

TMA4315: Project 3

jototlan@stud.ntnu.no (10018), martigtu@stud.ntnu.no (10037)

```
long <- read.csv("https://www.math.ntnu.no/emner/TMA4315/2020h/eliteserie.csv",
                 colClasses = c("factor", "factor", "factor", "numeric"))
head(long)
```

```
##           attack           defence home goals
## 1      Molde Sandefjord_Fotball   yes     5
## 2 Sandefjord_Fotball           Molde    no     0
## 3   Stroemsgodset           Stabaek   yes     2
## 4      Stabaek   Stroemsgodset    no     2
## 5           Odd   Haugesund   yes     1
## 6   Haugesund           Odd    no     2
```

a)

We consider the model

```
library(glmmTMB)
mod <- glmmTMB(goals ~ home + (1|attack) + (1|defence), poisson, data=long, REML=TRUE)
```

Model and Notation

We use a triple index to denote the response, y_{ijk} , where i is the attacking team, j is the defending team, and $k \in \{0, 1\}$ where $k = 1$ indicates that the attacking team, i , is playing home, while $k = 0$ indicates that the attacking team is playing away. Clearly, $i, j \in \{1, 2, \dots, 16\}$ and $i \neq j$. The distributional assumption on the response is $y_{ijk} | \gamma_i^a, \gamma_j^d \sim \text{Poisson}(\lambda_{ijk})$. Here, γ_i^a is the effect of team i attacking and γ_j^d is the effect of team j defending. The conditional mean is connected to the covariates by the canonical link function,

$$\lambda_{ijk} = \exp(\beta_0 + \beta_h k + \gamma_i^a + \gamma_j^d) = \exp(\eta_{ijk}),$$

where β_0 is the intercept and β_h is the effect of playing home. The random effects are independent and identically distributed, such that

$$\gamma_i^a \stackrel{iid}{\sim} \mathcal{N}(0, \tau_a^2) \quad \text{and} \quad \gamma_j^d \stackrel{iid}{\sim} \mathcal{N}(0, \tau_d^2).$$

We also assume that γ_i^a and γ_j^d are independent $\forall i, j$. The model parameters are computed with a restricted maximum likelihood approach (REML).

Distributional Assumption on Response

Assuming that the response follows a Poisson distribution amounts to making the following assumptions:

1. Goals are scored independently, i.e. the number of goals scored within disjoint time intervals is independent.
2. The number of goals scored in a time interval is proportional to the length of the interval.
3. Two (or more) goals cannot be scored at exactly the same instance.

The last two assumptions seem very reasonable; two goals can obviously not occur at the same time, and more time gives more opportunities for goal scoring. The first one, however, is more questionable. For example, a team which has just conceded a goal close to the end of the game might play more aggressively to salvage a draw, hence increasing the likelihood of more goals being scored. Despite this, the Poisson distribution seems like a reasonable choice to model this process.

b)

We print out the summary and random effects:

```
sum <- summary(mod)
sum

## Family: poisson ( log )
## Formula:          goals ~ home + (1 | attack) + (1 | defence)
## Data: long
##
##      AIC      BIC   logLik deviance df.resid
##  1147.2   1163.1   -569.6   1139.2     382
##
## Random effects:
##
## Conditional model:
##   Groups   Name              Variance Std.Dev.
##  attack (Intercept) 0.007478 0.08647
##  defence (Intercept) 0.016383 0.12800
## Number of obs: 384, groups:  attack, 16; defence, 16
##
## Conditional model:
##              Estimate Std. Error z value Pr(>|z|)
## (Intercept)  0.12421    0.07809   1.591   0.112
## homeyes      0.40716    0.08745   4.656 3.22e-06 ***
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

beta.0 <- sum$coefficients$cond[1]
beta.h <- sum$coefficients$cond[2]

rf <- ranef(mod)
rf
```

```
## $attack
## (Intercept)
## BodoeGlimt -0.036781062
## Brann 0.012026209
## Haugesund 0.011223106
## Kristiansund -0.011367328
## Lillestroem -0.049915996
## Molde 0.078390643
## Odd 0.003654179
## Ranheim_TF 0.023375599
## Rosenborg 0.050622609
## Sandefjord_Fotball -0.058333079
## Sarpsborg08 0.026946364
## Stabaek -0.026801293
## Start -0.060500163
## Stroemsgodset 0.024556017
## Tromsoe 0.005756700
## Vaalerenga 0.007147494
##
## $defence
## (Intercept)
## BodoeGlimt -0.042616090
## Brann -0.123934761
## Haugesund -0.061931278
## Kristiansund 0.008112432
## Lillestroem 0.030699257
## Molde -0.036630979
## Odd -0.052013600
## Ranheim_TF 0.062209734
## Rosenborg -0.152631173
## Sandefjord_Fotball 0.133164228
## Sarpsborg08 0.006574064
## Stabaek 0.085376126
## Start 0.081958112
## Stroemsgodset 0.040486666
## Tromsoe -0.009852817
## Vaalerenga 0.031030079
```

