Home advantage of European major football leagues under COVID-19 pandemic

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Abstract

After March 2020, the environment surrounding football has changed dramatically due to COVID-19 pandemic. After a few months’ break, the re-scheduled matches have been held behind the closed door without spectators. The main objective of this study is a quantitative evaluation of “crowd effects” on home advantage, using the match results of the closed matches. The proposed analysis uses pairwise comparison method in order to reduce the effects caused by unbalanced schedule. The following conclusion can be drawn from some statistical hypothesis tests: In four major European leagues, the home advantage is reduced in closed matches compared to normal situation with spectators. The reduction amount among leagues is different. In Germany, it shows the negative home advantage during the closed period. On the other hand, in England, statistically significant difference cannot be found between closed and normal situations.

I. INTRODUCTION

After March 2020, the environment surrounding football has changed dramatically — due to COVID-19 pandemic. Most of football leagues had been forced to be suspended, similar to many other crowd-pleasing events. Some of the leagues had been cancelled, while others resumed after a few months’ break. The resumed leagues, however, no decision was made to bring the spectators as before the suspension. The re-scheduled matches has been held behind the closed door without spectators.

The objective of this paper is to analyse how this unfortunate and unacceptable closed situation affected the match outcome of football. In particular, our main objective is a quantitative evaluation of “crowd effects” on home advantage.

Today, it seems that the existence of “home advantage” in sports, especially football, cannot be questioned[1][2][3]. However, there is still no definitive evidence on the factors that produce home advantage. Of course, the quantitative impact of each factor on home advantage has also been discussed.

“Home advantage” can be defined as that home teams consistently win more than 50 percent of the games under a balanced home-and-away schedule[4]. Quantitative research on home advantage in football dates back nearly 40 years ago to Morris[5], then, Dowie[6] and Pollard[2] followed. In a very brief and thorough review paper on home advantage[7], consisting of only three pages, Pollard presented eight main factors that could generate home advantage and explained conventional studies for each (of course, he did not forget to mention those interactions.
and other factors). The first one is “crowd effect”, i.e., effect caused by spectators. In [7], he wrote that “This is the most obvious factor involved with home advantage and one that fans certainly believe to be dominant[8][9].” Studies by Dowie[6] and Pollard[2] could find very little evidence that home advantage depends on crowd density (spectators per stadium capacity).

This paper utilizes the results of matches behind closed door held under the influence of the COVID-19 pandemic to determine the relationship between the presence of spectators and home advantage. Reade et al. used the results of the matches behind closed door since 2003 and reported a study on crowd effect[10]. The number of the matches in empty stadium, however, is small (160 out of approx. 34 thousand matches). In addition, in these closed matches, teams have typically been banned from admitting supporters into their stadiums as punishments for bad behaviour off the football pitch (e.g., due to corruption, racist abuse, or violence). Therefore, in this analysis, spectators’ characteristics could be biased, e.g., they were excessively violent or doing overly aggressive supporting behavior.

When making use of the results of these closed matches, it should also be noted that the schedule is unbalanced. Many European league matches are about two-thirds completed by mid-March suspension. It should be considered the possible bias for the strength of home teams in the resumed matches after the break. Most of famous and extensive previous studies on home advantage[11] and the latest report [12] used only several basic statistics, e.g., number of goals, fouls, and wins. It should be pointed out that they could be biased under unbalanced schedule.

For the problem on biased schedule, in this paper, assume a statistical model explains match results from the team strength parameters for each team and the home advantage parameter that is common for every team in the league. By fitting the parameters in this model to minimize explanation error, separate the home advantage even from the unbalanced schedule.

The specific techniques are as follows: each team i has one strength evaluation value $r_i$ called “rating”. And one league has one parameter $r_{homeAdv}$ that expresses home advantage. The strength difference $\Delta r$ is expressed by the difference of rating values between the teams indexed by $i$ and $j$ added by the home advantage, i.e., $\Delta r = r_i + r_{homeAdv} - r_j$. The strength difference explains the score ratio in a match via logistic regression model, i.e., $1/(1 + \exp(-\Delta r))$.

The rating values $r_i$ and the home advantage value $r_{homeAdv}$ at a particular date is estimated by using the most recent match results, e.g., five matchweeks. This calculation process is repeated for every matchweek. The home advantage value estimated only from the closed matches are compared to those of from the past “normal” match results.

