm_EE_fit$results
fig2_orig_plot_data <- dmm_orig_fit$results
```

```
infoTxt <- "model prediction with 95% CI and data with values"
```

```
fig2_ext_orig <- ggplot() +
  geom_line(data=fig2_EE_plot_data,
    aes(y = estimate, x=births_total, color=estLab), size = 1) +
  geom_point(data=dmm_EE[dmm_EE$births_total <17, ],
    aes(x=births_total, y=prob_twin, color=estLab, fill = estLab),
    alpha=0.1,
    position = position_nudge(x = -0.1)) +
  stat_summary(data=dmm_EE[dmm_EE$births_total <17, ],
    aes(x=births_total, y=prob_twin, color=estLab, fill = estLab),
    alpha=0.1,
    position = position_jitter(),
    fun.data=mean_se) +

  geom_ribbon(data=fig2_EE_plot_data,
    aes(y = estimate, x=births_total, ymin = lwr, ymax = upr,
      color=estLab, fill = estLab),
    alpha = 0.3) +
  geom_line(data=fig2_orig_plot_data,
    aes(y = estimate, x=births_total, color=westLab), size = 1) +
  geom_point(data=dmm_orig[dmm_orig$births_total <19, ],
    aes(x=births_total, y=prob_twin, color=estLab, fill = estLab),
    alpha=0.1,
    position = position_jitter()) +
  stat_summary(data=dmm_orig[dmm_orig$births_total <19, ],
    aes(x=births_total, y=prob_twin,
      color=westLab, fill=westLab),
    alpha=1,
    shape = 1,
    position = position_nudge(x = 0.1),
    fun.data=mean_se) +
  geom_ribbon(data=fig2_orig_plot_data,
    aes(y = estimate, x=births_total, ymin = lwr, ymax = upr,
      fill=westLab),
    alpha = 0.1) +
  ggplot2::scale_x_continuous(breaks = 1:18) +

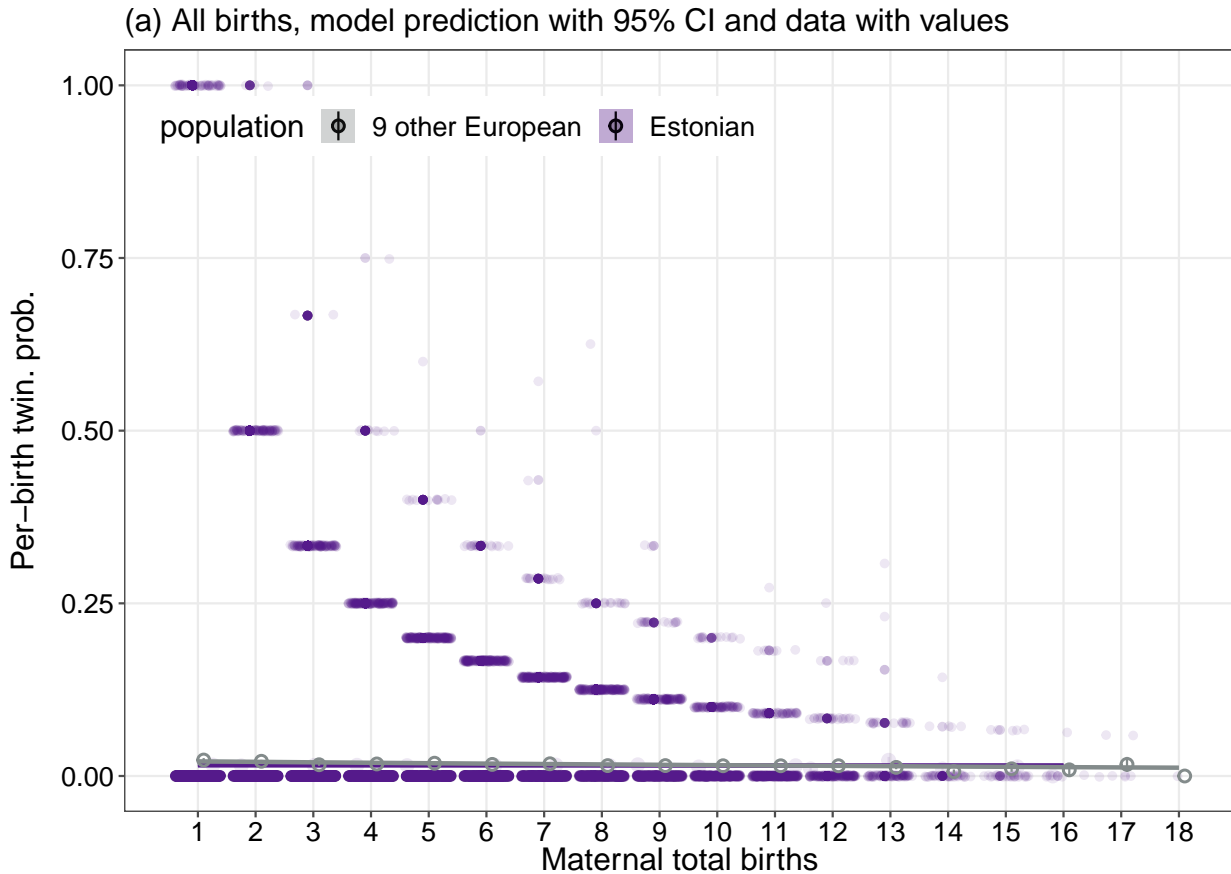
  ggplot2::coord_cartesian() +
  labs(subtitle = paste0("(a) All births, ", infoTxt),
    y="Per-birth twin. prob.",
    x="Maternal total births")
```

