

# Check fit diagnostics, analyse results

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## Summary

This Notebook fits the models, and extracts the results.

## Load packages

```
library(data.table)
library(ggplot2)
library(rstan)
library(stringr)
library(cowplot)

rstan_options(auto_write = TRUE)
options(mc.cores = parallel::detectCores())
```

```
source("code/ppc_coverage_plot.R")
source("code/MakeTimeSeriesPlot.R")
source("code/Create_model_data_for_TS2.R")
source("code/addTeamIds.R")
source("code/create_league_table.R")
source("code/MakeEPLPlotAbility.R")
source("code/games_predicted_vs_actual_intervals.R")
source("code/ppc_coverage_plot.R")
source("code/calc_rps_scores.R")
source("code/odds_to_probability.R")
source("code/ReadfitsandCalculateRPS.R")
source("code/FitOneStepAhead.R")
source("code/ReadfitsandExtractCoefs.R")
```

```
NL_ALL <- readRDS("data/NL Eredivisie 2000-2018.rds")

# set 2017/2018 season apart
NL_17 <- NL_ALL[Date > as.Date("2017-07-01")]

NL_ALL <- NL_ALL[Date < as.Date("2017-07-01")]
setkey(NL_ALL, Date)

# add round and season
nrounds <- nrow(NL_ALL)/9
nseasons <- nrow(NL_ALL)/(9*34)
NL_ALL <- NL_ALL[, round := rep(1:nrounds, each = 9)]
NL_ALL <- NL_ALL[, season := rep(1:nseasons, each = 34*9)]

# prep 2017/2018 separately
setkey(NL_17, Date)
nrounds <- ceiling(nrow(NL_17)/9)
```

```

start_nr_round <- max(NL_ALL$round)+1

round_vec <- rep(start_nr_round:(start_nr_round + nrounds), each = 9)
NL_17 <- NL_17[, round := round_vec[1:nrow(NL_17)]]
NL_17 <- NL_17[, season := 18]

# add to NL_ALL
NL_ALL <- rbind(NL_ALL, NL_17)

setkey(NL_ALL, Date)

NL_ALL <- NL_ALL[, row_id := 1:nrow(NL_ALL)]

# model checking
# res <- readRDS("output/res_match_type.rds")
# res_upper_lower <- readRDS("output/res_upper_lower.RDS")
# res_upper_lower <- res_upper_lower[, ul_type_name := "Upper / Upper"]
# res_upper_lower <- res_upper_lower[upper_lower_type == 1, ul_type_name := "Upper / Lower"]
# res_upper_lower <- res_upper_lower[upper_lower_type == 0, ul_type_name := "Lower / Lower"]
#
# res_upper_lower_at <- readRDS("output/res_upper_lower_at.RDS")
# res_time <- readRDS("output/res_time.RDS")

```

## MCMC Diagnostics

### Analyse rhat values

We screen all model fits for low  $n_{\text{eff}}$  of high Rhat values. Each model has about 150.000 to 300.000 parameters sampled in total.

```

# # check n_eff for T-dist and skellam base models.
# fit <- readRDS("c:/testversleutel/FITS/fitX_0.rds")
# #print(fit, pars = c("a"))
# fit <- readRDS("c:/testversleutel/FITS/fit_sd_0.rds")
# options(max.print=1000000)
# print(fit)
# Check Rhat
# tidy_rhat_neff_res[, .(mean(Rhat), sd(Rhat)), .(varnames)][order(-V1)][1:10]

```

```
table(tidy_rhat_neff_res$Rhat > 1.07)
```

```
##
## FALSE
## 2050463
```

```
table(tidy_rhat_neff_res$Rhat < 1.04 & tidy_rhat_neff_res$Rhat > 1.02)
```

```
##
## FALSE TRUE
## 2050428 35
```

```
table(tidy_rhat_neff_res$Rhat < 0.99)
```

```
##
```

```
## FALSE
## 2050463

#tidy_rhat_neff_res[, .(sum((ifelse(Rhat > 1.01, 1, 0)))), .(model_nr, shift_nr)][order(-V1)]
tidy_rhat_neff_res[!(varnames %in% c("sigma_a0", "tau_a")) & Rhat > 1.02, .(model_nr, shift_nr, varnames)]

##      model_nr shift_nr  varnames
## 1:         4      27  sigma_a[5]
## 2:         4      48  sigma_a[16]
## 3:         4      54  sigma_a[16]
## 4:         5       6  sigma_a[5]
## 5:         6      55    a[1,7]
## 6:         6      55    a[1,20]
## 7:         6      55    a[2,7]
## 8:         6      55    a[3,7]
## 9:         6      55    a[4,7]
## 10:        6      55    a[5,7]
## 11:        6      55  sigma_a[20]
## 12:        8      44  sigma_a[3]
## 13:        8      44  sigma_a[5]

tidy_rhat_neff_res[(varnames %in% c("sigma_a0", "tau_a")) & Rhat > 1.02, .N,]

## [1] 23

# model 6, shift 55 might have some problems. This is the model without home advantage.
```

## Analyse N\_eff values

```
N_total <- 3000
tidy_rhat_neff_res <- tidy_rhat_neff_res[, neff_ratio := n_eff/N_total]

tidy_rhat_neff_res[neff_ratio < 0.1 , .N, .(varnames, model_nr)]

##      varnames model_nr N
## 1:  sigma_a0         1 3
## 2:   tau_a         1 1
## 3:   tau_a         2 1
## 4:  sigma_a0         3 1
## 5: sigma_a[16]         4 1
## 6:   a[1,7]         6 2
## 7:  sigma_a0         6 5
## 8:   a[2,7]         6 1
## 9:   a[3,7]         6 1
## 10:  a[4,7]         6 1
## 11:  sigma_a0         7 1
## 12:   tau_a         8 3
## 13:  sigma_a0         8 2
## 14:  sigma_a0         9 2

tidy_rhat_neff_res[neff_ratio < 0.1 , .N,]

## [1] 25

tidy_rhat_neff_res[neff_ratio < 0.1 & Rhat >= 1.02,]
```

##	model_nr	name	stan_file
## 1:	1	T-dist original	epl_model.stan
## 2:	1	T-dist original	epl_model.stan
## 3:	2	T-dist with AT advantage	epl_model_art_turf.stan
## 4:	3	Skellam offense/defense	skellam_dynamic.stan
## 5:	6	T-dist no HA	epl_model_no_ha.stan
## 6:	6	T-dist no HA	epl_model_no_ha.stan
## 7:	6	T-dist no HA	epl_model_no_ha.stan
## 8:	6	T-dist no HA	epl_model_no_ha.stan
## 9:	6	T-dist no HA	epl_model_no_ha.stan
## 10:	6	T-dist no HA	epl_model_no_ha.stan
## 11:	6	T-dist no HA	epl_model_no_ha.stan
## 12:	8	T-dist with AT advantage run2	epl_model_art_turf.stan
## 13:	8	T-dist with AT advantage run2	epl_model_art_turf.stan
## 14:	8	T-dist with AT advantage run2	epl_model_art_turf.stan
## 15:	8	T-dist with AT advantage run2	epl_model_art_turf.stan

##	short_name
## 1:	fitX
## 2:	fitX
## 3:	fit_epl_at
## 4:	fit_sd
## 5:	fit_epl_xtra_no_ha
## 6:	fit_epl_xtra_no_ha
## 7:	fit_epl_xtra_no_ha
## 8:	fit_epl_xtra_no_ha
## 9:	fit_epl_xtra_no_ha
## 10:	fit_epl_xtra_no_ha
## 11:	fit_epl_xtra_no_ha
## 12:	fit_epl_at_xtra
## 13:	fit_epl_at_xtra
## 14:	fit_epl_at_xtra
## 15:	fit_epl_at_xtra

##	goal_difference_pred_rep, a
## 1:	goal_difference_pred_rep, a
## 2:	goal_difference_pred_rep, a
## 3:	goal_difference_pred_rep, a, b_home, b_prev
## 4:	goal_difference_pred_rep, a, b_home, b_prev, a_offense, a_defense, mixing_proportion, constant_mu, home_advantage, l
## 5:	goal_difference_pred_rep, a, b_home, b_prev
## 6:	goal_difference_pred_rep, a, b_home, b_prev
## 7:	goal_difference_pred_rep, a, b_home, b_prev
## 8:	goal_difference_pred_rep, a, b_home, b_prev
## 9:	goal_difference_pred_rep, a, b_home, b_prev
## 10:	goal_difference_pred_rep, a, b_home, b_prev
## 11:	goal_difference_pred_rep, a, b_home, b_prev
## 12:	goal_difference_pred_rep, a, b_home, b_prev
## 13:	goal_difference_pred_rep, a, b_home, b_prev
## 14:	goal_difference_pred_rep, a, b_home, b_prev
## 15:	goal_difference_pred_rep, a, b_home, b_prev