The effect of playing home is positive and statistically significant. According to the output, the team playing home scores $\exp(0.40716) = 1.5025445$ more goals on average, i.e. about 50% more goals on average. This seems reasonable from an intuitive perspective. Looking at the estimated random effects, we can e.g. consider $\gamma_{\text{Rosenborg}}^d \approx -0.153$. This is the lowest value among all teams, which indicates that Rosenborg is the best defending team. To check this, we calculate the average number of goals conceded per match by each team:

```
no.NA = long[!is.na(long$goals), c("defence", "goals")]
agg = aggregate(no.NA$goals, by = list(no.NA$defence), FUN = mean)
colnames(agg) <- c("Team", "Avg. # of conceded goals")
sorted <- agg[order(agg[,2]), ]
knitr::kable(sorted)
```

	Team	Avg. # of conceded goals
9	Rosenborg	0.8333333

	Team	Avg. # of conceded goals
2	Brann	0.9583333
3	Haugesund	1.1666667
7	Odd	1.2083333
1	BodoeGlimt	1.2500000
6	Molde	1.2500000
15	Tromsoe	1.3750000
11	Sarpsborg08	1.4166667
4	Kristiansund	1.4583333
5	Lillestroem	1.5416667
16	Vaalerenga	1.5416667
14	Stroemsgodset	1.5833333
8	Ranheim_TF	1.6666667
13	Start	1.7500000
12	Stabaek	1.7916667
10	Sandefjord_Fotball	1.9583333

As expected, Rosenborg has the lowest average number of conceded goals. Brann comes second, which is also reflected in their defence strength. We do the same analysis with respect to the average number of goals scored in each game:

```
no.NA = long[!is.na(long$goals), c("attack", "goals")]
agg = aggregate(no.NA$goals, by = list(no.NA$attack), FUN = mean)
colnames(agg) <- c("Team", "Avg. # of goals scored")
sorted <- agg[order(-agg[,2]), ]
knitr::kable(sorted)
```

	Team	Avg. # of goals scored
6	Molde	2.000000
9	Rosenborg	1.791667
11	Sarpsborg08	1.625000
8	Ranheim_TF	1.583333
14	Stroemsgodset	1.583333
2	Brann	1.500000
3	Haugesund	1.500000
7	Odd	1.458333
15	Tromsoe	1.458333
16	Vaalerenga	1.458333
4	Kristiansund	1.333333
12	Stabaek	1.208333
1	BodoeGlimt	1.166667
5	Lillestroem	1.083333
10	Sandefjord_Fotball	1.000000
13	Start	1.000000

We observe that Molde scores the most goals on average, which is reflected in their attacking strength. Next comes Rosenborg, etc. We conclude that the parameter estimates seem reasonable.

From the model assumptions, namely $\gamma_i^a \sim \mathcal{N}(0, \tau_a^2)$ and $\gamma_j^d \sim \mathcal{N}(0, \tau_d^2)$, the average attack strength and the average defense strength are equal to 0. An estimate of the expected number of goals which the average attacking team scores is thus given as

$$\exp(\beta_0 + \beta_h) \approx 1.701265.$$

Since the the number of goals scored is assumed to follow a Poisson distribution, an estimate of the variance is given by the same value. We now consider the the situation when the average defense team is attacking (here we assume that they also have average attack strength and that the average attack team has average defense). Then, an estimate of the number of goals scored is given as

$$\exp(\beta_0) \approx 1.132258.$$

Again, since we consider a Poisson-distributed variable, an estimate of the variance i given by the same value.

c)

The expected value and variance of goals scored by two randomly selected teams can be found by the laws of total expectation and total variance conditioned on the random effects given by the two teams. For this, we use that the distribution Lognormal(0, τ^2) has mean $\exp(\tau^2/2)$ and variance $(\exp(\tau^2) - 1) \exp(\tau^2)$.