```
## Warning: Using 'size' aesthetic for lines was deprecated in ggplot2 3.4.0.
## i Please use 'linewidth' instead.
## This warning is displayed once every 8 hours.
## Call 'lifecycle::last_lifecycle_warnings()' to see where this warning was
## generated.
```

```
p2 <- fig2_ext_orig + base_theme(larger=8) + scale_color_manual(values=bc) +
  scale_fill_manual(values=bc) + guides(color="none") + labs(fill = "population")
```

p2

```
## Warning: Removed 1 rows containing missing values ('geom_segment()').
```



The plot illustrates that we cannot plot the raw data along with model predictions, as such figure would be un-informative and highly confusing. We cannot think of a way about how to put such an amount of semi-categorical data into a plot so that it would give additional information.

Comment 4: Opposite-sex Twins

We can do the same analysis for opposite-sex twins.

```
#re-import the data
dbm_EE <- readRDS("../data/data_births_all_EE.rds")
```

```
#take out mothers that had twins of single sex
single_sex_twin_mothers <- as.character(unlist(unique(
  dbm_EE[dbm_EE$twins & dbm_EE$cf_sex != "mixed", "maternal_id"]
)))
```

```
dbmEE_wo_single_sex_twins <- dbm_EE[!(dbm_EE$maternal_id %in%
                                     single_sex_twin_mothers),]

#the twinR package expects population to be present
dbmEE_wo_single_sex_twins$pop <- "Estonia"

## Expand the birth level data for the fit of statistical models:
dbmEE_wo_single_sex_twins <- twinR::expand_data(dbmEE_wo_single_sex_twins)

dbmEE_wo_single_sex_twins <- add_last_birth(dbmEE_wo_single_sex_twins)

dbmEE_wo_single_sex_twins_not_last <- dbmEE_wo_single_sex_twins[!dbmEE_wo_single_sex_twins$last,]

#make the aggregates
dmm_EE_mixed <- twinR::aggregate_data(dbmEE_wo_single_sex_twins)
dmm_EE_mixed$prob_twin <- dmm_EE_mixed$twin_total / dmm_EE_mixed$births_total

dmm_EE_mixed_nl <- twinR::aggregate_data(dbmEE_wo_single_sex_twins_not_last)
dmm_EE_mixed_nl$prob_twin <- dmm_EE_mixed_nl$twin_total / dmm_EE_mixed_nl$births_total
```

Full Data

```
options(scipen = 99)
```

```
## Estonia
formula <- "cbind(twin_total, singleton_total) ~ 1 + births_total"
dmm_EE_mixed_fit <- fitPredictions(dmm_EE_mixed, formula)
```

```
## Warning in fitPredictions(dmm_EE_mixed, formula): Pre-computed fit returned from file:
## ./data/predictions/cbind(twin_total, singleton_total)~1+births_totaldmm_EE_mixed_fit.rds
## If you want to re-run this step delete the file or change the saveDir!
```

```
## Warning in get_predictions(predDataFname, fit, dataset, args, save): Pre-computed predictions returned
## ./data/predictions/cbind(twin_total, singleton_total)~1+births_totaldmm_EE_mixeddata_fig.rds
## If you want to re-run this step delete the file or change the saveDir!
```

```
knitr::kable(build_fit_summary.table(dmm_EE_mixed_fit$fit))
```

```
## Warning: Use of .data in tidyselect expressions was deprecated in tidyselect 1.2.0.
## i Please use "Estimate" instead of '.data$Estimate'
## This warning is displayed once every 8 hours.
## Call 'lifecycle::last_lifecycle_warnings()' to see where this warning was
## generated.
```

```
## Warning: Use of .data in tidyselect expressions was deprecated in tidyselect 1.2.0.
## i Please use "object" instead of '.data$object'
## This warning is displayed once every 8 hours.
## Call 'lifecycle::last_lifecycle_warnings()' to see where this warning was
## generated.
```

```
## Warning: Use of .data in tidyselect expressions was deprecated in tidyselect 1.2.0.
## i Please use "name" instead of '.data$name'
## This warning is displayed once every 8 hours.
## Call 'lifecycle::last_lifecycle_warnings()' to see where this warning was
## generated.
```

```
## Warning: Use of .data in tidyselect expressions was deprecated in tidyselect 1.2.0.
## i Please use "value" instead of '.data$value'
## This warning is displayed once every 8 hours.
## Call 'lifecycle::last_lifecycle_warnings()' to see where this warning was
## generated.
```

| Type | Variable | Value | Cond. SE | t-value |
|-----------------|-----------------------------------|---------|----------|---------|
| fixed effects | (Intercept) | -5.07 | 0.044 | -115 |
| | births_total | -0.0146 | 0.00843 | -1.73 |
| response family | binomial with logit link | | | |
| fit info | number of model parameters | 2 | | |
| | marginal log Likelihood | -11192 | | |
| | marginal AIC | 22388 | | |
| | conditional AIC (cAIC) | | | |
| data info | number of fitted observations (N) | 121779 | | |

No Last Births Data

```
## Estonia
formula <- "cbind(twin_total, singleton_total) ~ 1 + births_total"
dmm_EE_mixed_nl_fit <- fitPredictions(dmm_EE_mixed_nl, formula)
```