This paper is organized as follows: Section II states on the data and the detailed algorithm used in this study. This paper analysis on the five major top division of European football leagues – England, France, Germany, Italy, and Spain (in France, the top division has not been resumed after the suspension). The match results are collected from 2010-2011 season. Section III states statistical analysis results. The following conclusion can be drawn from some statistical hypothesis tests.

- In four major European leagues, the home advantage is reduced without spectators compared to normal situation with spectators.
- The reduction amount among leagues is different.
- For all four leagues, the home advantage still remains even in closed matches.

Section IV summarizes and concludes this paper.
II. Methods

In this section, at first, describe the leagues studied and the content of the used data. Then, describe a mathematical method for estimating home advantage.

i. Data set

Table 1 shows the leagues and the number of matches used in this study.

| Country | League    | Teams | Matches (2010/11-2018/19) | Matches (2019/20) |
|---------|-----------|-------|--------------------------|-------------------|
| England | Premier League | 20    | 3420                     | 290 90            |
| France  | Ligue 1   | 20    | 3420                     | 279 0             |
| Germany | Bundesliga | 18    | 2754                     | 216 90            |
| Italy   | Serie A   | 20    | 3420                     | 240 140           |
| Spain   | LaLiga    | 20    | 3420                     | 270 110           |
| Total   |           |       | 16434                    | 1295 430          |

This study analyses the home advantage in the top divisions in five European countries – England, France, Germany, Italy, and Spain. They are considered as the most major and highest-quality football leagues among the world. The match results from 2010-2011 season are collected from worldfootball.net (https://www.worldfootball.net/). The number of matches are 17729, including 430 closed matches.

All five leagues were suspended from mid-March due to COVID-19 pandemic. Four leagues except France resumed until late-June, and finished until early-August. Ligue 1 in France quickly decided and announced its cancellation at the end of April[13].

Table 2 summarizes their closed period.

| Country | League    | Matchweeks | Closed from | Closed matchweeks |
|---------|-----------|------------|-------------|-------------------|
| England | Premier League | 38         | 30          | 9                 |
| Germany | Bundesliga | 34         | 25          | 10                |
| Italy   | Serie A   | 38         | 25          | 14                |
| Spain   | LaLiga    | 38         | 28          | 11                |

ii. Mathematical model

We propose a unified and simple statistical estimation method of scoring ratios based on the score in each match, which is always officially recorded and is common to all ball games. This method is an extension of [14] as to incorporate home advantage. The study[14] reported that his proposed method achieved higher prediction accuracy for ten events of five sports e.g., basketball, handball, hockey, volleyball, and water polo, in the Rio Olympic Games compared to the official world rankings.
Assume that the scoring ratio of a home team $i$ in a match against an away team $j$ ($i$ and $j$ are team indices), denoted as $p_{i,j}$, is estimated as

$$p_{i,j} = \frac{1}{1 + e^{-(r_i + r_{\text{homeAdv}} - r_j)}},$$  \hspace{1cm} (1)$$

where $r_i$ is defined as the rating of team $i$ and $r_{\text{homeAdv}}$ is quantitative value of home advantage.

Given $(s_i, s_j)$, the actual scores in a match between $i$ and $j$,

$$s_{i,j} = \frac{s_i + 1}{s_i + 1 + s_j + 1} = p_{i,j} + \epsilon_{i,j},$$  \hspace{1cm} (2)$$

where $s_{i,j}$ and $\epsilon_{i,j}$ are the modified actual scoring ratio and the estimation error, respectively. In football, shut-out results such as 1–0 or 3–0 occur frequently. Thus, a simple scoring ratio, i.e., $s_{i,j} = \frac{s_i}{s_i + s_j}$, can result in invalid strength evaluation. Therefore, the score of each team is added by one. This modification is known as Colley’s method[15], and was originally used to rank college (American) football teams.

This mathematical structure is the well-known logistic regression model. It is widely used in areas such as the winning probability assumption of Elo ratings in chess games[16], and the correct answer probability for questions in item response theory[17].

