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Home Advantage in Ice Hockey Matches without Spectators

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Abstract

Measures to combat the COVID-19 pandemic have provided a unique dataset that can be analysed to test the influence of spectators on match results. Strict measures were introduced in the Czech Republic, where more than half of the 2020–2021 season was played completely without spectators. The matches of the Czech *Extraliga* from the last seven seasons (a total of 2604 matches were played between the seasons of 2016–2017 and 2022–2023) were used in the analysis of the influence of spectators on results. Previously developed models from association football were used to perform the analysis. The results of the analysis show that in matches without spectators, the influence of home advantage decreased significantly.

Keywords: home advantage, spectators, ice hockey, Czech *Extraliga*.

1. Introduction

Home advantage in sport and factors influencing it, are frequently studied topics. Measures to combat the COVID-19 pandemic have provided the opportunity to study a situation where spectators are not present at the matches for a significant part of the season, which is unimaginable in normal circumstances.

Naturally, a number of scientists took advantage of this situation, and a number of publications were created that focused on the analysis of this unique data. Fischer and Haucap (2021) used the data from the 2019–2020 season in the top three leagues in Germany, and found that home advantage in the top division was reduced, while the home advantage was not reduced in the two lower divisions. Reduced occupancy was identified as the main driver of lower home advantage, while the total crowd size was less important. Almeida and Leite (2021) analysed German Bundesliga, Spanish La Liga, the English Premier League, Portuguese Primeira Liga and Italian Serie A during the 2019–2020 season and — interestingly — found that home advantage was reduced only in German Bundesliga. Correia-Oliveira and Andrade-Souza (2022) also analysed the 2019–2020 season and found significant reduction of home advantage in the first division of the German and Italian leagues, while no significant effects were found in both top divisions of the Spanish and English leagues and the second division of the German league. In accordance with previous results, Matos, Monteiro, Antunes, Mendes, Botas, Clemente, and Amaro (2021) did not see a change in home advantage during the last 10 rounds of the Portuguese Football League in the 2019–2020 season. Wunderlich, Weigelt, Rein, and Memmert (2021) analysed the influence of spectators on referee biases and the home advantage in two top level leagues in Spain, England, Italy, and Germany, and in top level leagues in Portugal and Turkey. They found that due to the absence of spectators, the increased sanctioning of away teams disappeared.

Home advantage is important not only from the point of view of match strategy and preparation for it, but also from the point of view of betting. Winkelmann, Deutscher, and Ötting (2021) demonstrated that bookmakers had difficulties to price change in home advantage in German Bundesliga — in fact, they supposed that home advantage remained intact — and that opened opportunity for gamblers to gain profit of around 15% when betting on away teams.

Much research has been done on home advantage in football, and many more will arise. In other sports, however, there is less research done, both in general and with regard to the effect of empty stadiums. Delbianco, Fioravanti, and Tohmé (2023) found that home advantage in rugby decreased during the pandemic. Szabó and Pérez (2021) analysed home advantage in American football and found interesting fact that home advantage decreased on empty stadiums, but when up to 25% of spectators were admitted to the stadiums, the situation was not significantly different compared to normal circumstances. Price and Yan (2021) studied NBA (basketball) and found that, during the 2020 NBA playoffs – that were played inside of a bubble in Disney World – away teams significantly improved their two-point efficiency. They propose that home advantage results from adverse effects on the visiting team. Similar findings are stated by McHill and Chinoy (2020) in their analysis.

Ice hockey — same as other sports mentioned in the previous paragraph — is not as thoroughly studied as football. Gouge and Stephens (2021) indicate that in the 2019–2020 NHL playoffs, home advantage and referee bias were negatively influenced. They observed an increase in home penalty minutes and decrease in away penalty minutes. Home win percentage decreased by 9.8%, home team scoring by 6.1%, and shots on goal by 1.2%.

This paper analyses the top-level ice hockey league in the Czech Republic – Czech *Extraliga*. This league is chosen due to strict measures that were applied in the Czech Republic which led to the situation where a limited number of spectators were admitted to the stadiums in the first rounds of the season, but during the rest of the season, no spectators were allowed to enter the stadiums. In the Czech *Extraliga*, every two teams play together four times a season. In the first half of the season, every two teams play two matches against each other (once as a home and once as a visiting team) and the same system is applied in the second half of the season.