The law of total expectation gives

$$\begin{aligned} E[y_{ijk}] &= E [E [y_{ijk} \mid \gamma_i^a, \gamma_j^d]] \\ &= E [\exp (\beta_0 + \beta_h k + \gamma_i^a + \gamma_j^d)] \\ &= \exp (\beta_0 + \beta_h k) E [\exp (\gamma_i^a + \gamma_j^d)] \\ &= \exp (\beta_0 + \beta_h k) \exp \left(\frac{\tau_a^2 + \tau_d^2}{2} \right). \end{aligned}$$

The law of total variance gives

$$\begin{aligned} \text{Var}[y_{ijk}] &= E [\text{Var} [y_{ijk} \mid \gamma_i^a, \gamma_j^d]] + \text{Var} [E [y_{ijk} \mid \gamma_i^a, \gamma_j^d]] \\ &= E [\exp (\beta_0 + \beta_h k + \gamma_i^a + \gamma_j^d)] + \text{Var} [\exp (\beta_0 + \beta_h k + \gamma_i^a + \gamma_j^d)] \\ &= E[y_{ijk}] + \exp (2(\beta_0 + \beta_h k)) \text{Var} [\exp (\gamma_i^a + \gamma_j^d)] \\ &= \exp (\beta_0 + \beta_h k) \exp \left(\frac{\tau_a^2 + \tau_d^2}{2} \right) + \exp (2(\beta_0 + \beta_h k)) (\exp (\tau_a^2 + \tau_d^2) - 1) \exp (\tau_a^2 + \tau_d^2). \end{aligned}$$

Note that the total marginal variance consists of two terms, given as

$$\text{Var}[y_{ijk}] = \underbrace{E [\text{Var} [y_{ijk} \mid \gamma_i^a, \gamma_j^d]]}_{\text{Variance of the game}} + \underbrace{\text{Var} [E [y_{ijk} \mid \gamma_i^a, \gamma_j^d]]}_{\text{Variance of team strengths}}.$$

The first term is the expected variance of goals, which is a measure of the inherent randomness of the football game given the two teams. The second term is the variance of the expected goals, which is attributed to the variance in the strength of the two teams, since the expected goals are constant given two teams, so the randomness comes from the difference in strengths among the teams. We now calculate the proportion of variance explained by the two terms without and with home field advantage.

Estimating the proportions with no home field advantage:

```

# Parameters from model
beta <- summary(mod)$coefficients$cond[,1]
beta0 = beta[1]
beta.h = beta[2]

# Variance of random effects
tau2.attack <- summary(mod)$var$cond$attack[1]
tau2.defence <- summary(mod)$var$cond$defence[1]
tau2 <- tau2.attack + tau2.defence

# Marginal variance
var0.game <- exp(beta0 + tau2/2)
var0.strength <- exp(2*beta0)*(exp(tau2)-1)*exp(tau2)
var0 <- var0.game + var0.strength

# Proportion of variance
prop0.game = var0.game/var0
prop0.strength = var0.strength/var0

```

With no home field advantage for the attacking team, the total marginal variance of the number of goals is 1.1775525, where the inherent randomness of the game accounts for 0.9731 and the variation in team strengths account for 0.0269.

Estimating the proportions with home field advantage:

```

# Marginal variance
var1.game <- exp(beta0 + beta.h + tau2/2)
var1.strength <- exp(2*(beta0 + beta.h))*(exp(tau2)-1)*exp(tau2)
var1 <- var1.game + var1.strength

# Proportions of variance
prop1.game = var1.game / var1
prop1.strength = var1.strength / var1

```

If the attacking team has a home field advantage, the total marginal variance of the number of goals is 1.7932623, where the inherent randomness of the game accounts for 0.9601 and the variation in team strengths account for 0.0399. We note that also here the majority of variance can be explained by the game itself.