##	dist	ata	ha	part_pool	n_ability	zif
## 1:	T-dist	0	1	1	1	0
## 2:	T-dist	0	1	1	1	0
## 3:	T-dist	1	1	1	1	0
## 4:	Skellam	0	1	1	2	1
## 5:	T-dist	0	0	1	1	0

```

## 6: T-dist 0 0 1 1 0
## 7: T-dist 0 0 1 1 0
## 8: T-dist 0 0 1 1 0
## 9: T-dist 0 0 1 1 0
## 10: T-dist 0 0 1 1 0
## 11: T-dist 0 0 1 1 0
## 12: T-dist 1 1 1 1 0
## 13: T-dist 1 1 1 1 0
## 14: T-dist 1 1 1 1 0
## 15: T-dist 1 1 1 1 0
##
## extract_pars active varnames n_eff
## 1: b_home, b_prev, sigma_y 0 tau_a 228.2
## 2: b_home, b_prev, sigma_y 0 sigma_a0 290.5
## 3: b_home, b_prev, sigma_y, art_turf_effect 0 tau_a 297.0
## 4: constant_mu, home_advantage, mixing_proportion 0 sigma_a0 207.3
## 5: b_prev, sigma_y 0 sigma_a0 244.4
## 6: b_prev, sigma_y 0 a[1,7] 212.1
## 7: b_prev, sigma_y 0 a[2,7] 229.1
## 8: b_prev, sigma_y 0 a[3,7] 234.1
## 9: b_prev, sigma_y 0 a[4,7] 270.6
## 10: b_prev, sigma_y 0 sigma_a0 93.8
## 11: b_prev, sigma_y 0 sigma_a0 283.7
## 12: b_home, b_prev, sigma_y, art_turf_effect 0 tau_a 265.3
## 13: b_home, b_prev, sigma_y, art_turf_effect 0 tau_a 287.3
## 14: b_home, b_prev, sigma_y, art_turf_effect 0 sigma_a0 252.0
## 15: b_home, b_prev, sigma_y, art_turf_effect 0 tau_a 209.4
##
## Rhat shift_nr neff_ratio
## 1: 1.025 48 0.07607
## 2: 1.030 54 0.09685
## 3: 1.025 31 0.09901
## 4: 1.034 12 0.06911
## 5: 1.021 24 0.08145
## 6: 1.029 55 0.07072
## 7: 1.027 55 0.07638
## 8: 1.027 55 0.07803
## 9: 1.023 55 0.09019
## 10: 1.066 55 0.03127
## 11: 1.021 61 0.09457
## 12: 1.023 31 0.08843
## 13: 1.032 44 0.09578
## 14: 1.037 53 0.08402
## 15: 1.029 54 0.06982

```

```
tidy_rhat_neff_res[neff_ratio < 0.1 & Rhat < 1.02,]
```

```

## model_nr name stan_file
## 1: 1 T-dist original epl_model.stan
## 2: 1 T-dist original epl_model.stan
## 3: 4 T-dist no pooling epl_model_no_pooling.stan
## 4: 6 T-dist no HA epl_model_no_ha.stan
## 5: 6 T-dist no HA epl_model_no_ha.stan
## 6: 6 T-dist no HA epl_model_no_ha.stan
## 7: 7 Skellam, no zif, offense/defense skellam_dynamic_no_zif.stan
## 8: 8 T-dist with AT advantage run2 epl_model_art_turf.stan
## 9: 9 T-dist run2 epl_model.stan

```

```

## 10:          9                      T-dist run2                      epl_model.stan
##          short_name
## 1:          fitX
## 2:          fitX
## 3:          fit_epl_np
## 4: fit_epl_xtra_no_ha
## 5: fit_epl_xtra_no_ha
## 6: fit_epl_xtra_no_ha
## 7:          fit_sd_nozif
## 8:          fit_epl_at_xtra
## 9:          fit_epl_xtra
## 10:         fit_epl_xtra
##
## 1:
## 2:
## 3:
## 4:
## 5:
## 6:
## 7: goal_difference_pred_rep, a, b_home, b_prev, s
## 8:
## 9:
## 10:
##          dist ata ha part_pool n_ability zif
## 1: T-dist    0 1          1          1 0
## 2: T-dist    0 1          1          1 0
## 3: T-dist    0 1          0          1 0
## 4: T-dist    0 0          1          1 0
## 5: T-dist    0 0          1          1 0
## 6: T-dist    0 0          1          1 0
## 7: Skellam   0 1          1          2 0
## 8: T-dist    1 1          1          1 0
## 9: T-dist    0 1          1          1 0
## 10: T-dist   0 1          1          1 0
##
##          extract_pars active    varnames n_eff
## 1:          b_home, b_prev, sigma_y    0    sigma_a0 271.6
## 2:          b_home, b_prev, sigma_y    0    sigma_a0 288.2
## 3:          b_home, b_prev, sigma_y    0 sigma_a[16] 279.0
## 4:          b_prev, sigma_y            0    a[1,7] 279.1
## 5:          b_prev, sigma_y            0    sigma_a0 234.7
## 6:          b_prev, sigma_y            0    sigma_a0 264.8
## 7:          constant_mu, home_advantage    0    sigma_a0 262.0
## 8: b_home, b_prev, sigma_y, art_turf_effect    0    sigma_a0 246.3
## 9:          b_home, b_prev, sigma_y    0    sigma_a0 252.7
## 10:         b_home, b_prev, sigma_y    0    sigma_a0 285.2
##          Rhat shift_nr neff_ratio
## 1: 1.012          28    0.09052
## 2: 1.018          29    0.09608
## 3: 1.015          50    0.09301
## 4: 1.013          18    0.09304
## 5: 1.015          18    0.07824
## 6: 1.014          20    0.08826
## 7: 1.011          53    0.08733
## 8: 1.020          39    0.08209

```

```
## 9: 1.020      8    0.08422
## 10: 1.017     31    0.09507
```

```
tidy_rhat_neff_res[, .(min = min(n_eff), mean(n_eff), sd(n_eff)), .(model_nr, varnames, name)][order(min
```

```
##      model_nr  varnames      name    min    V2
## 1:         6  sigma_a0      T-dist no HA  93.8  628.3
## 2:         3  sigma_a0  Skellam offense/defense 207.3  675.1
## 3:         8    tau_a  T-dist with AT advantage run2 209.4  728.2
## 4:         6   a[1,7]      T-dist no HA 212.1  948.4
## 5:         1    tau_a  T-dist original 228.2  726.8
## 6:         6   a[2,7]      T-dist no HA 229.1 1036.3
## 7:         6   a[3,7]      T-dist no HA 234.1 1133.7
## 8:         8  sigma_a0  T-dist with AT advantage run2 246.3  661.8
## 9:         9  sigma_a0      T-dist run2 252.7  634.7
## 10:        7  sigma_a0  Skellam, no zif, offense/defense 262.0  665.2
## 11:        6   a[4,7]      T-dist no HA 270.6 1218.4
## 12:        1  sigma_a0  T-dist original 271.6  661.6
## 13:        4 sigma_a[16]      T-dist no pooling 279.0  755.3
## 14:        2    tau_a  T-dist with AT advantage 297.0  732.0
## 15:        6    tau_a      T-dist no HA 302.2  708.8
## 16:        2  sigma_a0  T-dist with AT advantage 305.6  700.5
## 17:       10    tau_a  Skellam offense/defense with AT 323.6  748.2
## 18:       10  sigma_a0  Skellam offense/defense with AT 336.2  676.5
## 19:        9    tau_a      T-dist run2 336.3  703.9
## 20:        3 sigma_a[7]  Skellam offense/defense 341.8 1037.9
```

```
##      V3
## 1: 199.5
## 2: 144.5
## 3: 223.6
## 4: 314.3
## 5: 186.1
## 6: 334.7
## 7: 344.8
## 8: 192.2
## 9: 178.0
## 10: 181.0
## 11: 346.4
## 12: 197.4
## 13: 241.0
## 14: 204.8
## 15: 199.0
## 16: 208.2
## 17: 171.2
## 18: 198.8
## 19: 172.2
## 20: 202.6
```

```
tidy_rhat_neff_res[varnames != "sigma_a0", .(min = min(n_eff), mean(n_eff), sd(n_eff)), .(model_nr, var
```

```
##      model_nr  varnames      name    min    V2
## 1:         8    tau_a  T-dist with AT advantage run2 209.4  728.2
## 2:         6   a[1,7]      T-dist no HA 212.1  948.4
## 3:         1    tau_a  T-dist original 228.2  726.8
## 4:         6   a[2,7]      T-dist no HA 229.1 1036.3
```

```
## 5:      6      a[3,7]                      T-dist no HA 234.1 1133.7
## 6:      6      a[4,7]                      T-dist no HA 270.6 1218.4
## 7:      4 sigma_a[16]                    T-dist no pooling 279.0 755.3
## 8:      2      tau_a                    T-dist with AT advantage 297.0 732.0
## 9:      6      tau_a                    T-dist no HA 302.2 708.8
## 10:     10      tau_a Skellam offense/defense with AT 323.6 748.2
## 11:      9      tau_a                    T-dist run2 336.3 703.9
## 12:      3 sigma_a[7]                    Skellam offense/defense 341.8 1037.9
## 13:      1 sigma_a[5]                    T-dist original 346.9 979.0
## 14:      6      a[5,7]                    T-dist no HA 361.2 1372.6
## 15:      4 sigma_a[12]                  T-dist no pooling 375.1 766.1
## 16:      8 sigma_a[3]                    T-dist with AT advantage run2 376.5 1087.6
## 17:      1      a[1,7]                    T-dist original 389.4 1051.3
## 18:      8 sigma_a[5]                    T-dist with AT advantage run2 393.1 982.6
## 19:      8 sigma_a[14]                  T-dist with AT advantage run2 407.5 1040.2
## 20:      7      tau_a Skellam, no zif, offense/defense 417.4 755.5
##      V3
## 1: 223.6
## 2: 314.3
## 3: 186.1
## 4: 334.7
## 5: 344.8
## 6: 346.4
## 7: 241.0
## 8: 204.8
## 9: 199.0
## 10: 171.2
## 11: 172.2
## 12: 202.6
## 13: 254.7
## 14: 442.3
## 15: 176.9
## 16: 252.2
## 17: 328.2
## 18: 262.8
## 19: 277.5
## 20: 165.1
```

```
#summary(tidy_rhat_neff_res[varnames == "tau_a" & model_nr == 10, ]$n_eff)
```

The parameters with the lowest `n_eff` are the `sigma_a0`, that we use to initialize the time series. And `tau`, the hyper prior for the hierarchical model.