This makes available the first half of the 2020–2021 season with limited number of spectators and then completely without spectators. The fact that conditions have changed may to some extent affect the conclusions for this half-season (autumn 2020–2021 half-season), as well as the fact that players from foreign leagues that had a delayed start until 2021 (e.g. NHL, AHL) moved to the Czech *Extraliga* during this time, i.e. the composition of the teams varied more than in the usual half-season.

Nevertheless, in the second half of the 2020–2021 season (winter 2020–2021 half-season) all matches were played completely without spectators. Thanks to this, we have two matches without spectators available for each pair of teams, where both performed once as a home team and once as a visiting team – this is a necessary condition to perform an even analysis, based on the method introduced by Marek and Vávra (2020b) and Marek and Vávra (2020a).

The situation offers a unique opportunity to analyse home advantage with the complete exclusion of spectators. In the case of ice hockey, this is one of the few datasets that offers this possibility. For the first time in modern ice hockey history, such a dataset is available and it is possible to show that spectators affect home advantage. The procedure introduced by Marek and Vávra (2020b) and Marek and Vávra (2020a) will be first applied to ice hockey data, which show a different nature and course of the season (e.g. that teams play each other four times in one season). Unlike football, the home team in ice hockey is favoured by the rules. The home team has the right of "last change", i.e. the home team has longer time for players change during stoppage and that gives the home team advantage because it can choose which players will play against visiting team players that are already on the ice.

The method introduced by Marek and Vávra (2020b) is applied on the last seven seasons (from 2016–2017 to 2022–2023) to study recent changes in home advantage. The data is analysed from the perspective of the entire league and from the perspective of individual teams.

2. Data

Data of the Czech *Extraliga* — the highest ice hockey league in the Czech Republic — was obtained from LiveSport s.r.o. (2023). We used data from the last seven seasons, i.e. from the 2016–2017 season to the 2022–2023 season. The 2020–2021 season was played under COVID-19 restrictions on spectators. The analysis used only results after 60 minutes, so that all matches lasted the same time, i.e. goals scored in the eventual five-minute overtime and goals awarded as a result of the eventual shootouts are not considered (this does not exclude any matches from the analysis). Only matches from the regular season were used, whilst matches from the playoffs were not considered.

In a regular season, *Extraliga* uses a balanced system where all two teams play together four times a season, twice as a home team and twice as a visiting team. Each season is compiled of 14 teams, however, thanks to relegation and promotion, the number of teams that played in *Extraliga* in the five analysed seasons, is 17. The only exception to the usual 14-team season was the 2021–2022 season, which featured 15 teams. This was due to the fact that no team was relegated after the restricted 2020–2021 season. The total number of analysed matches was 2604.

As we will analyse paired matches — i.e. matches played between teams A and B will be paired with match played between teams B and A — we will not analyse full seasons but half-seasons (for a more precise explanation of the pairing mechanism, we refer to Section 3, where the concept *combined measure of home advantage* is explained). The main reason is that the 2020–2021 season, which is the main objective of this paper, was not completely played without spectators as the first rounds of the season allowed a limited number of spectators into the stadiums. This offers us one complete half-season without spectators and one half-season with a limited number, or later no, spectators.

Because some matches were postponed, we used the first pair of matches between opposing teams for the autumn half season, and for the winter half-season, the second set of matches between teams A and B and B and A were analysed. This also applies to seasons not affected by COVID-19, as a small number of matches may be rescheduled (e.g. due to technical problems).

3. Methods

Marek and Vávra (2020b) proposed method how the home advantage can be measured in detail. They do not use individual matches but combine them together into pairs (as mentioned in section 2) and, based on observed goal differences in home and away matches, they define a random variable C: *combined measure of home advantage* that can take values $-1, 0,$ and 1. For each pair of matches they obtained a realisation of this random variable, where $C = 1$ indicates a situation where the result at home was better; $C = 0$ indicates a situation where the result was, from the view of goal differences, the same; and $C = -1$ indicates a situation where the result was better away from home.