An interesting observation is that when the home field advantage is present, the proportion of variance explained by the strengths of the teams is higher. This follows directly from the equation of the total marginal variance when $\beta_h > 0$, as the second term is multiplied by an extra factor of $\exp(\beta_h) > 1$.

d)

We want to test if the two random effects in the model are significant. Since $\gamma^a \sim \mathcal{N}(0, \tau_a^2)$ and $\gamma^d \sim \mathcal{N}(0, \tau_d^2)$, this is equivalent to testing whether the variance of each random effect is positive. The hypothesis test for determining if the effect of attacking is significant can be formulated as

$$H_0 : \tau_a^2 = 0 \quad \text{vs.} \quad H_1 : \tau_a^2 > 0,$$

and a similar test can be constructed for the effect of defending.

This can be carried out using a likelihood-ratio test. The test statistic is $\lambda_{LRT} := -2(l_0 - l_1)$, where l_0 and l_1 are the log-likelihoods of the under H_0 and H_1 , respectively. We cannot apply Wilks' theorem directly here, as standard asymptotic theory is violated. The reason for this is that under H_0 , there is a 50% chance that the MLE of τ_a under H_1 falls on the boundary, such that the corresponding LRT statistic takes a value of 0. This is due to the expected value of the score function $s(\tau_a^2) := \frac{\partial l_1}{\partial \tau_a^2}$ evaluated at zero is zero, $E[s(0)] = 0$, implying that whenever the slope of $s(0)$ is negative, the maximum likelihood estimator is zero. This results in a mixture of two distributions

$$\lambda_{LRT} \sim \frac{1}{2}\chi_0^2 + \frac{1}{2}\chi_1^2$$

where χ_0^2 is simply the point mass distribution located at zero. The critical value C of the likelihood-ratio test is given as

$$P(\lambda_{LRT} \geq C) = \frac{1}{2}P(\chi_0^2 \geq C) + \frac{1}{2}P(\chi_1^2 \geq C) = \alpha.$$

Since $C > 0$ for $\alpha < \frac{1}{2}$ the first term vanishes, so C is the upper 2α quantile of a chi-squared distribution with one degree of freedom. Using $\alpha = 0.05$ we get the critical value

```
alpha <- 0.05
qchisq(1-2*alpha, df=1)
```

```
## [1] 2.705543
```

Testing significance of effect of attack

```
mod.no_attack <- glmmTMB(goals ~ home + (1|defence), poisson, data=long, REML=TRUE)
LRT.no_attack <- -2*as.numeric(logLik(mod.no_attack) - logLik(mod))

p.value <- 0.5 * pchisq(LRT.no_attack, df=0, lower.tail = FALSE) +
          0.5 * pchisq(LRT.no_attack, df=1, lower.tail = FALSE)
p.value
```

```
## [1] 0.2587558
```

The p -value suggest that we can not reject H_0 , meaning that the effect of attack is not significant. The test statistic has value 0.4188496, which is lower than the critical value.

Testing significance of effect of defence

We now consider

$$H_0 : \tau_d^2 = 0 \quad \text{vs.} \quad H_1 : \tau_d^2 > 0,$$

which results in a similar test:

```
mod.no_defence <- glmmTMB(goals ~ home + (1|attack), poisson, data=long, REML=TRUE)
LRT.no_defence <- -2*as.numeric(logLik(mod.no_defence) - logLik(mod))

p.value <- 0.5 * pchisq(LRT.no_defence, df=0, lower.tail = FALSE) +
          0.5 * pchisq(LRT.no_defence, df=1, lower.tail = FALSE)
p.value
```

```
## [1] 0.09843786
```

The p -value suggest that the effect of defence is not significant. The test statistic has value 1.6654006, which is again lower than the critical value.

Testing the effect of home field advantage

Our hypothesis can be formulated as

$$H_0 : \beta_h = 0 \quad \text{vs.} \quad H_1 : \beta_h \neq 0,$$

where under H_1 , the home field advantage could be either negative or positive.