## MCMC error and run consistency

To check MCMC error / consistency of MCMC runs, we ran for two models the whole forecasting procedure (including fitting all out of sample weeks) twice and compared our main quantity of interest, the RPS score per match.

```
# check correlation between runs
rps_tdist <- NL_ALL_PRED[model_nr %in% c(1, 9) & has_pred == 1,.(matchKey, round, rps_vec, model_nr)]
rps_tdist_cast <- dcast(rps_tdist, matchKey + round ~ model_nr, value.var = "rps_vec")
cor(rps_tdist_cast[, "1", with = F], rps_tdist_cast[, "9", with = F])
```

```
##      9
```



```
## 1 0.9976
# 0.998

# check correlation between runs
rps_tdist <- NL_ALL_PRED[model_nr %in% c(2, 8) & has_pred == 1,.(matchKey, round, rps_vec, model_nr)]
rps_tdist_cast <- dcast(rps_tdist, matchKey + round ~ model_nr, value.var = "rps_vec")
cor(rps_tdist_cast[, "2", with = F], rps_tdist_cast[, "8", with = F])

##          8
## 2 0.9979
# 0.998
```

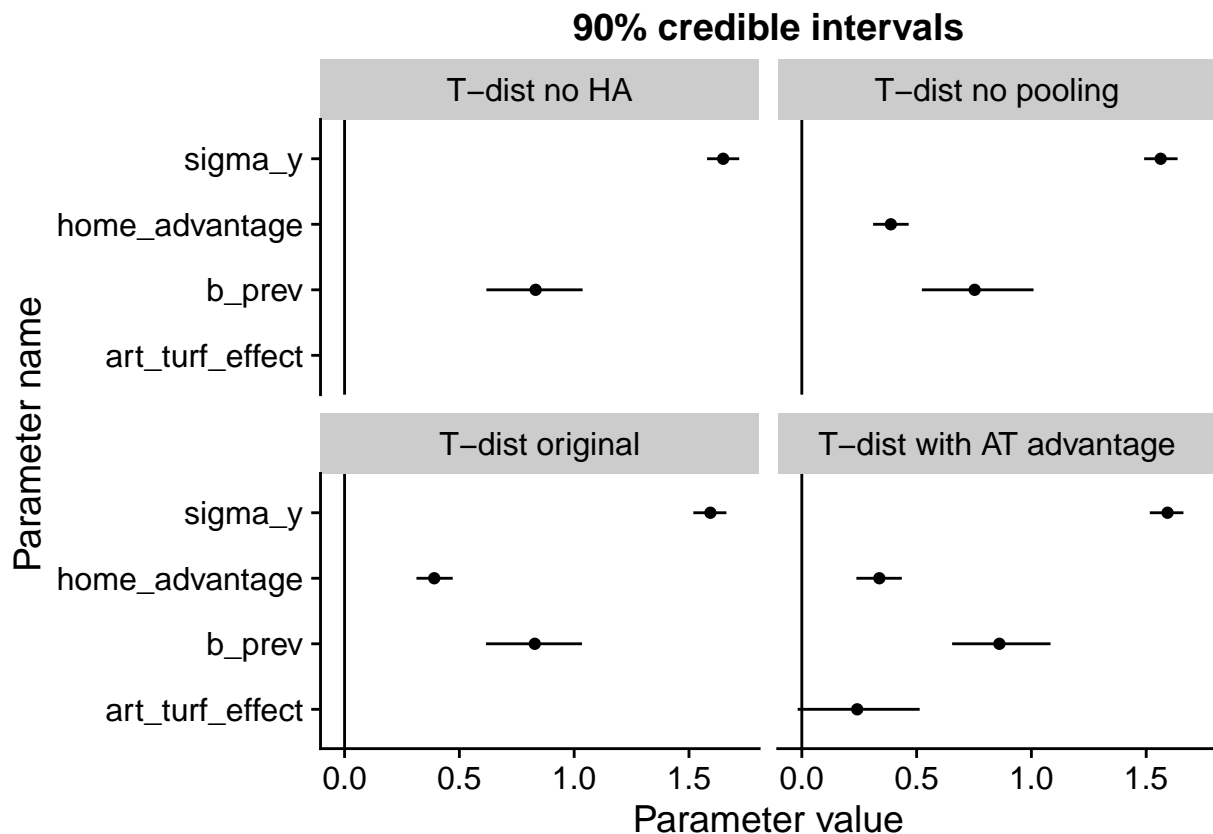
We judge that the correlation is sufficiently high for our purposes.

## Panel plot of in-sample coefficients using four seasons of data

### T-distribution models

Plot all coefs for all models in one big panel plot. Do this for the final model (ie.. shift\_nr = 67)

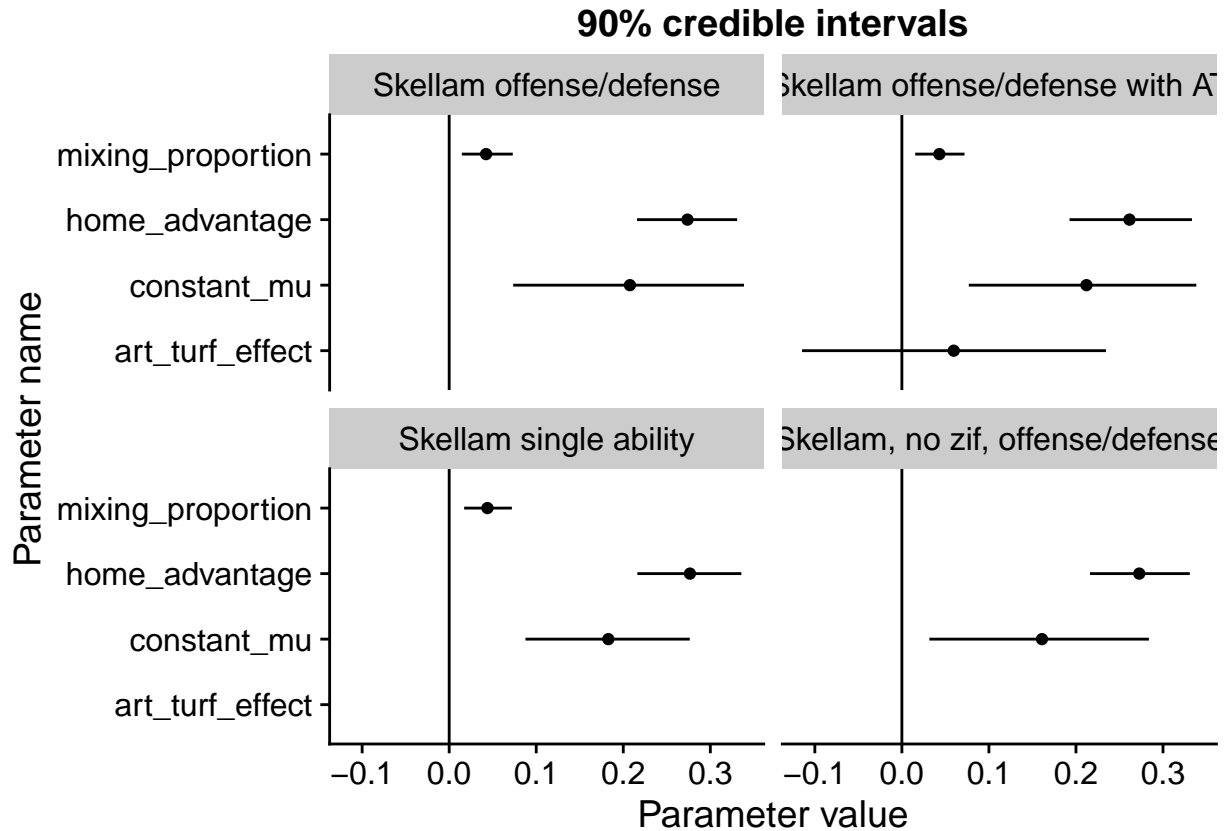
```
ggplot(tidy_coef_res[shift_nr == 67 & !(model_nr %in% c(8,9)) & dist == "T-dist",] , aes(x=L1, y = Q50)) +
  geom_linerange(aes(ymin = Q5, ymax = Q95)) +
  geom_line() + geom_point() + facet_wrap(~ name) + coord_flip() +
  geom_hline(yintercept = 0) + ggtitle("90% credible intervals") + ylab("Parameter value") + xlab("Parameter name")
```



## Skellam models

Plot all coefs for all models in one big panel plot. Do this for the final model (ie.. shift\_nr = 67)

```
ggplot(tidy_coef_res[shift_nr == 67 & !(model_nr %in% c(8,9)) & dist == "Skellam",] , aes(x=L1, y = Q50)) +
  geom_linerange(aes(ymin = Q5, ymax = Q95)) +
  geom_line() + geom_point() + facet_wrap(~ name) + coord_flip() +
  geom_hline(yintercept = 0) + ggtitle("90% credible intervals") + ylab("Parameter value") + xlab("Parameter name")
```



## DM-like test for differences in predictions

Can we perform statistical testing to compare the RPS values from two models? (Constantinou et al plot the cumulative RPS difference.) Use the best bookmaker odds as reference.

```
knitr::kable(result_by_model[!(model_nr %in% c(8,9)), .(model_nr, name, DMstat_12, DMpval_12)] [order(DMstat_12)])
```

model_nr	name	DMstat_12	DMpval_12
13	Equal probability odds	-8.443	0.000
4	T-dist no pooling	-2.986	0.003
6	T-dist no HA	-2.915	0.004
1	T-dist original	-1.727	0.085
2	T-dist with AT advantage	-1.715	0.087
5	Skellam single ability	-1.674	0.095
11	William_hill odds	-1.469	0.142
3	Skellam offense/defense	-1.440	0.150

model_nr	name	DMstat_12	DMpval_12
10	Skellam offense/defense with AT	-1.427	0.154
7	Skellam, no zif, offense/defense	-1.283	0.200
12	Bet365 odds	NA	NA

So it appears that for both the partial pooling and the regular home advantage we have sufficient statistical power to conclude that those models perform worse in OOS predictions. As well as the equal probability reference predictions.