```
## Warning in fitPredictions(dmm_EE_mixed_nl, formula): Pre-computed fit returned from file:
## ./data/predictions/cbind(twin_total,singleton_total)~1+births_totaldmm_EE_mixed_nl_fit.rds
## If you want to re-run this step delete the file or change the saveDir!
```

```
## Warning in get_predictions(predDataFname, fit, dataset, args, save): Pre-computed predictions returned
## ./data/predictions/cbind(twin_total,singleton_total)~1+births_totaldmm_EE_mixed_nldata_fig.rds
## If you want to re-run this step delete the file or change the saveDir!
```

```
knitr::kable(build_fit_summary.table(dmm_EE_mixed_nl_fit$fit))
```

| Type | Variable | Value | Cond. SE | t-value |
|-----------------|-----------------------------------|----------|----------|---------|
| fixed effects | (Intercept) | -5.27 | 0.0549 | -96 |
| | births_total | -0.00123 | 0.0112 | -0.11 |
| response family | binomial with logit link | | | |
| fit info | number of model parameters | 2 | | |
| | marginal log Likelihood | -7104 | | |
| | marginal AIC | 14212 | | |
| | conditional AIC (cAIC) | | | |
| data info | number of fitted observations (N) | 94662 | | |

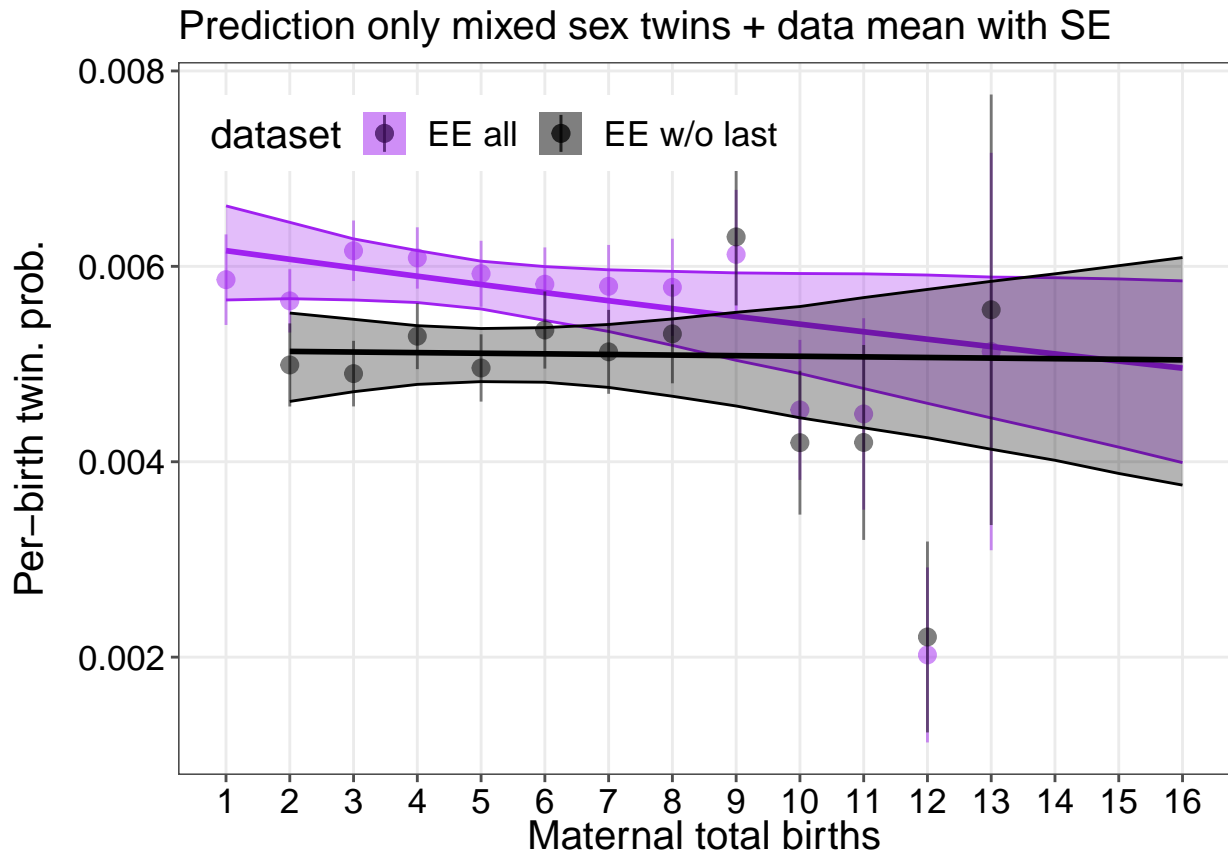
Plot the Predictions

```
fig2_EE_plot_data <- dmm_EE_mixed_fit$results
fig2_EE_plot_data_nl <- dmm_EE_mixed_nl_fit$results
fig2_EE_plot_data_nl$births_total <- fig2_EE_plot_data_nl$births_total + 1
```

```
dmm_EE_mixed_nl_plot <- dmm_EE_mixed_nl
dmm_EE_mixed_nl_plot$births_total <- dmm_EE_mixed_nl_plot$births_total + 1
```