The restricted maximum likelihood (REML) is often preferred when fitting generalized mixed models as they often produce less biased estimators compared to normal maximum likelihood estimation. The REML works by integrating out ‘nuisance’ parameters from the likelihood. Under H_0 , this amounts to integrating out the intercept β_0 , while under H_1 , we also have the parameter β_h for the home field advantage. Using REML, this means that we integrate over a different parameter space under H_1 compared to H_0 , which makes the likelihoods non-comparable. Setting `REML = FALSE` avoids this issue and fits the models using normal maximum likelihoods.

```
mod.ML <- glmmTMB(goals ~ home + (1|attack) + (1|defence), poisson, data=long, REML=FALSE)
mod.no_home <- glmmTMB(goals ~ (1|attack) + (1|defence), poisson, data=long, REML=FALSE)

LRT.no_home <- -2*as.numeric(logLik(mod.no_home) - logLik(mod.ML))

p.value <- pchisq(LRT.no_home, df=1, lower.tail = FALSE)
p.value
```

```
## [1] 2.507328e-06
```

The low p -value is smaller than the significance level, indicating that the effect of home field is significant.

e)

```
frankv <- data.table::frankv

ranking <- function(df){
  n.teams <- length(unique(df$attack))
  stats <- data.frame(row.names = unique(df$attack), points = rep(0, n.teams),
                     goal.diff = rep(0, n.teams), goals.scored = rep(0, n.teams))

  for(n in seq(1, dim(df)[1], 2)){
    team1 <- as.character(df$attack[n])
    team2 <- as.character(df$defence[n])
    goals1 = df$goals[n]
    goals2 = df$goals[n+1]

    # skip missing values
    if (is.na(goals1) | is.na(goals2)){
      next
    }
    else if(goals1 > goals2){
      stats[team1,"points"] = stats[team1,"points"] + 3
    }
    else if(goals2 > goals1){
```



```

    stats[team2,"points"] = stats[team2,"points"] + 3
  }
  else {
    stats[team1,"points"] = stats[team1,"points"] + 1
    stats[team2,"points"] = stats[team2,"points"] + 1
  }
  stats[team1,"goal.diff"] = stats[team1,"goal.diff"] + goals1 - goals2
  stats[team2,"goal.diff"] = stats[team2,"goal.diff"] + goals2 - goals1
  stats[team1,"goals.scored"] = stats[team1,"goals.scored"] + goals1
  stats[team2,"goals.scored"] = stats[team2,"goals.scored"] + goals2
}
stats$rank <- frankv(stats, cols=c("points","goal.diff","goals.scored"),
                     order=-1, ties.method="random")

stats
}

stats <- ranking(long)
knitr::kable(stats[order(stats$rank),])

```

	points	goal.diff	goals.scored	rank
Rosenborg	52	23	43	1
Brann	48	13	36	2
Molde	43	18	48	3
Haugesund	41	8	36	4
Ranheim_TF	38	-2	38	5
Vaalerenga	36	-2	35	6
Odd	34	6	35	7
Tromsøe	33	2	35	8
Sarpsborg08	32	5	39	9
Kristiansund	31	-3	32	10
Bodø/Glimt	27	-2	28	11
Stroemsgodset	26	0	38	12
Lillestrøm	25	-11	26	13
Stabæk	23	-14	29	14
Start	23	-18	24	15
Sandefjord Fotball	15	-23	24	16

f)

We simulate 1000 realization of the whole series by using the predicted mean $\hat{\mu} := \hat{\lambda}$ from the model created in a).

```

set.seed(0)
# number of matches
n = dim(long)[1]

# predicted mean goals scored in each match
mu.hat <- predict(mod, newdata=long, type="response")

# matrix to store all simulated rankings

```

```

rank.matrix <- matrix(0, nrow = 1000, ncol = 16)
colnames(rank.matrix) = unique(long$attack)

# doing the simulations
temp <- long$goals
for(i in 1:1000){
  long$goals <- rpois(n, mu.hat)
  rank.matrix[i,] <- ranking(long)$rank
}
long$goals <- temp

# probabilities of each observation
probabilities <- apply(rank.matrix, 2, table)/1000

# summary with mean ranking and probabilities
rank.summary <- data.frame(row.names = unique(long$attack),
                           mean = colMeans(rank.matrix),
                           P = t(probabilities))

# print the summary
output <- rank.summary[order(rank.summary$mean),]
library(kableExtra)
knitr::kable(output) %>% landscape()