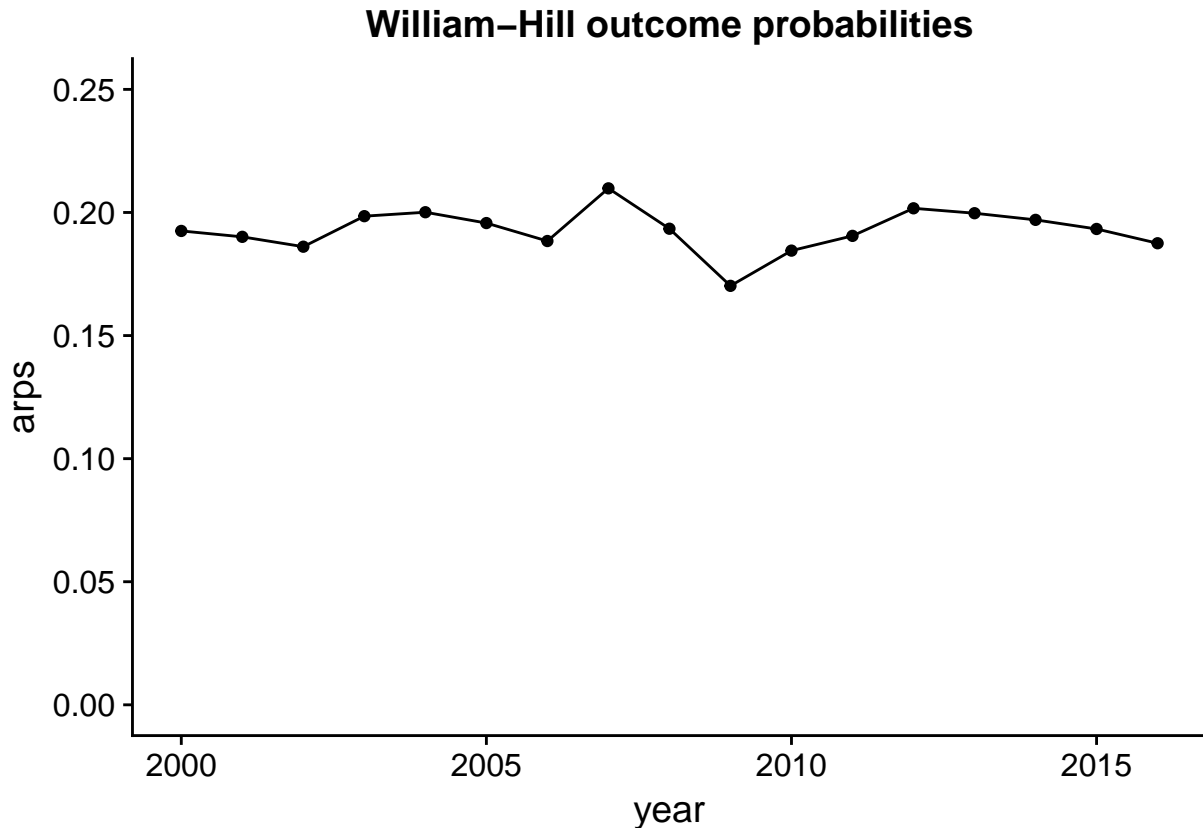
The other models can not reliably be distinguished based on 608 match predictions.

## Analyse Bookmaker odds over time 2000-2017

Check year to year variability in the average RPS of William Hill. Apparently sometimes there are no odds for a match.

```
arps_season <-c()
for(i in 1:17){
  WH_probs <- odds_to_probability(NL_ALL[season %in% c(i), .(WHH, WHD, WHA)])
  actual_scorez <- Convert_actual_to_win_draw_loss_vector(NL_ALL[season %in% c(i),]$goal_difference)
  # select non-NA records
  selection <- !is.na(WH_probs$prob_win)
  arps_season[i] <- calculate_arps(WH_probs[selection,.( prob_win, prob_draw, prob_loss)], actual_scorez)
}

ggplot(data.frame(year = 2000:2016, arps = arps_season), aes(x= year, y = arps)) +
  geom_point() + ylim(0, 0.25) + geom_line() + ggtitle("William-Hill outcome probabilities")
```



We conclude that there is a large variability from season to season ranging between 0.17 and 0.2.

## Calculate Bookmaker benchmark for Lit et al study

Check what the benchmark is, **\*\* exactly \*\***, for the Lit study. They use the period 2009/2010 to 2015/2016, i.e. the average of seven seasons as out-of-sample.

```
# calculate arps bookmakers for oos period Lit:
WH_probs <- odds_to_probability(NL_ALL[season %in% c(10:16), .(WHH, WHD, WHA)])
actual_scorez <- Convert_actual_to_win_draw_loss_vector(NL_ALL[season %in% c(10:16),]$goal_difference)
# select non-NA records
selection <- !is.na(WH_probs$prob_win)
print(calculate_arps(WH_probs[selection,.(prob_win, prob_draw, prob_loss)], actual_scorez[selection,.](
## [1] 0.191
```

So Lit et al also do not “beat the bookies” with their best dynamic models (0.193) for the NL Eredivisie.

## analyse long shot bias

There is some literature on “long shot bias” in bookmakers odds, where models could outperform the bookmakers. We interpret this as checking calibration for low-probability events. To get sufficient statistics, we choose the probability bin between 5% and 15%. Check all three outcomes.

For 100 events with a probability of 0.1 of happening, we expect a range of values between 5 and 15, ie.. percentages of 0.05 to 0.15.

```
summary(rbinom(1000, 100, 0.1))
```

```
##      Min. 1st Qu.  Median    Mean 3rd Qu.    Max.
##      2.0     8.0    10.0    10.1    12.0    22.0
```

```
summary(rbinom(1000, 50, 0.1))
```

```
##      Min. 1st Qu.  Median    Mean 3rd Qu.    Max.
##      0.00   4.00   5.00   4.99   6.00   12.00
```

```
NL_ALL_PRED[p_win >= 0.05 & p_win < 0.15, .(mean(act_win), .N), .(model_nr)][order(-N)]
```

```
##      model_nr      V1  N
## 1:         6 0.09804 51
## 2:        12 0.08571 35
## 3:         5 0.09677 31
## 4:         8 0.09677 31
## 5:         2 0.10000 30
## 6:        10 0.10000 30
## 7:         3 0.10714 28
## 8:        11 0.11538 26
## 9:         1 0.11538 26
## 10:        4 0.12000 25
## 11:        9 0.12000 25
## 12:        7 0.13043 23
```

```
NL_ALL_PRED[p_draw >= 0.05 & p_draw < 0.15, .(mean(act_draw), .N), .(model_nr)][order(-N)]
```

```
##      model_nr      V1  N
## 1:         4 0.2158 139
## 2:         2 0.2000  75
## 3:         8 0.1831  71
## 4:         1 0.1884  69
## 5:         9 0.1940  67
## 6:         6 0.2419  62
## 7:        12 0.1707  41
## 8:         7 0.2432  37
## 9:        11 0.2308  26
## 10:        5 0.1538  13
## 11:        10 0.2000  10
## 12:         3 0.1250   8
```

```
NL_ALL_PRED[p_loss >= 0.05 & p_loss < 0.15, .(mean(act_loss), .N), .(model_nr)][order(-N)]
```

```
##      model_nr      V1  N
## 1:        12 0.06306 111
## 2:        10 0.09000 100
## 3:         5 0.08163  98
## 4:         3 0.07368  95
## 5:        11 0.05376  93
## 6:         7 0.06818  88
## 7:         9 0.06818  88
## 8:         2 0.08046  87
## 9:         4 0.05814  86
## 10:        1 0.04878  82
```

```
## 11:      8 0.07317  82
## 12:      6 0.02000  50
```

The actual frequency for low probability wins and losses are within acceptable range of sampling error if we assume that the predicted probabilities are correct. The frequencies for the low probability draws however are structurally too high (around 20% instead of 10%). I.e. they occur more often than predicted.

## Model checking

The Rank Probability score quantifies the quality of our model-based forecasts. We can use this metric to learn about the performance of our models. The purpose is not to select the best model, but to identify strengths and weaknesses for each model, and how they compare with one another.

We stratify the matches along four dimensions and calculating average RPS for each stratum:

- Team type (Artificial turf or natural grass)
- playing surface type (Artificial turf or natural grass)
- Relative team strength
- time (Round number)

```
res <- NL_ALL_PRED[, .(arps = mean(rps_vec, na.rm = T),
                                N = length(na.omit(rps_vec))), .(match_type,model_nr)]
setkey(res, model_nr)
setkey(result_by_model, model_nr)
res <- result_by_model[res]
#res

# use in manuscript
saveRDS(res, "output/res_match_type.rds")
```

As a benchmark, we also plot the odds-derived predictions, as well as the before mentioned equal-probability (win, draw, loss) uninformed model.