For teams T_1 and T_2 the value of C is determined as

$$C = \operatorname{sgn}[(h_{T_1} - a_{T_2}) - (a_{T_1} - h_{T_2})], \tag{1}$$

where $h_{T_1} : a_{T_2}$ is the result of the first match (T_1 is the home team) and $h_{T_2} : a_{T_1}$ is the result of the second match (T_2 is the home team). It can be easily seen that computing value of C from the view of T_1 or T_2 always produce the same value.

The advantage of this approach — in comparison to methods based on points gained (introduced by Pollard (1986)) — is that it can detect home advantage even if both matches ended with a loss of team T_1, e.g., imagine a situation where $h_{T_1} : a_{T_2}$ is 1:4 and $h_{T_2} : a_{T_1}$ is 7:2, i.e. both matches ended with a loss of the team T_1. Substituting these results into Equation 1 we obtain $C = 1$, i.e. the team T_1 performed better at home as the loss was not as high as the loss away from home. Looking on these results from the view of the team T_2 we obtain, again, $C = 1$ as the win at home was more significant than the win away from home.

Random variable C follows trinomial distribution with parameters K (number of trials), p_{-1}, p_0 and p_1 (event probabilities). Based on the number of pairs K and observations of appropriate situation k_{-1}, k_0, k_1 ($k_{-1} + k_0 + k_1 = K$), e.g., k_{-1} is number of cases where $C = -1$, we can estimate probability of occurrence of home advantage (see Marek and Vávra (2020b) for details)

$$P(p_1 > p_{-1}) = 1 - I_{1/2}(k_1 + 1, k_{-1} + 1), \tag{2}$$

where $I_{1/2}(k_1+1, k_{-1}+1)$ is regularized incomplete beta function. Marek and Vávra (2020b) state that $P(p_1 > p_{-1})$ can be used as a measure of home advantage (the higher the value of $P(p_1 > p_{-1})$, the higher home advantage) and the hypothesis that home advantage is real can be accepted if $P(p_1 > p_{-1}) \geq 1 - \alpha$. In this paper, we will use $\alpha = 0.05$, i.e. the common value that was also used in Marek and Vávra (2020b). This probability will be estimated for each half-season and for each team in a given half-season.

Remark 1 *The situation where we use only the worse ($C = -1$), same ($C = 0$) and better ($C = 1$) indicator against the exact score difference is appropriate for three reasons:*

- *In ice hockey, goaltenders are relatively often recalled and it is not uncommon for a team to score two empty net goals in an evenly matched game.*
- *When the score difference is large, the leading team may let its best players rest at the end of the game and this can also cause bias.*
- *Only a limited number of results are available for comparison (one half-season), so a trinomial distribution with only three parameters is appropriate for parameter estimation and the construction of confidence intervals.*

We consider this method to be more robust and more suitable for practical estimation than using the direct difference in scores. In the case of football, the situation could be different and with smaller differences in the final score (compared to ice hockey) and the absence of the problems mentioned above, the score difference could be considered without adjustment. In some other approaches, e.g., based on the bivariate Poisson regression the score is used with no change; for example, Benz and Lopez (2023) used it to estimate change in home advantage in European football leagues during COVID-19 pandemic.

We will use additional information to quantify the uncertainty of our estimates by unconditional confidence intervals for p_{-1}, p_0, and p_1 presented by Marek and Vávra (2020b). These symmetric individual $(1-\alpha)$-confidence intervals for $p_r, r = -1, 0, 1$ are given by quantiles of Beta distribution where $k_r, r = -1, 0, 1$ and K has the same meaning as in Equation 2

$$\hat{p}_{r,l} = \operatorname{Beta}^{-1}(\frac{\alpha}{2}, k_r + 1, K - k_r + 2) \tag{3}$$

Table 1: Observed averages and sample standard deviations of goals scored in analysed half-seasons