```

	mean	P.1	P.2	P.3	P.4	P.5	P.6	P.7	P.8	P.9	P.10	P.11	P.12	P.13	P.14	P.15	P.16
Rosenborg	5.239	0.184	0.130	0.125	0.097	0.076	0.064	0.071	0.053	0.035	0.034	0.034	0.027	0.026	0.016	0.016	0.012
Brann	6.276	0.140	0.102	0.098	0.087	0.070	0.074	0.066	0.056	0.050	0.064	0.058	0.027	0.040	0.025	0.024	0.019
Molde	6.422	0.120	0.107	0.090	0.086	0.081	0.082	0.066	0.057	0.053	0.060	0.044	0.038	0.040	0.033	0.028	0.015
Haugesund	7.221	0.094	0.098	0.074	0.074	0.079	0.076	0.056	0.058	0.070	0.047	0.057	0.056	0.052	0.038	0.037	0.034
Odd	7.651	0.060	0.079	0.087	0.078	0.077	0.068	0.060	0.071	0.055	0.065	0.063	0.061	0.051	0.057	0.040	0.028
Sarpsborg08	8.133	0.061	0.062	0.068	0.056	0.082	0.075	0.066	0.071	0.068	0.060	0.071	0.046	0.062	0.050	0.053	0.049
Tromsøe	8.278	0.045	0.061	0.074	0.074	0.069	0.059	0.061	0.074	0.069	0.065	0.066	0.071	0.065	0.056	0.059	0.032
BodoeGlimt	8.422	0.053	0.064	0.048	0.066	0.067	0.080	0.058	0.061	0.081	0.061	0.062	0.075	0.074	0.056	0.047	0.047
Stroemsgodset	8.825	0.048	0.056	0.067	0.061	0.051	0.055	0.067	0.053	0.074	0.072	0.065	0.060	0.061	0.082	0.068	0.060
Kristiansund	8.872	0.047	0.051	0.051	0.062	0.057	0.058	0.065	0.072	0.063	0.065	0.074	0.084	0.072	0.056	0.069	0.054
Ranheim_TF	9.035	0.038	0.050	0.055	0.055	0.062	0.070	0.070	0.059	0.066	0.064	0.062	0.061	0.066	0.079	0.080	0.063
Vaalerenga	9.079	0.036	0.044	0.051	0.063	0.051	0.062	0.079	0.069	0.068	0.064	0.071	0.058	0.077	0.079	0.066	0.062
Lillestroem	9.962	0.019	0.036	0.032	0.049	0.053	0.057	0.051	0.066	0.071	0.082	0.064	0.073	0.079	0.094	0.079	0.095
Stabaek	10.201	0.027	0.030	0.036	0.043	0.047	0.039	0.056	0.065	0.057	0.067	0.061	0.099	0.094	0.086	0.103	0.090
Start	10.819	0.016	0.023	0.024	0.021	0.046	0.042	0.059	0.067	0.059	0.070	0.078	0.080	0.073	0.094	0.112	0.136
Sandefjord_Fotball	11.565	0.012	0.007	0.020	0.028	0.032	0.039	0.049	0.048	0.061	0.060	0.070	0.084	0.068	0.099	0.119	0.204

The results of the simulations are summarized on the previous page, where we have included the ranking probabilities of each team and the mean ranking. Sorting the teams by their average ranking in ascending order, we see that Rosenborg has the lowest mean ranking, as is expected from the rankings obtained in e).

g)

We start by creating a data frame with the rankings from f) and the corresponding random effects, as well as the difference between attack strength and defense strength.