## T-distribution models stratified by relative team strength

We start with comparing the T-distribution models. We expect that matches where the team abilities are similar are more difficult to predict. Based on a two-season league table, we label each team as relatively “strong” when it ranks in the upper half of the league table, and as relatively “weak” when it ends up in the lower half of the ranking. With these labels, we then classify each match as a match between two strong teams, a match between a weak and a strong team, or a match between two weak team. For each of the three match types we calculate the average RPS for each model. The results are plotted in Figure ??fig:figTdist). It should be noted that the “Lower / Lower” segment contains less matches (N = 110) than the “Upper / Upper” segment (N= 180) because of relegated and promoted teams between the two seasons.

```
ltab <- create_league_table(NL_ALL_PRED)
lower_half <- ltab[order(total_points)][1:10,]$HomeTeam
upper_half <- ltab[order(total_points)][11:20,]$HomeTeam

NL_ALL_PRED[, upper_lower_type := 0]
NL_ALL_PRED[HomeTeam %in% upper_half, upper_lower_type := upper_lower_type+1]
NL_ALL_PRED[AwayTeam %in% upper_half, upper_lower_type := upper_lower_type+1]

res_upper_lower <- NL_ALL_PRED[, .(arps = mean(rps_vec, na.rm = T),
                                N = length(na.omit(rps_vec))), .(upper_lower_type, model_nr)]
```

```

setkey(res_upper_lower, model_nr)
setkey(result_by_model, model_nr)
res_upper_lower <- result_by_model[res_upper_lower]

res_upper_lower <- res_upper_lower[, ul_type_name := "Upper / Upper"]
res_upper_lower <- res_upper_lower[upper_lower_type == 1, ul_type_name := "Upper / Lower"]
res_upper_lower <- res_upper_lower[upper_lower_type == 0, ul_type_name := "Lower / Lower"]

saveRDS(res_upper_lower, "output/res_upper_lower.RDS")

```

We first compare the base model (with home advantage and partial pooling) with odds-based predictions, as well as models that leave out these two elements.

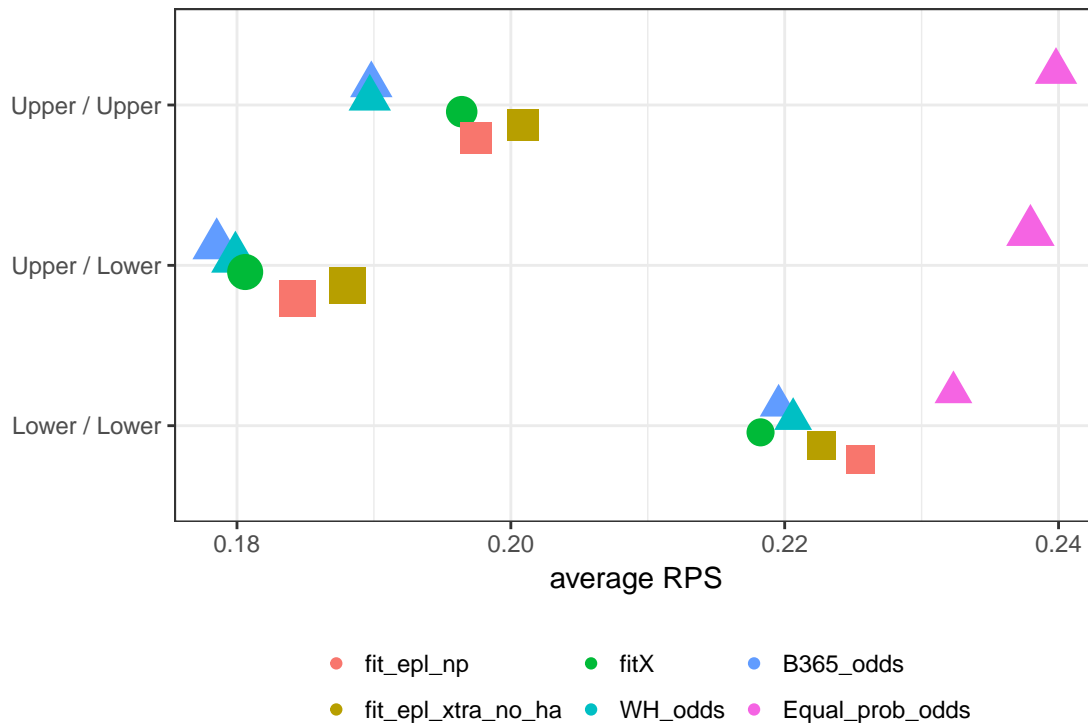


Figure 1: T-distribution models compared by match type.

Not including the regular home advantage, or leaving out the partial pooling caused by the hierarchical model results in worse predictions for all three match types (squared symbols). From here on we consider these two elements as “must haves” for optimal predictive performance, and no longer include them in the graphs. Compared to the odds-based predictions (triangle symbols), we find that only for matches between two lower ranking teams do the model predictions perform (slightly) better. The largest room for model improvement seems to be for matches between two “upper half” ranking teams.

Next we compare the base model with an expanded model that includes the artificial turf advantage (ATA) predictor. Figure @ref(fig:figTdistATA) shows both models.

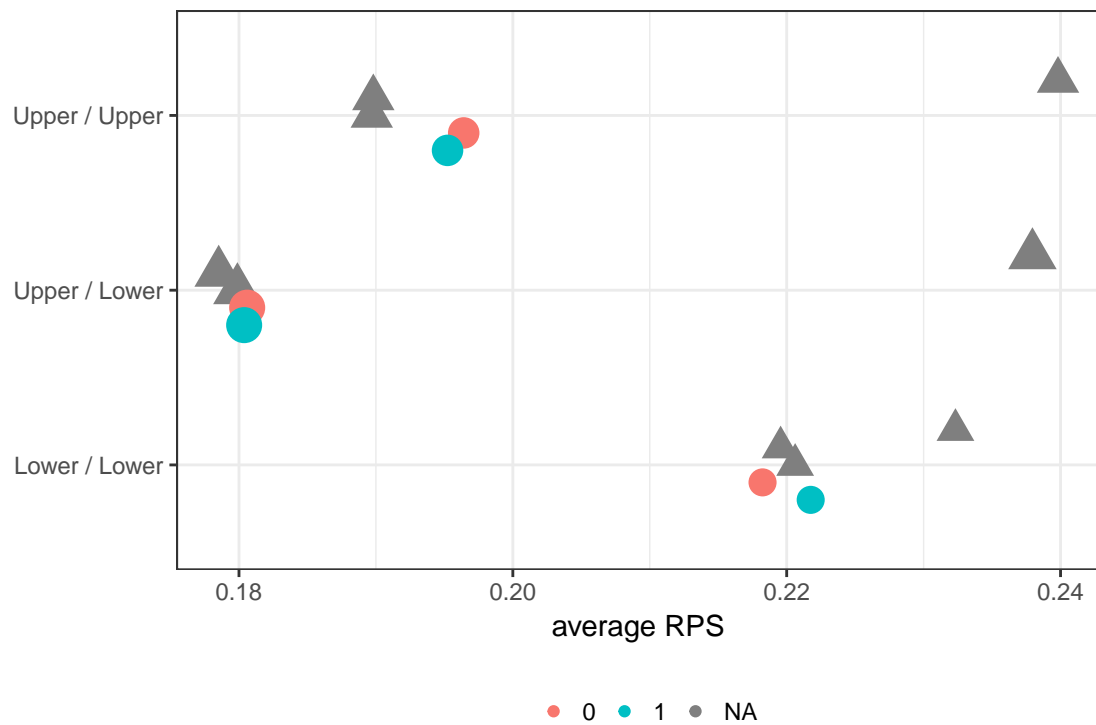


Figure 2: T-distribution model with and without Artificial turf advantage.

Including the ATA predictor slightly improves predictions for matches between upper half ranking teams (i.e. Heracles), but results in worse predictions for matches between lower half ranking teams. For matches between a strong and a weak team, the quality of the predictions is similar for both models.



## T-distribution models by Team playing surface

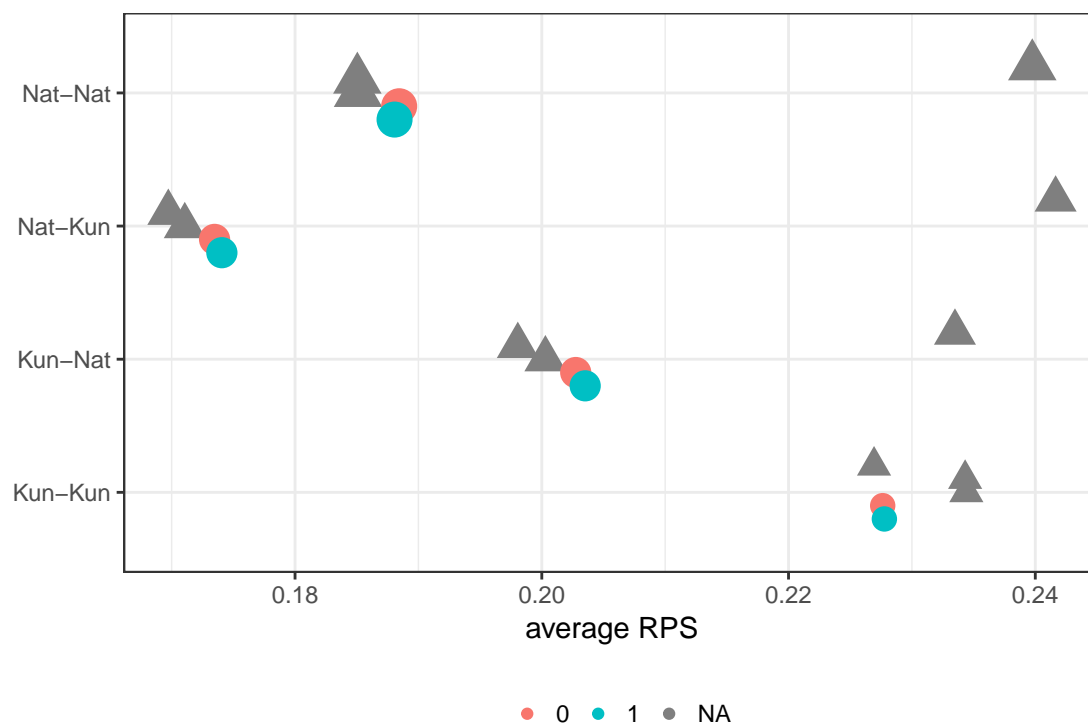


Figure 3: T-distribution model with and without Artificial turf advantage by playing surface.