```
#colors
bc <- c("purple", "black")
fig2_ext_orig <- ggplot() +
  geom_line(data=fig2_EE_plot_data,
            aes(y = estimate, x=births_total, color="EE all"),
            linewidth = 1) +
  stat_summary(data=dmm_EE_mixed[dmm_EE_mixed$births_total <14, ],
              aes(x=births_total, y=prob_twin, color="EE all",
                  fill = "EE all"), alpha=0.5,
              fun.data=mean_se) +
  geom_ribbon(data=fig2_EE_plot_data,
             aes(y = estimate, x=births_total,
                 ymin = lwr, ymax = upr, color="EE all", fill = "EE all"),
             alpha = 0.3) +
  geom_line(data=fig2_EE_plot_data_nl,
            aes(y = estimate, x=births_total, color="EE w/o last"),
            linewidth = 1) +
  stat_summary(data=dmm_EE_mixed_nl_plot[dmm_EE_mixed_nl_plot$births_total <14,],
              aes(x=births_total, y=prob_twin, color="EE w/o last",
                  fill = "EE w/o last"), alpha=0.5,
              fun.data=mean_se) +
  geom_ribbon(data=fig2_EE_plot_data_nl,
             aes(y = estimate, x=births_total, ymin = lwr,
                 ymax = upr, color="EE w/o last", fill = "EE w/o last"),
             alpha = 0.3) +
  ggplot2::scale_x_continuous(breaks = 1:18) +
  ggplot2::scale_y_continuous(breaks = seq(0,0.03, by=0.002)) +
  ggplot2::coord_cartesian() +
  labs(subtitle = "Prediction only mixed sex twins + data mean with SE",
       y="Per-birth twin. prob.",
       x="Maternal total births")
p2 <- fig2_ext_orig + base_theme(larger=8) + scale_color_manual(values=bc) +
  scale_fill_manual(values=bc) + guides(color="none") + labs(fill = "dataset")

p2
```



The mixed sex twinning rate is independent on the number of total births if last births are excluded from the data. If last births are included, the association between mixed sex twinning rate and number of total births is negative.

Comment 5: Illegitimate Maternities

We can add a predictor to the model describing if the women had first birth or first conception before being married. We will do both to investigate if illegitimate maternities affect twinning rate.

```
#add the illegitimate children columns
illegitimate_birth <- unique(data_births_monthly_EE[c( "illegitimate_birth",
                                                       "maternal_id")])
illegitimate_birth <- setNames(illegitimate_birth$illegitimate_birth,
                               illegitimate_birth$maternal_id)

illegitimate_conception <- unique(data_births_monthly_EE[c( "illegitimate_conception", "maternal_id")])
illegitimate_conception <- setNames(illegitimate_conception$illegitimate_conception, illegitimate_conception$maternal_id)

dmm_EE$illegitimate_conception <- illegitimate_conception[dmm_EE$maternal_id]
dmm_EE$illegitimate_birth <- illegitimate_birth[dmm_EE$maternal_id]

dmm_EE_n1$illegitimate_conception <- illegitimate_conception[dmm_EE_n1$maternal_id]
dmm_EE_n1$illegitimate_birth <- illegitimate_birth[dmm_EE_n1$maternal_id]
```

```
cat("First birth before marriage:\n")
```

```
## First birth before marriage:
```

```
table(dmm_EE$illigimate_birth)
```

```
##
## FALSE TRUE
## 108483 17092
```

```
cat("First conception before marriage:\n")
```

```
## First conception before marriage:
```

```
table(dmm_EE$illigimate_conception)
```

```
##
## FALSE TRUE
## 89896 35679
```

With All Data

```
## Estonia
formula <- "cbind(twin_total, singleton_total) ~ 1 + births_total + illigimate_birth"
dmm_EE_fit_birth <- fitPredictions(dmm_EE, formula)
```

```
## Warning in fitPredictions(dmm_EE, formula): Pre-computed fit returned from file:
## ./data/predictions/cbind(twin_total,singleton_total)~1+births_total+illigimate_birthdmm_EE_fit.rds
## If you want to re-run this step delete the file or change the saveDir!
```

```
## Warning in get_predictions(predDataFname, fit, dataset, args, save): Pre-computed predictions returned
## ./data/predictions/cbind(twin_total,singleton_total)~1+births_total+illigimate_birthdmm_EEdata_fig.rds
## If you want to re-run this step delete the file or change the saveDir!
```

```
knitr::kable(build_fit_summary.table(dmm_EE_fit_birth$fit))
```

| Type | Variable | Value | Cond. SE | t-value |
|-----------------|-----------------------------------|----------|----------|---------|
| fixed effects | (Intercept) | -4.14 | 0.0276 | -150 |
| | births_total | -0.00255 | 0.00504 | -0.506 |
| | illigimate_birthTRUE | -0.0759 | 0.0425 | -1.79 |
| response family | binomial with logit link | | | |
| fit info | number of model parameters | 3 | | |
| | marginal log Likelihood | -24445 | | |
| | marginal AIC | 48895 | | |
| | conditional AIC (cAIC) | | | |
| data info | number of fitted observations (N) | 125575 | | |

| Type | Variable | Value | Cond. SE | t-value |
|------|----------|-------|----------|---------|
|------|----------|-------|----------|---------|

```
## Estonia
```

```
formula <- "cbind(twin_total, singleton_total) ~ 1 + births_total + illigimate_conception"
dmm_EE_fit_conception <- fitPredictions(dmm_EE, formula)
```

```
## Warning in fitPredictions(dmm_EE, formula): Pre-computed fit returned from file:
```

```
## ./data/predictions/cbind(twin_total, singleton_total)~1+births_total+illigimate_conceptiondmm_EE_fit.rds
```

```
## If you want to re-run this step delete the file or change the saveDir!
```

```
## Warning in get_predictions(predDataFname, fit, dataset, args, save): Pre-computed predictions returned from file:
```