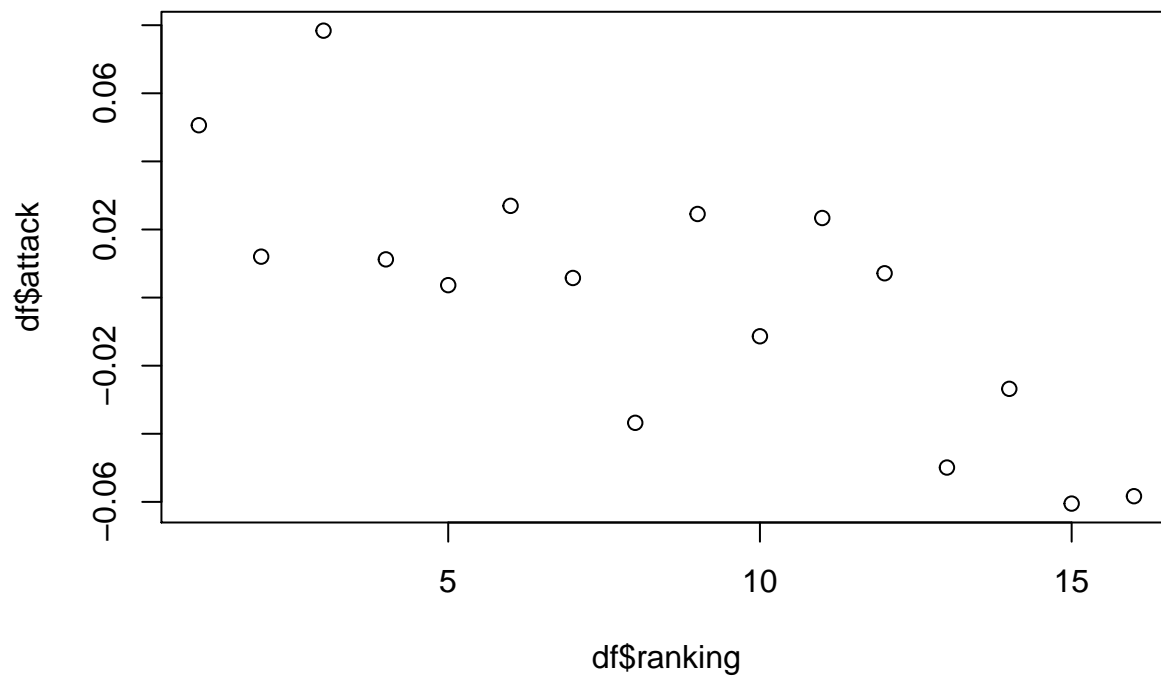
```
re <- ranef(mod)

# Create new data frame for rankings and random effects.
df <- data.frame("ranking" = 1:16)
row.names(df) <- row.names(output)
df$attack <- re$cond$attack[row.names(df), ]
df$defence <- re$cond$defence[row.names(df), ]
df$difference = df$attack - df$defence
df
```

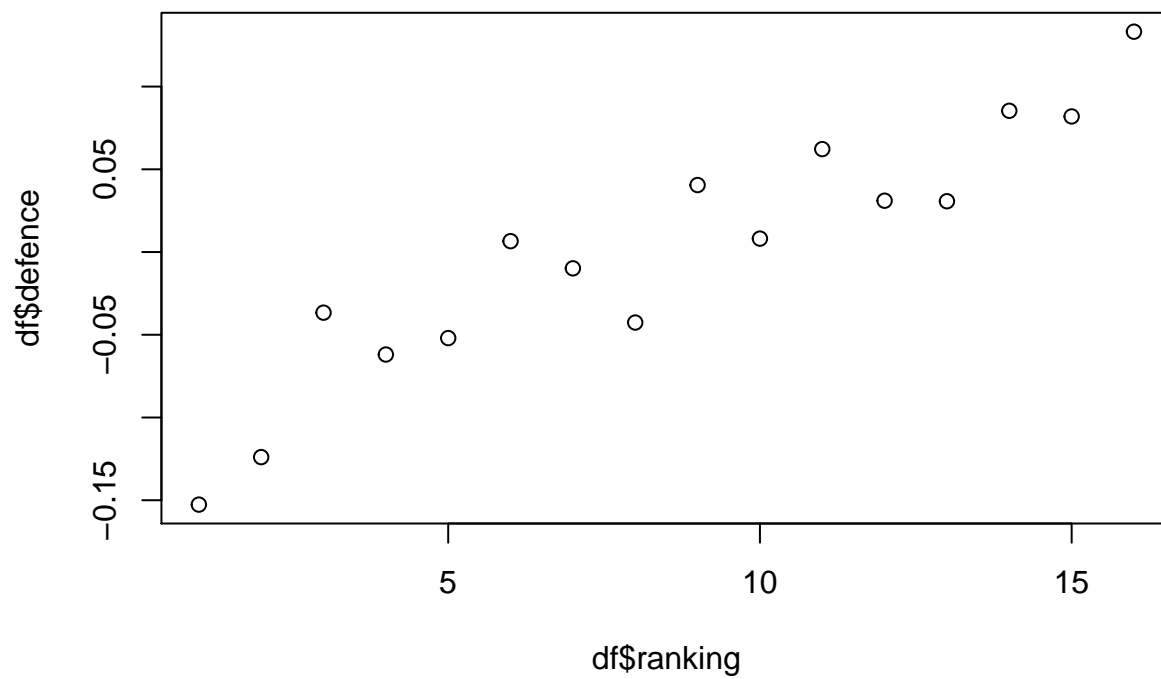
##	ranking	attack	defence	difference
## Rosenborg	1	0.050622609	-0.152631173	0.203253783
## Brann	2	0.012026209	-0.123934761	0.135960970
## Molde	3	0.078390643	-0.036630979	0.115021622
## Haugesund	4	0.011223106	-0.061931278	0.073154385
## Odd	5	0.003654179	-0.052013600	0.055667779
## Sarpsborg08	6	0.026946364	0.006574064	0.020372301
## Tromsø	7	0.005756700	-0.009852817	0.015609517
## Bodø/Glimt	8	-0.036781062	-0.042616090	0.005835029
## Strømsgodset	9	0.024556017	0.040486666	-0.015930650
## Kristiansund	10	-0.011367328	0.008112432	-0.019479760
## Ranheim TF	11	0.023375599	0.062209734	-0.038834135
## Vålerenga	12	0.007147494	0.031030079	-0.023882585
## Lillestrøm	13	-0.049915996	0.030699257	-0.080615253
## Stabæk	14	-0.026801293	0.085376126	-0.112177420
## Start	15	-0.060500163	0.081958112	-0.142458276
## Sandefjord Fotball	16	-0.058333079	0.133164228	-0.191497307