We see that there is no stratum for which the artificial turf model clearly outperforms the base T-distribution model.

## Skellam models stratified by relative team strength

We also compare several Skellam models. Here we focus on the choice between one or two team ability parameters, as well as the zero inflation component.

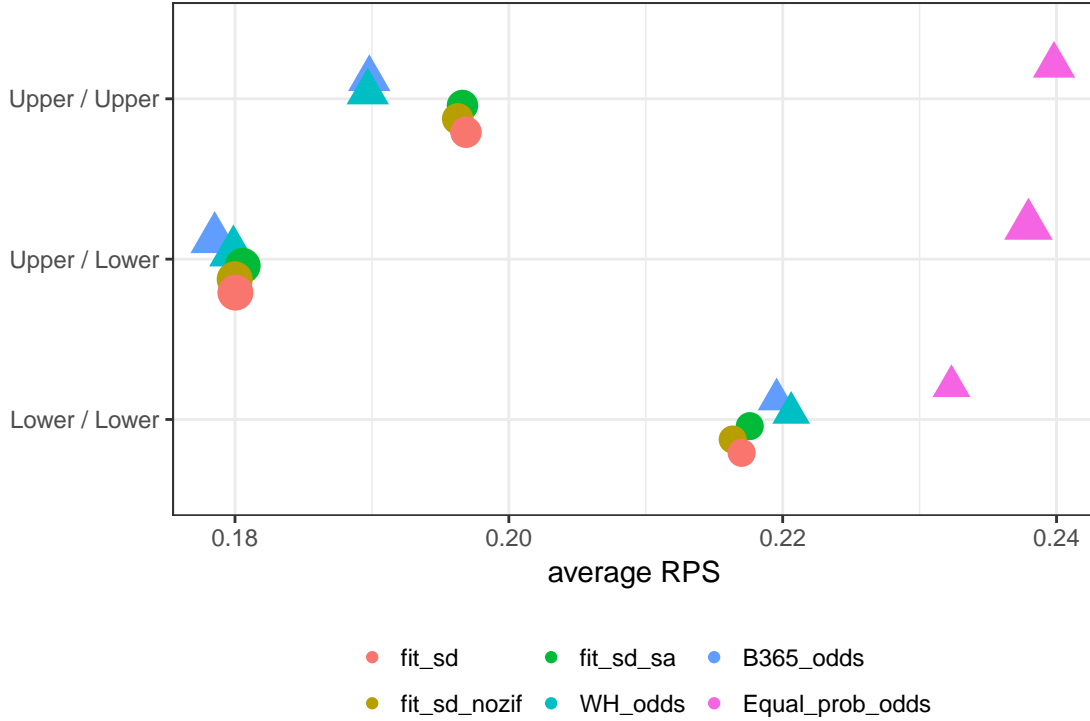


Figure 4: Skellam models compared by Relative team strength match type.

Interestingly, when two strong teams play each other, the odd-based predictions clearly outperforms the Skellam models. For matches between a lower half ranking team and a upper half ranking team, the models perform similar to the betting odds derived predictions. And finally, when two lower half ranking teams play each other, the models outperform the betting odds.

The differences between the three Skellam variants are very small. The model with a single team strength parameter appears slightly worse. Leaving out the zero inflation slightly improves the predictions. That adding a zero inflation element does not contribute to model fit was also found by [@karlis\_bayesian\_2009-1] as well as [@koopman\_dynamic\_2014-1].

Next we compare the base Skellam model with an expanded model that includes the artificial turf advantage (ATA) predictor. Figure @ref(fig:figSkellamATA) shows both models.

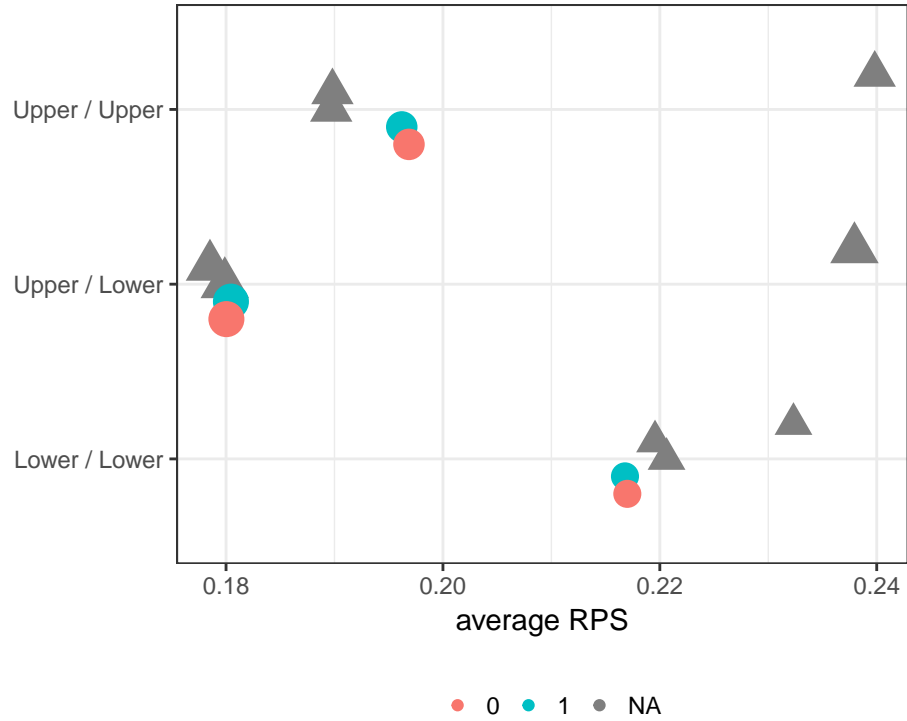


Figure 5: Skellam model with and without Artificial turf advantage.

For all three categories, the average RPS is very similar comparing with and without the artificial turf advantage parameter. Including the AT effect slightly improves predictions between two upper half ranking teams (as we see later because match outcome prediction for Heracles improve), but at the cost of slightly worse predictions for matches between an upper half and a lower half ranking team.

## Skellam models by Team playing surface

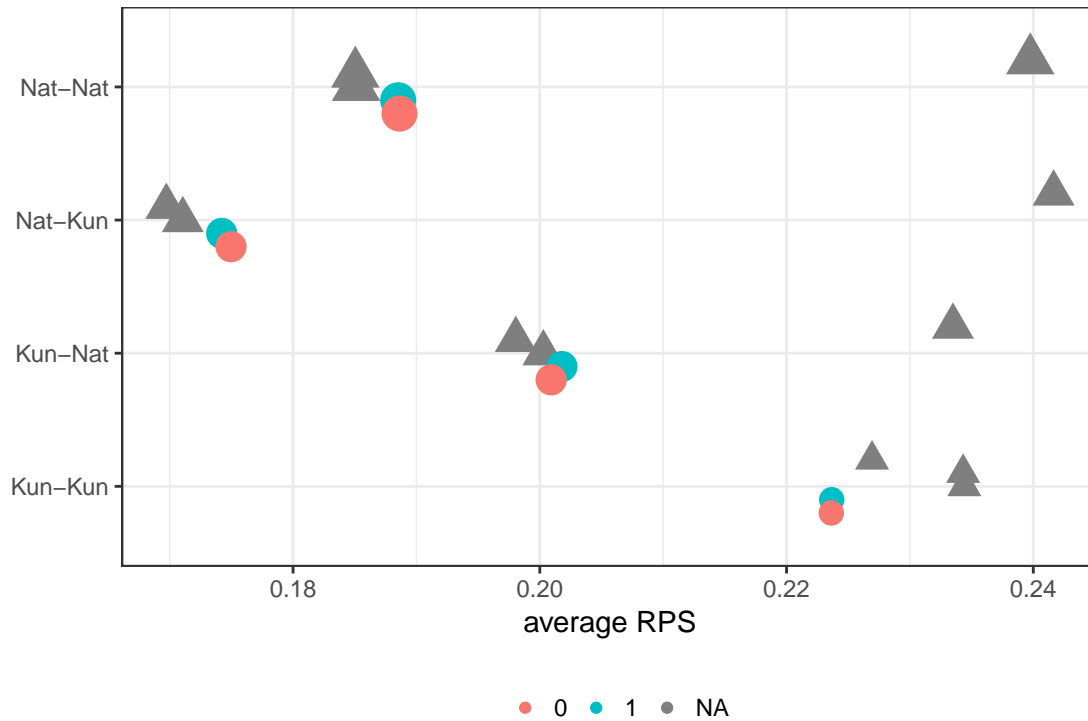


Figure 6: Skellam model with and without Artificial turf advantage by playing surface.

We see that there is no stratum for which the artificial turf model clearly outperforms the base Skellam model.

## Stratifying by Match surface and relative team strength

```
res_upper_lower_at <- NL_ALL_PRED[, .(arps = mean(rps_vec, na.rm = T),
      N = length(na.omit(rps_vec))), .(upper_lower_type, art_turf, model_nr)]

res_upper_lower_at[, upper_lower_art_turf_type := paste(upper_lower_type, "at=", art_turf, sep = '')]
setkey(res_upper_lower_at, model_nr)
setkey(result_by_model, model_nr)
res_upper_lower_at <- result_by_model[res_upper_lower_at]
saveRDS(res_upper_lower_at, "output/res_upper_lower_at.RDS")
```

In Figure x, we stratify the matches by playing surface type and relative team strength. There are clear differences in predictability in this section, with matches played on natural grass between a relatively strong and a relatively weak team having the highest predictability.