The update method is designed to minimize the sum of the squared error $E^2$ between the result and the prediction, defined by the following equation:

$$E^2 = \sum_{(i,j) \in \text{all matches}} (s_{i,j} - p_{i,j})^2.$$  \hspace{1cm} (3)$$

It is straightforward to obtain the following update based on the steepest-descent method:

$$r_i \leftarrow r_i - \alpha \cdot \frac{\partial E^2}{\partial r_i}, \quad r_{\text{homeAdv}} \leftarrow r_{\text{homeAdv}} - \alpha \cdot \frac{\partial E^2}{\partial r_{\text{homeAdv}}},$$  \hspace{1cm} (4)$$

where $\alpha$ is a constant.

By definition, the rating is an interval scale. Therefore, its origin, $r = 0$, can be selected arbitrarily and a constant value can be added to all $r_i$. For example,

$$r \leftarrow r - (\max r) \cdot 1$$  \hspace{1cm} (5)$$

implies that $r = 0$ always shows the highest rating, and $r < 0$ shows the distance from the top team.

ii.1 Convert rating on scoring ratio to winning probability

The rating $r_i$ in (1) explains the scoring ratio. Once we have the scoring ratio $p_{i,j}$ given in (1), assume that the following independent Bernoulli process is executed $N$ times, starting from $(s_i, s_j) = (0, 0)$ and with the parameter $0 < \beta \leq 1$.

$$\begin{cases}
  s_i \leftarrow s_i + 1 & \text{with probability } \beta p_{i,j}, \\
  s_j \leftarrow s_j + 1 & \text{with probability } \beta (1 - p_{i,j}), \\
  s_i \leftarrow s_i, s_j \leftarrow s_j & \text{with probability } (1 - \beta).
\end{cases}$$  \hspace{1cm} (6)$$

This is a unified (and approximated) model of a scoring process for all ball games, where $s_i$ and $s_j$ model the scores of teams $i$ and $j$, respectively.
The parameters $N$ and $\beta$ vary among the sports and between definitions of a unit of play. For example, in basketball, if a unit of play is defined as 10[s], we have $N = 40[\text{min}] \times 60[\text{s}] / 10 = 240$. In football, if a unit of play is defined as 1[\text{min}], we have $N = 90$. For both sports, $\beta$ is determined as $\beta = \frac{E(s_i + s_j)}{N}$.

At the end of the match, $s_i > s_j$ shows that team $i$ wins against team $j$. Figure 1 shows the simulated winning probability for different $N\beta$ and rating gap $(r_i - r_j)$, with $N = 240$. This probability is expressed by the cumulative distribution function for a normal distribution. In many applications, it is common to use a logistic regression model rather than a cumulative distribution[18].

![Figure 1: Rating gap and winning probability](image)

Based on the discussions above, we convert the rating on the scoring ratio to that of a winning probability, as follows:

$$w_{i,j} = 1 \ (i \text{ wins}), \ 0.5 \ (\text{draw}), \ or \ 0 \ (j \text{ wins}),$$  \hspace{1cm} (7)

which denotes a win, draw, or loss for team $i$ against team $j$. Find $D_k^*$, where $k$ is an index of sports, that satisfies

$$\hat{w}_{i,j} = \frac{1}{1 + \exp \left( -D_k \left( r_i + r_{\text{home Adv}} - r_j \right) \right)},$$  \hspace{1cm} (8)

$$D_k^* = \arg \min_{D_k} \sum_{i,j} (w_{i,j} - \hat{w}_{i,j})^2.$$  \hspace{1cm} (9)

Then, $r_i$ is converted as follows:

$$r_i = D_k^* r_i, \ i = 1, 2, \cdots, N_T, \text{ and } \text{home Adv},$$  \hspace{1cm} (10)

where $N_T$ denotes the number of teams. Therefore, $\bar{r}_{\text{home Adv}}$ is a quantitative home advantage estimation that explains the effect on the winning probability.

In Equations (3) and (9), the sum of squared errors are used as a loss function instead of the cross-entropy. This is because these problems are regression problems, not classification ones.
Short-term estimation of home advantage

The proposed method in the previous section is used to estimate the rating of each team and the home advantage in the league using the results of the last five matchweeks, including itself, for every matchweek.

By using five matchweeks, we can estimate the average of each team’s strength and league-wide home advantage over approximately from three weeks to one month.