```
## ./data/predictions/cbind(twin_total, singleton_total)~1+births_total+illigimate_conceptiondmm_EEdata_fit.rds
```

```
## If you want to re-run this step delete the file or change the saveDir!
```

```
knitr::kable(build_fit_summary.table(dmm_EE_fit_conception$fit))
```

| Type | Variable | Value | Cond. SE | t-value |
|-----------------|-----------------------------------|----------|----------|---------|
| fixed effects | (Intercept) | -4.15 | 0.0278 | -149 |
| | births_total | -0.00178 | 0.00502 | -0.356 |
| | illigimate_conceptionTRUE | -0.00944 | 0.0283 | -0.334 |
| response family | binomial with logit link | | | |
| fit info | number of model parameters | 3 | | |
| | marginal log Likelihood | -24446 | | |
| | marginal AIC | 48898 | | |
| | conditional AIC (cAIC) | | | |
| data info | number of fitted observations (N) | 125575 | | |

No Last Births Data

```
## Estonia
```

```
formula <- "cbind(twin_total, singleton_total) ~ 1 + births_total + illigimate_birth"
dmm_EE_nl_fit_birth <- fitPredictions(dmm_EE_nl, formula)
```

```
## Warning in fitPredictions(dmm_EE_nl, formula): Pre-computed fit returned from file:
```

```
## ./data/predictions/cbind(twin_total, singleton_total)~1+births_total+illigimate_birthdmm_EE_nl_fit.rds
```

```
## If you want to re-run this step delete the file or change the saveDir!
```

```
## Warning in get_predictions(predDataFname, fit, dataset, args, save): Pre-computed predictions returned from file:
```

```
## ./data/predictions/cbind(twin_total, singleton_total)~1+births_total+illigimate_birthdmm_EE_nldata_fit.rds
```

```
## If you want to re-run this step delete the file or change the saveDir!
```

```
knitr::kable(build_fit_summary.table(dmm_EE_nl_fit_birth$fit))
```

| Type | Variable | Value | Cond. SE | t-value |
|---------------|-------------|-------|----------|---------|
| fixed effects | (Intercept) | -4.37 | 0.0338 | -129 |

| Type | Variable | Value | Cond. SE | t-value |
|-----------------------------|-----------------------------------|--------|----------|---------|
| response family fit info | births_total | 0.018 | 0.00655 | 2.74 |
| | illigimate_birthTRUE | 0.0364 | 0.0547 | 0.665 |
| | binomial with logit link | | | |
| | number of model parameters | 3 | | |
| | marginal log Likelihood | -15893 | | |
| | marginal AIC | 31792 | | |
| data info | conditional AIC (cAIC) | | | |
| | number of fitted observations (N) | 98183 | | |

```
## Estonia
```

```
formula <- "cbind(twin_total, singleton_total) ~ 1 + births_total + illigimate_conception"
dmm_EE_fit_nl_conception <- fitPredictions(dmm_EE_nl, formula)
```

```
## Warning in fitPredictions(dmm_EE_nl, formula): Pre-computed fit returned from file:
```

```
## ./data/predictions/cbind(twin_total, singleton_total)~1+births_total+illigimate_conceptiondmm_EE_nl_f
```

```
## If you want to re-run this step delete the file or change the saveDir!
```

```
## Warning in get_predictions(predDataFname, fit, dataset, args, save): Pre-computed predictions return
```

```
## ./data/predictions/cbind(twin_total, singleton_total)~1+births_total+illigimate_conceptiondmm_EE_nlda
```

```
## If you want to re-run this step delete the file or change the saveDir!
```

```
knitr::kable(build_fit_summary.table(dmm_EE_fit_nl_conception$fit))
```

| Type | Variable | Value | Cond. SE | t-value |
|-----------------------------|-----------------------------------|--------|----------|---------|
| fixed effects | (Intercept) | -4.37 | 0.0344 | -127 |
| | births_total | 0.0174 | 0.00656 | 2.65 |
| | illigimate_conceptionTRUE | 0.0443 | 0.0355 | 1.25 |
| response family fit info | binomial with logit link | | | |
| | number of model parameters | 3 | | |
| | marginal log Likelihood | -15892 | | |
| | marginal AIC | 31790 | | |
| | conditional AIC (cAIC) | | | |
| data info | number of fitted observations (N) | 98183 | | |

Illigimate Birth Figures for Estonian mothers With and Without Last Birth

```
## Plot Binary Predictions
##
## This function generates a ggplot based on the provided parameters.
##
## @param plot_data The data to be plotted.
## @param summary_data The data to be summarized.
## @param color_var The color variable for the plot.
## @param threshold The threshold for births_total mean data to display.
##
## @return A ggplot object.
##
```

```

plot_predictions <- function(plot_data, summary_data, color_var, threshold = 13) {
  fig2_ext_orig <- ggplot() +
    geom_line(data=plot_data,
              aes_string(y = "estimate", x="births_total", color=color_var),
              linewidth = 1) +
    stat_summary(data=summary_data[summary_data$births_total < threshold, ],
                 aes_string(x="births_total", y="prob_twin", color=color_var,
                             fill = color_var), alpha=0.5,
                 fun.data=mean_se) +
    geom_ribbon(data=plot_data,
               aes_string(y = "estimate", x="births_total", ymin = "lwr",
                           ymax = "upr",
                           color=color_var, fill = color_var),
               alpha = 0.3) +
    ggplot2::scale_x_continuous(breaks = 1:18) +
    ggplot2::scale_y_continuous(breaks = seq(0,0.03, by=0.005)) +
    ggplot2::coord_cartesian()
  return(fig2_ext_orig)
}

```