	Average			Standard deviation		
Half-season	Home	Away	Difference	Home	Away	Difference
2016–2017 (Aut)	2.76	2.34	0.43	1.72	1.50	2.39
2016–2017 (Wint)	2.71	2.29	0.42	1.68	1.45	2.28
2017–2018 (Aut)	2.73	2.15	0.58	1.77	1.35	2.36
2017–2018 (Wint)	2.79	2.19	0.60	1.66	1.45	2.23
2018–2019 (Aut)	2.83	2.30	0.53	1.59	1.55	2.37
2018–2019 (Wint)	2.95	2.30	0.65	1.97	1.47	2.58
2019–2020 (Aut)	2.93	2.57	0.36	1.89	1.64	2.50
2019–2020 (Wint)	3.16	2.41	0.75	1.83	1.66	2.49
2020–2021 (Aut)	2.83	2.59	0.24	1.86	1.55	2.50
2020–2021 (Wint)	2.80	2.62	0.18	1.93	1.60	2.53
2021–2022 (Aut)	2.84	2.49	0.35	1.53	1.60	2.25
2021–2022 (Wint)	2.86	2.42	0.44	1.59	1.63	2.44
2022–2023 (Aut)	2.86	2.17	0.69	1.75	1.47	2.27
2022–2023 (Wint)	2.73	2.42	0.31	1.68	1.54	2.40

and

$$\hat{p}_{r,u} = \text{Beta}^{-1}(1 - \frac{\alpha}{2}, k_r + 1, K - k_r + 2). \tag{4}$$

These results will mainly serve as supplementary information for our testing and better understanding of results.

Data processing and calculations were performed in MS Excel.

4. Results

A total of 2604 matches were analysed, i.e. 182 matches in each half-season (210 matches in 2021–2022 half-seasons). An overview of the data can be made based on Table 1. The observed averages are in line with the expectation that the absence of spectators reduces home advantage. The lowest value of the average of the differences is recorded in the winter 2020–2021 half-season and the second lowest value is recorded in the autumn 2020–2021 half-season. At the same time, it can be seen that the average number of goals scored by the visiting team is the highest in the winter 2020–2021 half-season and the second highest in the autumn 2020-2021 half-season. However, no conclusions can be drawn from this, and statistical testing will be performed based on the method described in Section 3.

Table 2 shows observed values of combined measure in the analysed half-seasons, e.g., the line for the winter 2020–2021 half-season tells us that we observed 35 pairs of matches where the better result was achieved away from home (in the sense of Equation 1); 15 pairs of matches where the goal difference was the same at home and away from home; and 41 pairs of matches where the better result was achieved at home. We recall that each pair consists of the same two teams where each team plays once as a home team and once as a visiting team.

Before evaluating the results in Table 2, we tested each pair of half-seasons to check whether the Combined measure of home advantage in half-seasons come from the same distribution. We used a test for homogeneity of parallel samples (see Marek and Vávra (2020a) for details of the procedure that compares occurrence counts of C in half-seasons listed in Table 2). The results are shown in Table 3 and there are 7 pairs of seasons for which the hypothesis that distributions differ can be accepted, i.e. $p < 0.05$. However, if we were testing the global hypothesis that all half-seasons come from the same distribution, there would be no rejection of this hypothesis after adjusting the significance level to 5/91% (Bonferroni correction with

Table 2: Combined measure and evolution of $P(p_1 > p_{-1})$ in analysed half-seasons

Half-season	$C = -1$	$C = 0$	$C = 1$	$P(p_1 > p_{-1})$
2016–2017 (Aut)	28	10	53	0.997
2016–2017 (Wint)	24	15	52	0.999
2017–2018 (Aut)	30	10	51	0.990
2017–2018 (Wint)	26	11	54	0.999
2018–2019 (Aut)	27	11	53	0.998
2018–2019 (Wint)	32	7	52	0.985
2019–2020 (Aut)	32	14	45	0.930
2019–2020 (Wint)	29	11	51	0.993
2020–2021 (Aut)	37	6	48	0.882
2020–2021 (Wint)	35	15	41	0.753
2021–2022 (Aut)	34	19	52	0.973
2021–2022 (Wint)	35	10	60	0.995
2022–2023 (Aut)	27	4	60	0.999
2022–2023 (Wint)	33	12	46	0.927