The calculated home advantage is classified into the following four classes based on the spectator attendance.

- Past: The home advantage calculated using the matches from 2010-2011 to 2018-2019 seasons. It includes closed matches as punishments, if exist.
- Normal: The home advantage calculated using the matches before suspension in 2019-2020. The matches are basically with spectators. Note that closed matches as punishments are included here, if exist.
- Mixed: The home advantage calculated using the matches in which with and without spectators are mixed.
- Closed: The home advantage calculated using the matches without spectators.

III. Results and discussions

This chapter describes the analysis results and discussions.

i. Basic stats

Figure 2 depicts the basic stats, e.g., goals difference per match and win ratio difference, in normal and closed periods.

From this counting, home teams goal approximately from 0.3 to 0.5 more per match than away teams in average under the “past and normal” situation. As a result, the home teams win more approximately 0.15 to 0.25 against the away teams. In addition, it seems obvious that the home advantage is reduced under the closed situation. Especially, in Bundesliga, the goals difference and win ratio difference are both negative in the closed matches. In this counting, however, possible schedule unbalance for the closed matches is not considered. In other words, it is possible that the most of the home teams are consistently weak (or strong) in the closed matches.

ii. Estimation of home advantage

Figure 3 shows the estimation results of the home advantage $\hat{r}_{\text{homeAdv}}$ in five leagues. The medians are all positive for every four classes. This means that the home advantage remains even if the match is closed and without spectators. The medians in the past and normal periods looks similar. On the other hand, the median in the closed period is smaller than those of the past and the normal periods.

We tested null hypotheses that the home advantage $\hat{r}_{\text{homeAdv}}$ from two different categories are samples from continuous distributions with equal medians. Wilcoxon’s rank sum test [19, 20] is used as a test method because any assumption on the shape of the distribution of $\hat{r}_{\text{homeAdv}}$ can be posed. $p-$values between classes are depicted in Figure 3 and Table 3 summarizes the test result.

From these test results, the followings can be concluded.
Figure 2: Goals difference and win probability difference

Table 3: Test results

| Sample X       | Sample Y       | $N_X$ | $N_Y$ | $p$-value     | $z$-value | ranksum |
|----------------|----------------|-------|-------|---------------|-----------|---------|
| Past Normal    | 1494           | 112   |       | $1.18 \times 10^{-1}$ | 1.562     | 1207821 |
| Past Mixed     | 1494           | 16    |       | $2.45 \times 10^{-3}$ | 3.029     | 1133973 |
| Past Closed    | 1494           | 28    |       | $8.37 \times 10^{-7}$ | 4.927     | 1149033 |
| Normal Mixed   | 112            | 16    |       | $2.77 \times 10^{-2}$ | 2.201     | 7530    |
| Normal Closed  | 112            | 28    |       | $6.26 \times 10^{-4}$ | 3.420     | 8553    |
| Mixed Closed   | 16             | 28    |       | $4.28 \times 10^{-1}$ | 0.792     | 393     |

- There is no significant difference in home advantage between the past and 2019-2020 season’s normal matches ($p > 0.1$).
- There is significant difference in home advantage between the normal matches and the closed matches ($p < 10^{-3}$). The significant difference is more obvious between the past and the closed matches ($p < 10^{-6}$). The median of the home advantage in the closed matches is clearly smaller.

Therefore, this study provides strong quantitative evidence of the impact of the crowd effect on home advantage in the top leagues in Europe. It should be noted that, however, all of the closed matches in this season have been with several months’ suspension, and held in summer when the matches have not normally been played. It can not be rejected the possible effect by these factors.
ii.1 Detailed analysis for each league

The last section described the results for all five leagues. In this section, the estimation results will be explained for each league. Table 4 lists the detailed test results of Wilcoxon’s rank sum test for each league. Figure 4 shows the number of home matches in the closed period. The teams are ordered by the final standings. Figures from 5 to 9 show the estimated value of $\tau_{\text{home Adv}}$ for each league from 2010-11 season.