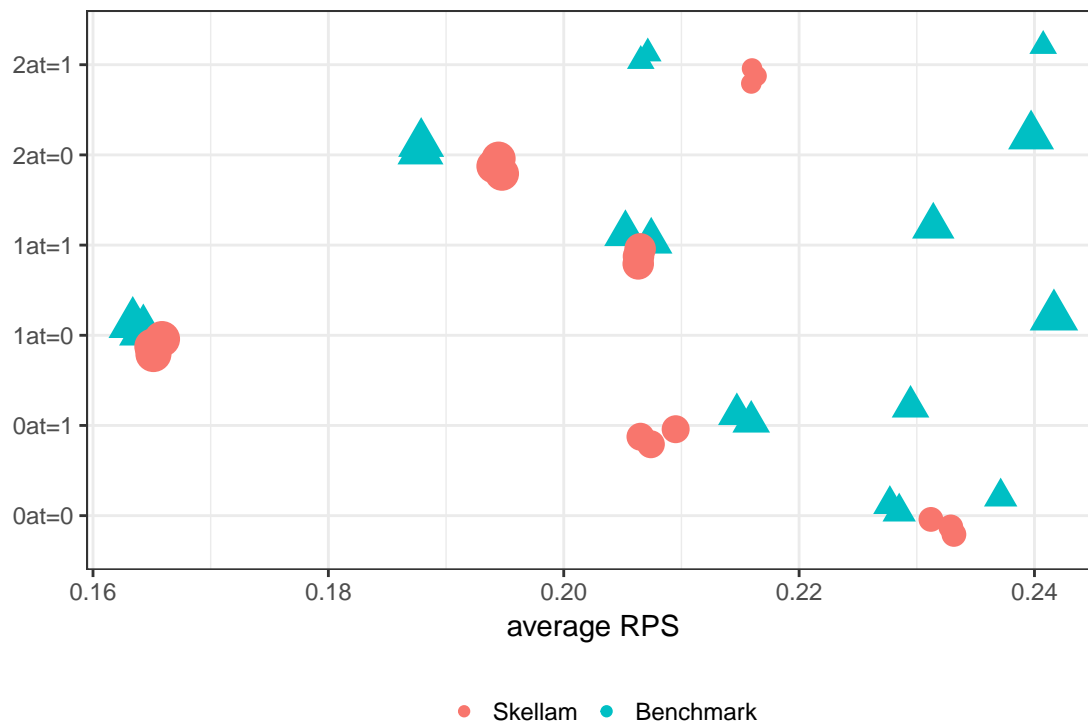


Figure 7: Skellam models compared by playing surface and relative team strength.

Here we find that there are no large differences between the various “flavors” for the Skellam. Now compare base model with and without AT:

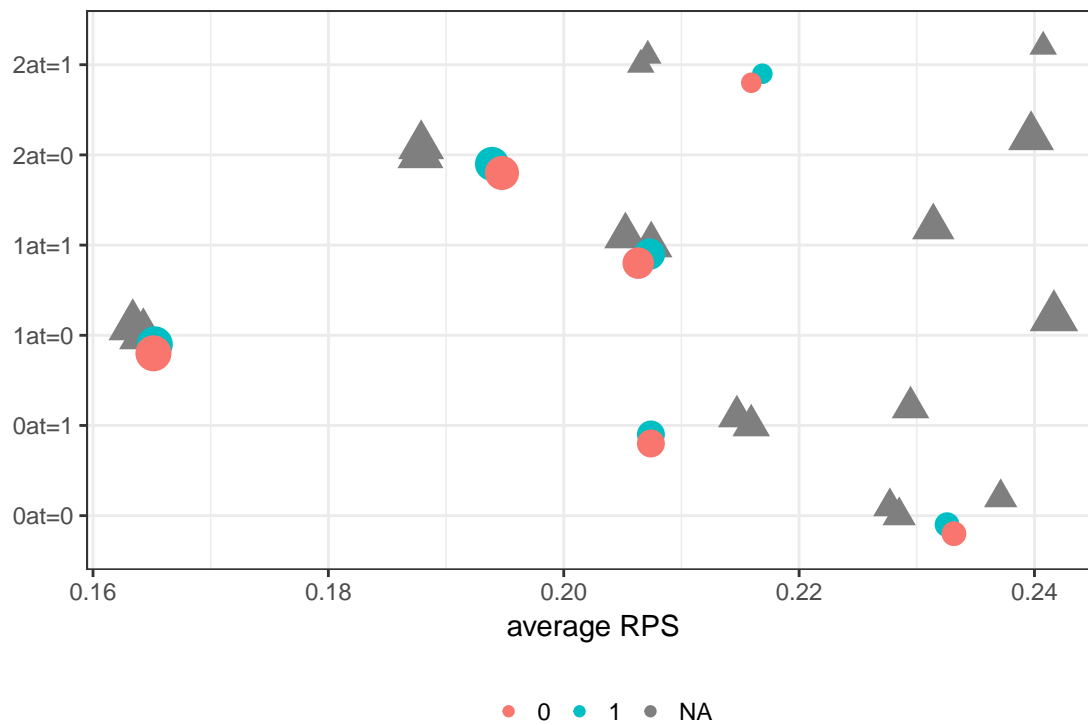


Figure 8: Skellam models compared by playing surface and relative team strength.

Including the AT parameter does not do much, but since the coefficient is small this is no surprise.

## Comparing Skellam and t-distribution models by match surface x relative team strength

Compare the best Skellam and T-dist models with this slicing:

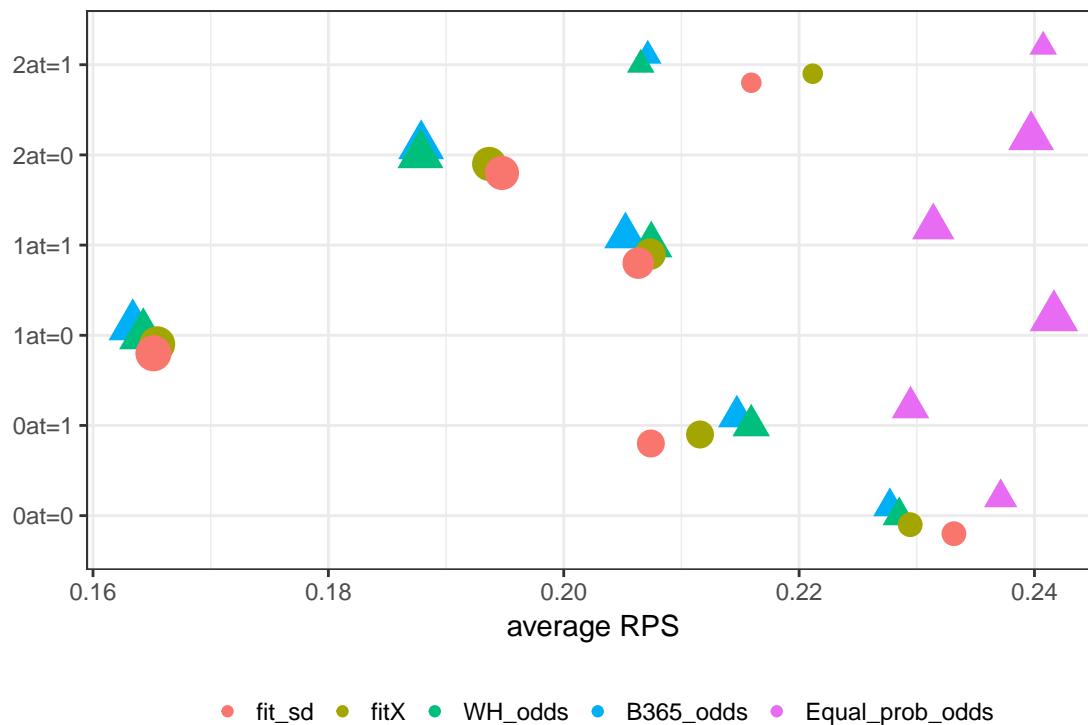


Figure 9: Skellam models compared by match surface type and relative team strength.

We see that for some subgroups, the Skellam model outperforms the t-distribution model and vice versa.