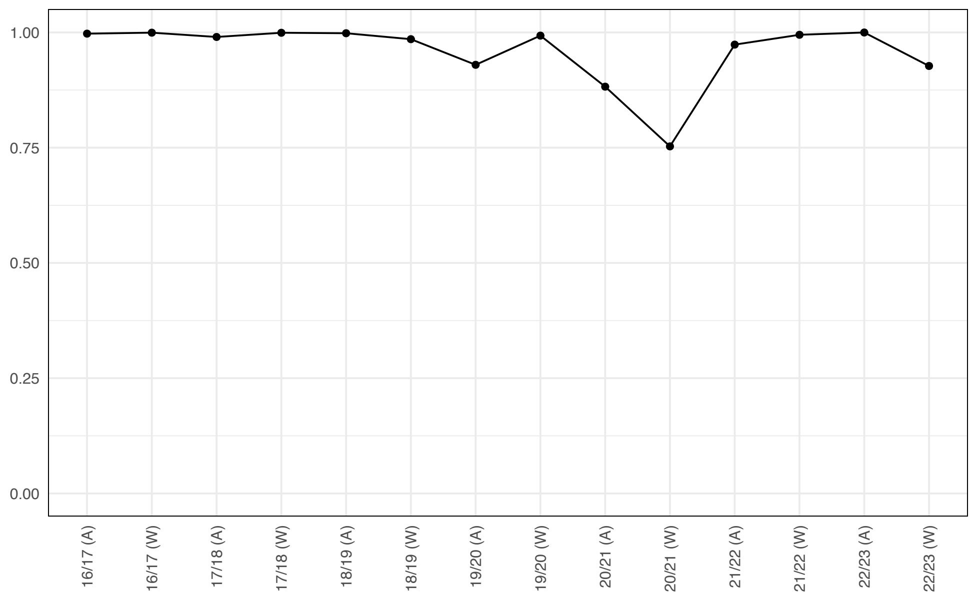

Figure 1: Evolution of $P(p_1 > p_{-1})$ in the half-seasons

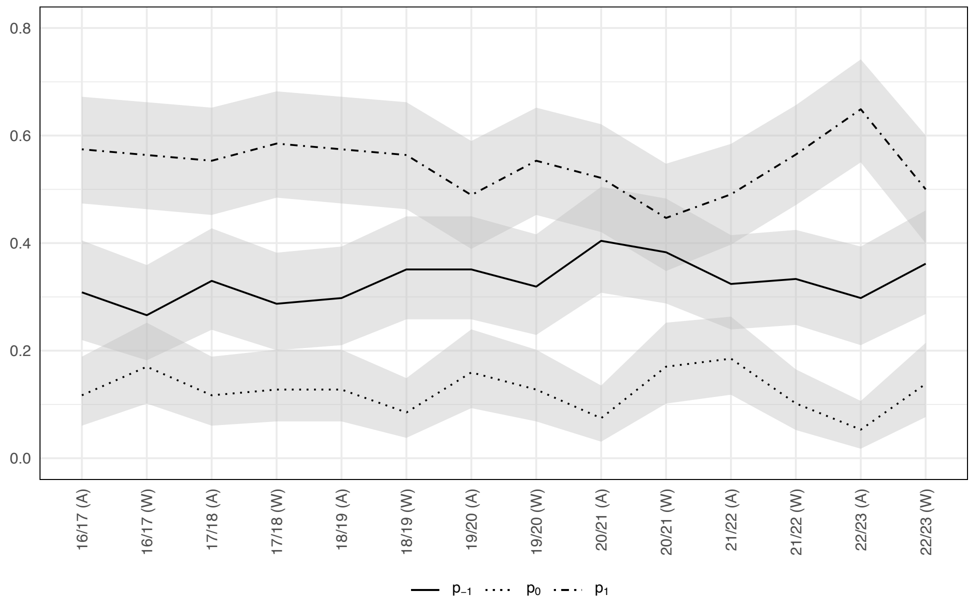

Figure 2: Unconditioned 95% confidence intervals of p_1, p_0 and p_{-1} in the half-seasons

a total of 91 hypotheses were tested).

The last column of Table 2 contains the value of $P(p_1 > p_{-1})$ estimated according to Equation 2, and its evolution during the analysed half-seasons is shown in Figure 1. The value of $P(p_1 > p_{-1})$ is less than 0.95 only in four half-seasons: autumn 2019–2020 half-season, both 2020–2021 half-seasons, and winter 2022–2023 half–season. Hypothesis that home advantage is real has not been proven in these four half-seasons. For all other half-seasons we can accept hypothesis that home advantage was present.