**England** In England, the home advantage value in the closed period obtained by the propose method has no significant difference to those of in the past and normal periods. This result shows that the basic stats, such as the goals difference and the win ratio difference shown in Figure 2, are smaller in the closed period because of the unbalanced schedule. In other words, the most of the home teams are consistently weak (or strong) in the closed matches. Figure 4 supports this assertion. In England, there are weak correlation between the number of home matches in the closed period and the final standings. The correlation value is 0.4052. In the other leagues, Germany, Italy, and Spain, the correlation values are much smaller (0.2863, 0.0867, and $-0.1561$).

**France** In France, there is not significant difference of $\tau_{\text{home Adv}}$ between past and normal periods.

**Germany** In Germany, the home advantage value in the closed period has significant difference to those of in the past and normal periods. Both $p$-values are less than $1.00 \times 10^{-2}$. In the closed period, Bundesliga showed home “dis”advantage, i.e., $\tau_{\text{home Adv}} < 0$. 

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**Figure 3:** Distribution of $\tau_{\text{home Adv}}$ in five major European football leagues
Table 4: Test results: League breakdown

| League   | Sample | Sample | \(N_X\) | \(N_Y\) | \(p\)−value | \(z\)−value | ranksum |
|----------|--------|--------|---------|---------|-------------|-------------|---------|
| England  | Past   | Normal | 306     | 25      | 1.74 \times 10^{-1} | -1.3596     | 3524    |
| England  | Past   | Closed | 306     | 5       | 4.42 \times 10^{-1}  | 0.7696      | 47890   |
| England  | Normal | Closed | 25      | 5       | 8.67 \times 10^{-1}  | -0.1669     | 384     |
| France   | Past   | Normal | 306     | 24      | 8.79 \times 10^{-1}  | -0.1522     | 3903    |
| Germany  | Past   | Normal | 270     | 20      | 1.24 \times 10^{-1}  | -1.5378     | 2353    |
| Germany  | Past   | Closed | 270     | 6       | 4.07 \times 10^{-5}  | 4.1034      | 38189   |
| Germany  | Normal | Closed | 20      | 6       | 3.84 \times 10^{-3}  | 2.8908      | 318     |
| Italy    | Past   | Normal | 306     | 20      | 1.56 \times 10^{-2}  | -2.4181     | 2282    |
| Italy    | Past   | Closed | 306     | 10      | 7.48 \times 10^{-2}  | 1.7815      | 49008   |
| Italy    | Normal | Closed | 20      | 10      | 5.53 \times 10^{-1}  | -0.5939     | 296     |
| Spain    | Past   | Normal | 306     | 23      | 3.87 \times 10^{-2}  | 2.0673      | 4705    |
| Spain    | Past   | Closed | 306     | 7       | 1.48 \times 10^{-4}  | 3.7952      | 48941   |
| Spain    | Normal | Closed | 23      | 7       | 8.76 \times 10^{-5}  | 3.9227      | 437     |

**Italy** In Italy, the home advantage value in the closed period has significant difference to that of in the past periods \((p < 0.01)\).

**Spain** In Spain, the home advantage value in the closed period has significant difference to those of in the past and normal periods. Both \(p\)−values are less than \(1.00 \times 10^{-2}\). In the closed period, similar to Bundesliga, laLiga showed home disadvantage in the closed period.

### IV. Conclusion

In this paper, the results of matches behind closed door held under the influence of the COVID-19 pandemic are used to determine the relationship between the presence of spectators and home advantage. In order to reduce the effect of schedule unbalance in the closed period, this paper proposed a short-term (e.g., five matchweeks) rating method considering home advantage. The proposed method has been applied to the match results in five major European football leagues (England, France, Germany, Italy, and Spain) from 2010-2011 to 2019-2020 seasons.

The distributions of the home advantage for both the past normal and the closed periods are calculated. Their median values are compared by using statistical hypothesis test. A null hypothesis, “the home advantage \(\bar{r}_{HomeAdv}\) from two different periods are samples from continuous distributions with equal medians” are rejected with sufficiently small \(p\)−value \((p < 10^{-3})\). The home advantage became smaller behind the closed door.

Our future work is to extend the proposed method to the match results all over the world. This work could clarify the crowd effect to home advantage.

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Figure 4: Number of home matches in closed period

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Figure 7: History of $r_{\text{homeAdv}}$: Germany

Figure 8: History of $r_{\text{homeAdv}}$: Italy
Figure 9: History of $\bar{r}_{\text{homeAdv}}$ Spain