```

fig2_EE_plot_data <- dmm_EE_fit_birth$results
fig2_EE_plot_data_nl <- dmm_EE_nl_fit_birth$results
fig2_EE_plot_data_nl$births_total <- fig2_EE_plot_data_nl$births_total + 1

```

```

dmm_EE_nl_plot <- dmm_EE_nl
dmm_EE_nl_plot$births_total <- dmm_EE_nl_plot$births_total + 1

```

```

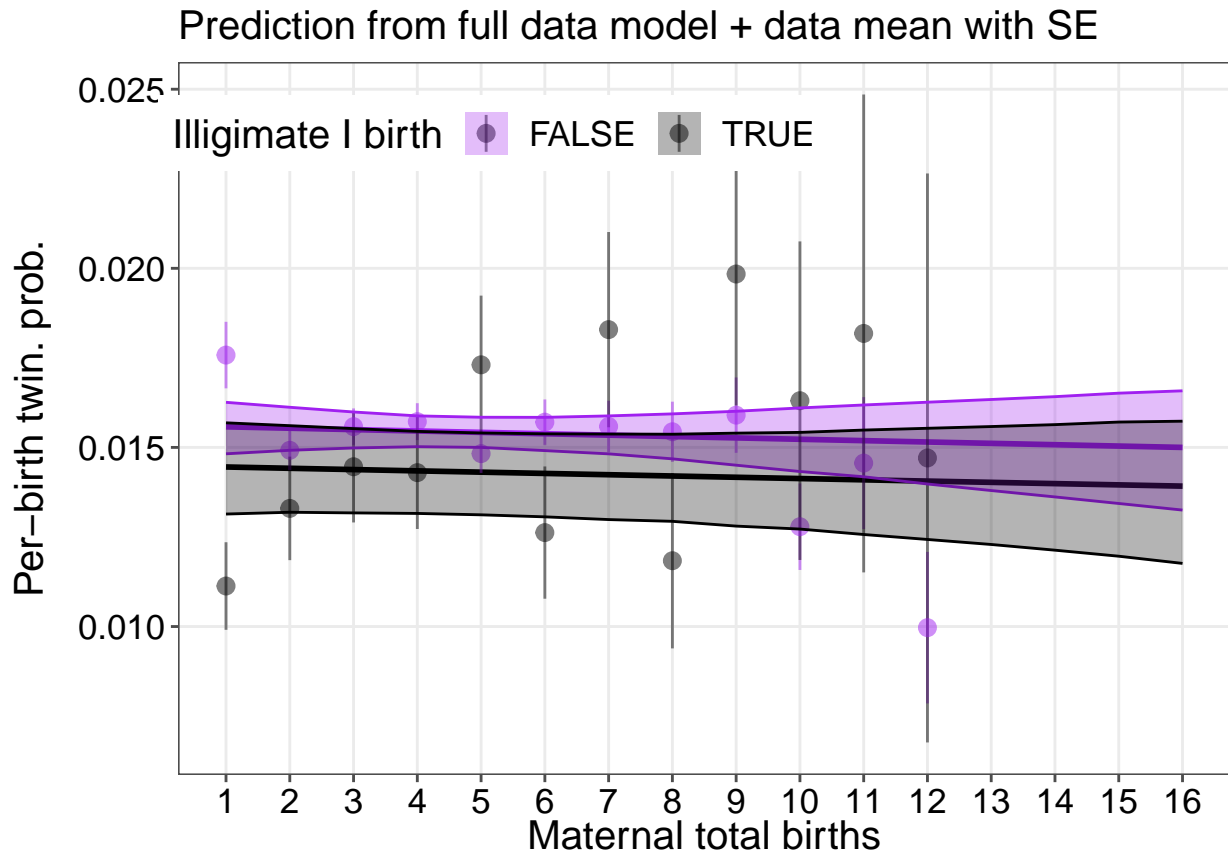
plot_predictions(plot_data = fig2_EE_plot_data,
                  summary_data = dmm_EE,
                  color_var = "illigimate_birth") +
  labs(subtitle = "Prediction from full data model + data mean with SE",
       y="Per-birth twin. prob.",
       x="Maternal total births") +
  base_theme(larger=8) + scale_color_manual(values=bc) +
  scale_fill_manual(values=bc) + guides(color="none") +
  labs(fill = "Illigimate I birth")

```

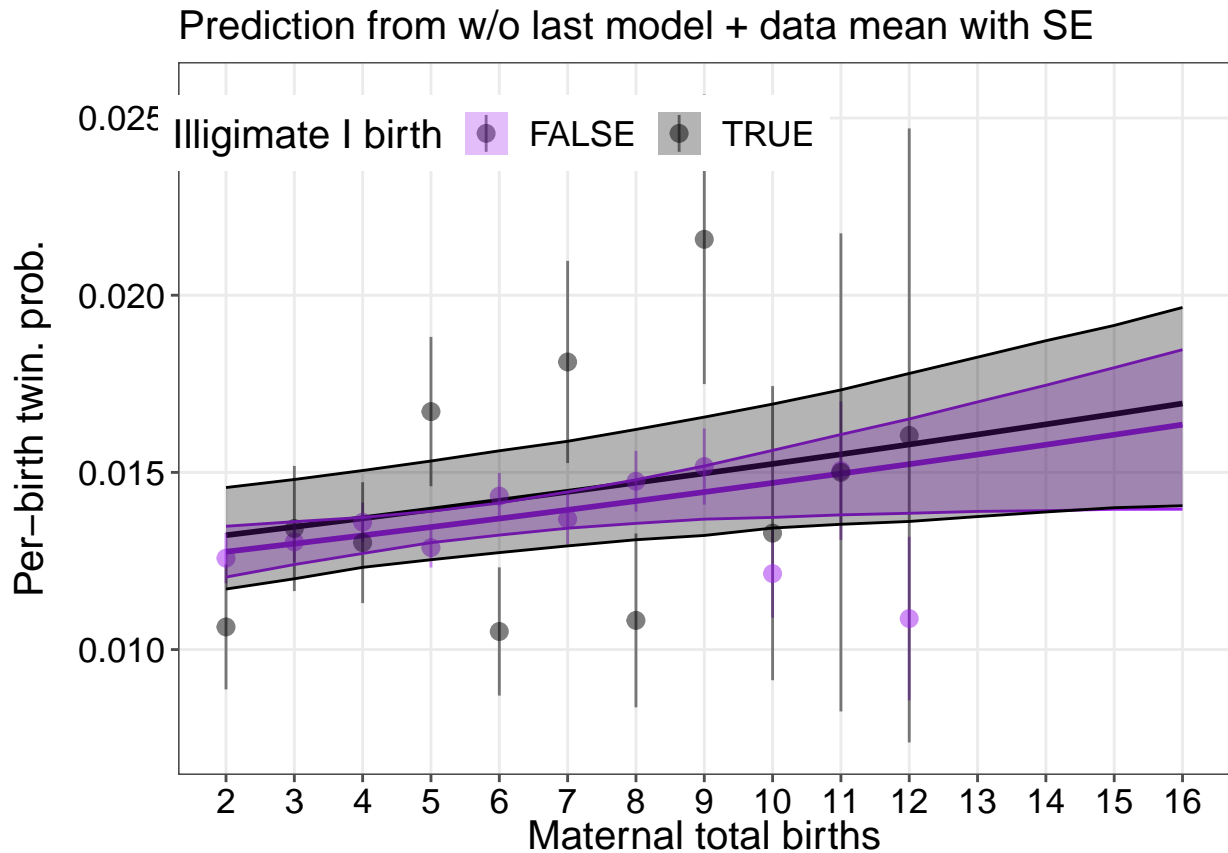
```