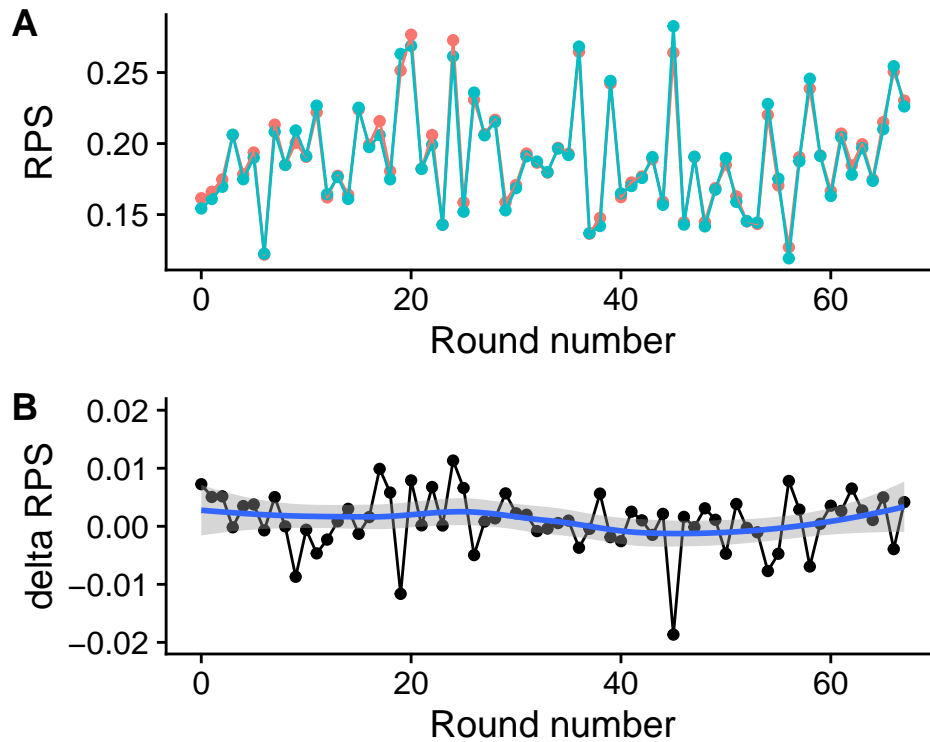
## Stratifying by round (time)

Given the suggestion that the artificial turf effect is strongest during the second season of forecasts, we check how the predictions of the various models change over time.

```
res_time <- NL_ALL_PRED[, .(arps = mean(rps_vec, na.rm = T),
                                   N = length(na.omit(rps_vec))), .(model_nr, round)]
setkey(res_time, model_nr)
setkey(result_by_model, model_nr)
res_time <- result_by_model[res_time]
saveRDS(res_time, "output/res_time.rds")
```

We first compare the two bookmakers, to see how they line up.

```
## `geom_smooth()` using method = 'loess'
```



There are small differences in the forecast accuracy between the two bookmakers, but no particular trend over time.

Next, we are curious if the artificial turf advantage model starts outperforming the base model in the second season, when the in-sample coefficient value for the artificial turf advantage starts to increase.

We first compare the t-distribution model with and without AT effect:

```
## `geom_smooth()` using method = 'loess'
## Warning: Removed 1 rows containing non-finite values (stat_smooth).
## Warning: Removed 1 rows containing missing values (geom_point).
```



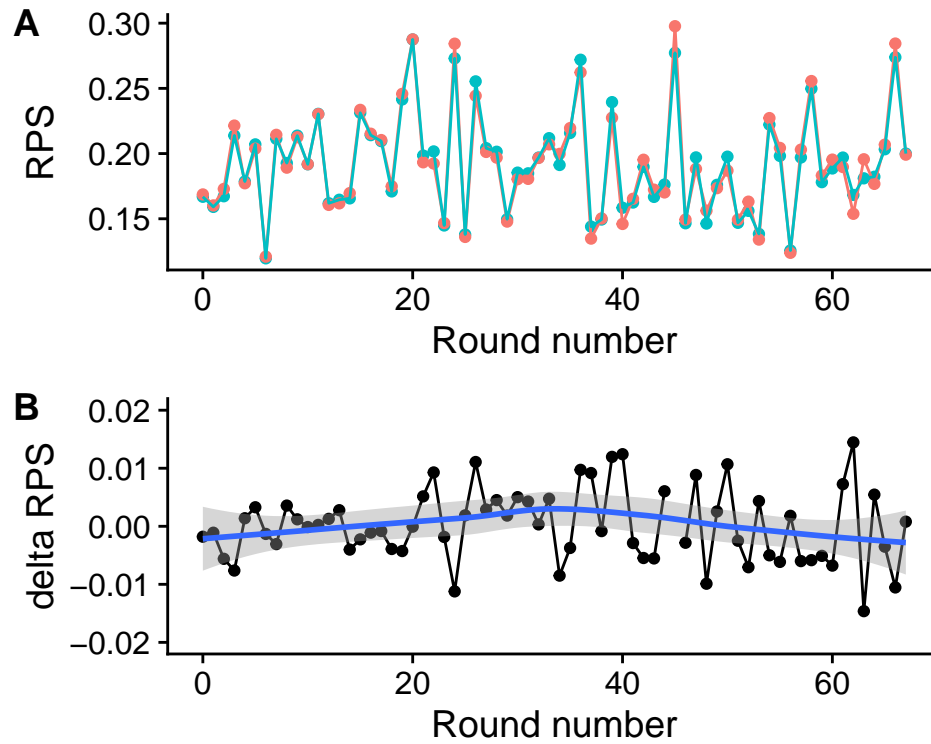


Figure 10: T-distribution model with and with artificial turf advantage.

This turns out not to be the case. There appears no pattern over time in differences between the parametric models.

The same check for the Skellam model:

```
## `geom_smooth()` using method = 'loess'
```

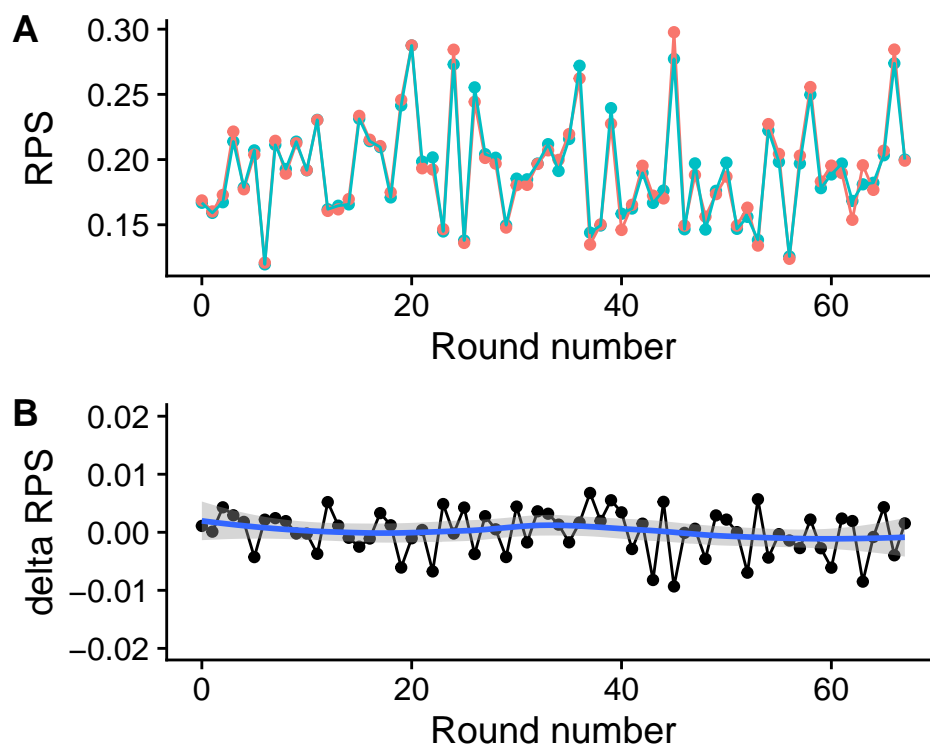


Figure 11: Skellam model with and with artificial turf advantage.

For the Skellam model with and without AT effect, the difference in weekly averaged RPS over time are very small, consistent with the small estimated value of the parameter.

Finally, we compare the best bookmaker odds (Bet365) to our best parametric model, the Skellam model without zero inflation. This might suggests directions for improvement.

```
## `geom_smooth()` using method = 'loess'
```

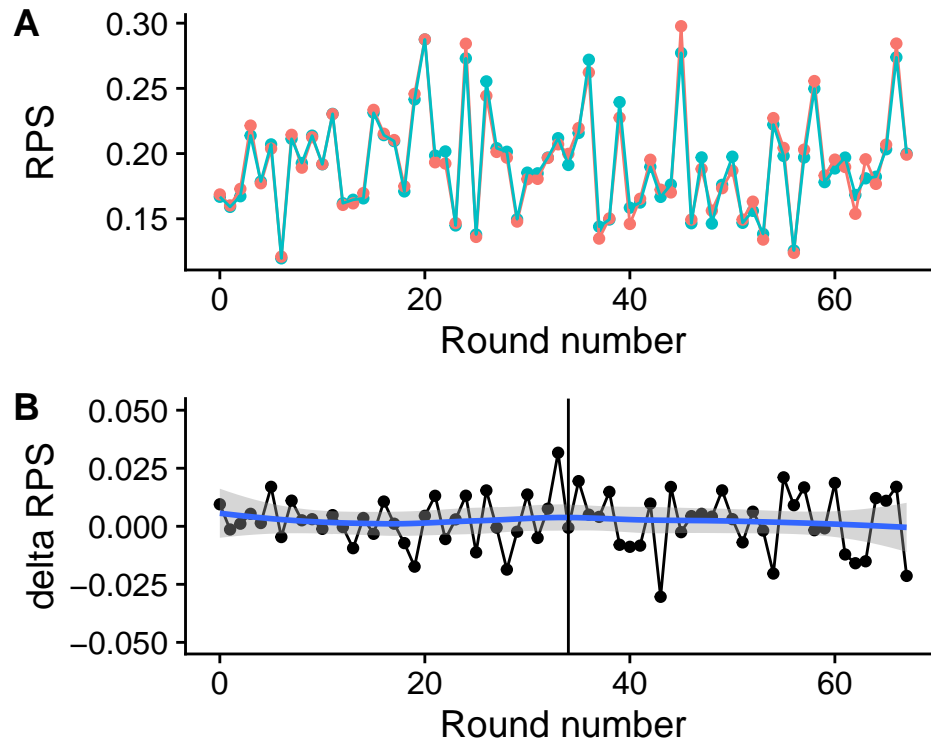


Figure 12: Bet365 vs best Skellam model forecasts compared over time.

In particular the last round of the first season shows the models performing worse. However, this is reversed for the last round of the second season.