Next, we do some plotting:

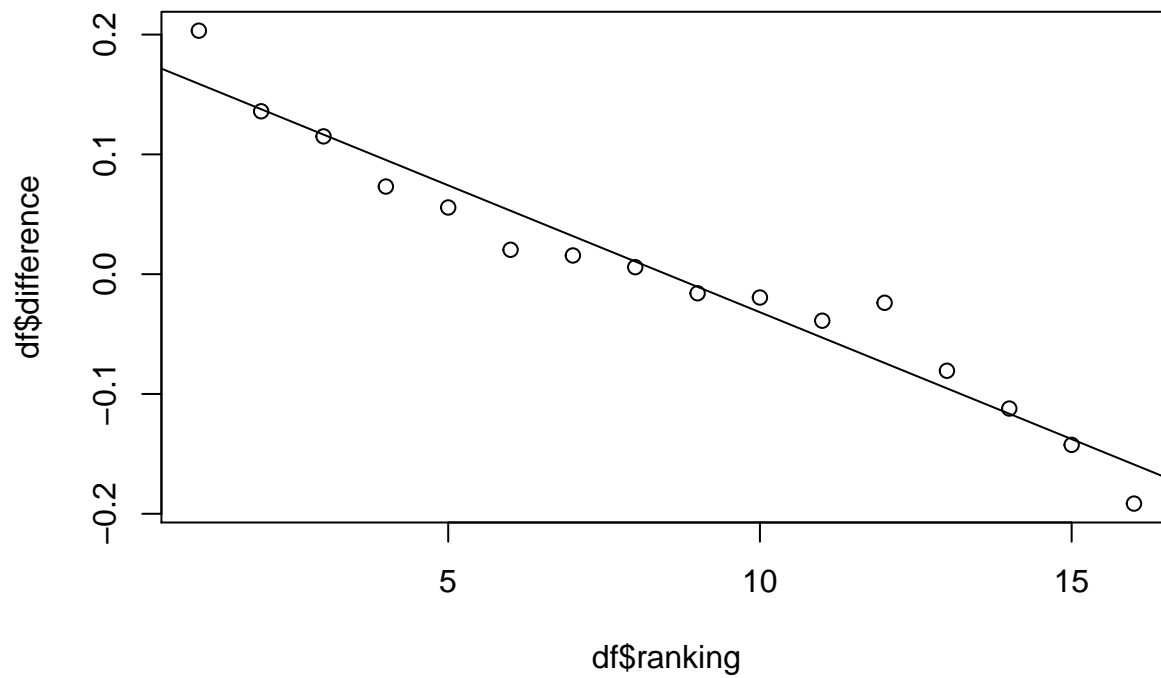
```
# Plot ranking against random effects.
plot(df$ranking, df$attack)
```



```
plot(df$ranking, df$defence)
```



```
# Plot ranking against difference of r.e. with regression line.
linreg <- lm(difference ~ ranking, data = df)
plot(df$ranking, df$difference)
abline(linreg)
```



From the plots, there seems to be a linear relationship between both the random effects and the simulated ranking. The linear relationship is clearly visible when we plot the difference against the ranking.