## Warning: 'aes_string()' was deprecated in ggplot2 3.0.0.
## i Please use tidy evaluation idioms with 'aes()'.
## i See also 'vignette("ggplot2-in-packages")' for more information.
## This warning is displayed once every 8 hours.
## Call 'lifecycle::last_lifecycle_warnings()' to see where this warning was
## generated.

```



```
plot_predictions(plot_data = fig2_EE_plot_data_nl,
                 summary_data = dmm_EE_nl_plot,
                 color_var = "illigimate_birth") +
  labs(subtitle = "Prediction from w/o last model + data mean with SE",
       y="Per-birth twin. prob.",
       x="Maternal total births")+
  base_theme(larger=8) + scale_color_manual(values=bc) +
  scale_fill_manual(values=bc) + guides(color="none") +
  labs(fill = "Illigimate I birth")
```

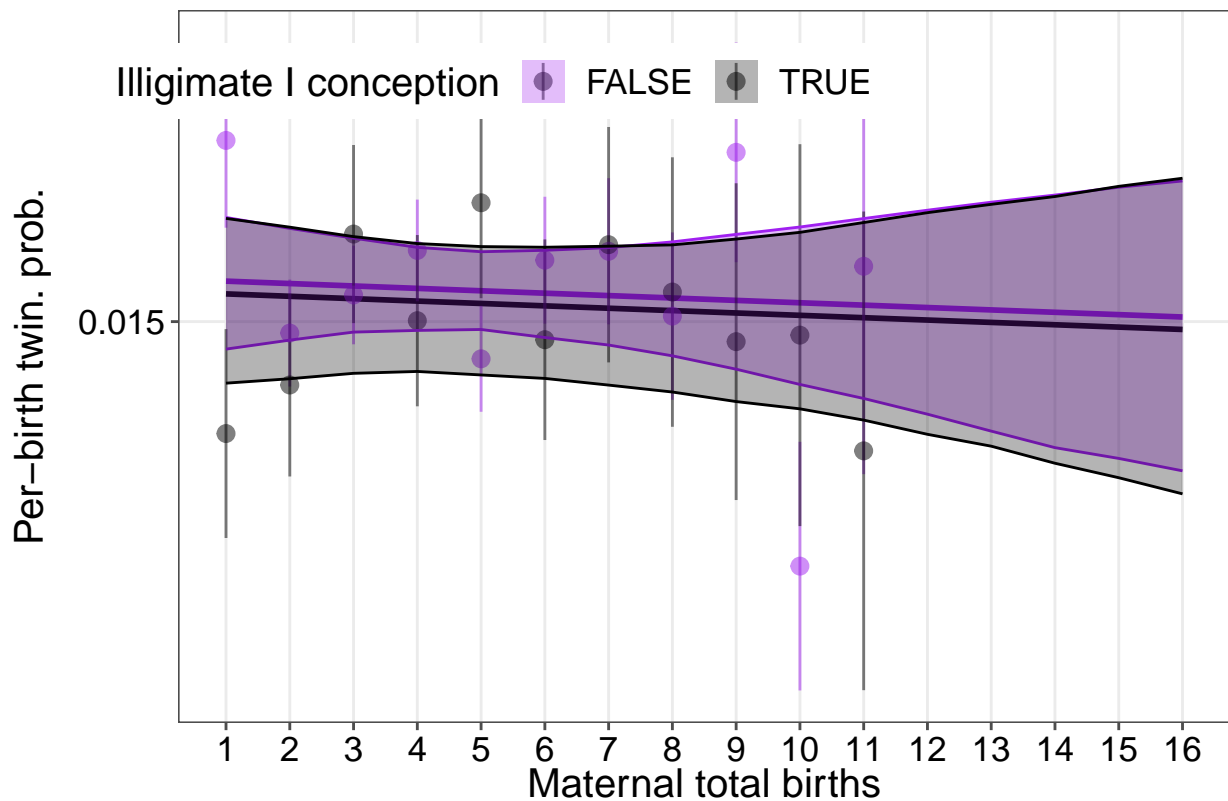


Illigimate Conception Figures for Estonian mothers With and Without Last Birth

```
fig2_EE_plot_data <- dmm_EE_fit_conception$results
fig2_EE_plot_data_nl <- dmm_EE_fit_nl_conception$results
fig2_EE_plot_data_nl$births_total <- fig2_EE_plot_data_nl$births_total + 1
```

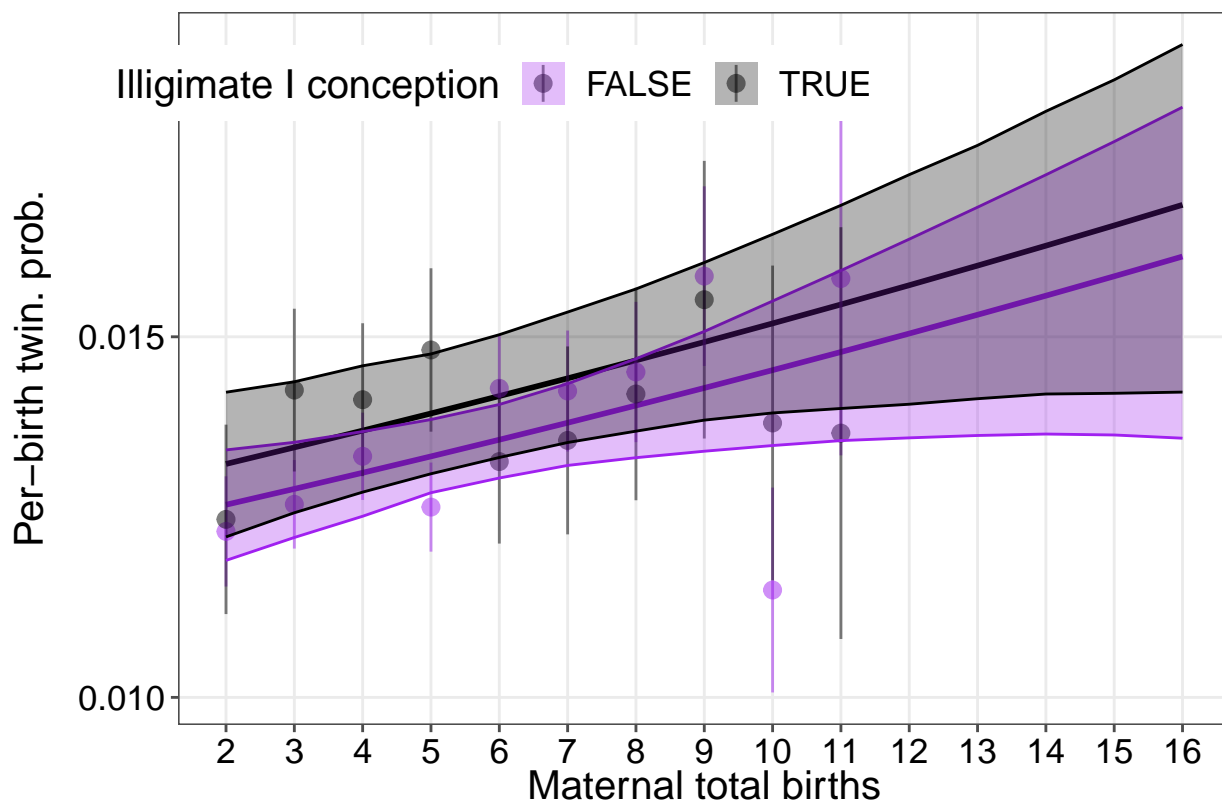
```
plot_predictions(plot_data = fig2_EE_plot_data,
  summary_data = dmm_EE,
  color_var = "illigimate_conception",
  threshold = 12) +
  labs(subtitle = "Prediction from full data model + data mean with SE",
    y="Per-birth twin. prob.",
    x="Maternal total births") +
  base_theme(larger=8) + scale_color_manual(values=bc) +
  scale_fill_manual(values=bc) + guides(color="none") +
  labs(fill = "Illigimate I conception")
```

Prediction from full data model + data mean with SE



```
plot_predictions(plot_data = fig2_EE_plot_data_nl,
  summary_data = dmm_EE_nl_plot,
  color_var = "illegitimate_conception",
  threshold = 12) +
  labs(subtitle = "Prediction from w/o last model + data mean with SE",
    y="Per-birth twin. prob.",
    x="Maternal total births")+
  base_theme(larger=8) + scale_color_manual(values=bc) +
  scale_fill_manual(values=bc) + guides(color="none") +
  labs(fill = "Illegitimate I conception")
```

Prediction from w/o last model + data mean with SE



#END