Figure 1 provides information that can be further elucidated by examining the unconditioned 95% confidence intervals for p_{-1}, p_0, and p_1 presented in Figure 2. Based on these confidence intervals, our conclusions are largely consistent, except for the autumn half-season of 2021–2022 where the intervals for p_{-1} and p_1 overlap, preventing us from drawing definitive conclusions about their differences. Nevertheless, we regard these results as supplementary to our main findings. It's worth noting that both half-seasons in 2020–2021 exhibit the largest overlap of intervals.

If we use $P(p_1 > p_{-1})$ as a measure of home advantage — as Marek and Vávra (2020b) suggested — we see that the lowest value (0.753) was recorded in the winter 2020–2021 half-season, i.e. the half-season completely without spectators. Whilst the second lowest value (0.882) was recorded in the autumn 2020–2021 half-season, i.e. the half-season with limited number, and eventually no spectators (as mentioned in the Introduction, this half-season was also affected by the fact that some matches of the Czech *Extraliga* were played with the addition of players from the NHL and other leagues). The only two half-season where the value of $P(p_1 > p_{-1})$ was bellow 0.95 are autumn 2019–2020 half-season with value 0.930 and winter 2022–2023 half season with value 0.927, i.e. higher than both values in 2020–2021 half-season. All other half-seasons recorded $P(p_1 > p_{-1})$ at least 0.973. From this point of view, it is possible to claim that the decline in home advantage was significant when spectators were banned from attending matches.

The described procedure can also be used for individual teams. The results of the individual teams are shown in Table 4 and Figure 3. Results are based on 13 observed pairs of matches, except for the 2021–2022 season, where the results are based on 14 observed pairs. The small number of observations is probably the main reason for high variability. Conclusions must be drawn given that they are based on a relatively small number of observations. There is only

Table 3: P-values of the test for homogeneity of parallel samples for all pairs of half-seasons

	16–17 (Wint)	17–18 (Aut)	17–18 (Wint)	18–19 (Aut)	18–19 (Wint)	19–20 (Aut)	19–20 (Wint)	20–21 (Aut)	20–21 (Wint)	21–22 (Aut)	21–22 (Wint)	22–23 (Aut)	22–23 (Wint)
2016–2017 (Aut)	0.518	0.948	0.937	0.968	0.668	0.452	0.950	0.287	0.191	0.302	0.899	0.221	0.581
2016–2017 (Wint)		0.432	0.693	0.670	0.132	0.431	0.578	0.034	0.187	0.549	0.268	0.028	0.346
2017–2018 (Aut)			0.811	0.885	0.739	0.575	0.968	0.402	0.291	0.356	0.944	0.177	0.747
2017–2018 (Wint)				0.986	0.461	0.407	0.883	0.154	0.156	0.325	0.707	0.165	0.469
2018–2019 (Aut)					0.516	0.488	0.947	0.194	0.204	0.376	0.773	0.157	0.566
2018–2019 (Wint)						0.242	0.593	0.741	0.114	0.099	0.889	0.404	0.428
2019–2020 (Aut)							0.643	0.160	0.837	0.850	0.376	0.017	0.914
2019–2020 (Wint)								0.282	0.322	0.461	0.843	0.131	0.756
2020–2021 (Aut)									0.107	0.048	0.498	0.192	0.321
2020–2021 (Wint)										0.674	0.166	0.004	0.712
2021–2022 (Aut)											0.185	0.006	0.616
2021–2022 (Wint)												0.270	0.578
2022–2023 (Aut)													0.040

Table 4: Values of $P(p_1 > p_{-1})$ of the individual teams in analysed half-seasons

	2016–2017		2017–2018		2018–2019		2019–2020		2020–2021		2021–2022		2022–2023	
Team	Aut	Wint	Aut	Wint	Aut	Wint	Aut	Wint	Aut	Wint	Aut	Wint	Aut	Wint
Brno	0.994	0.967	0.726	0.828	0.806	0.613	0.605	0.806	0.395	0.709	0.927	0.910	0.709	0.967
Chomutov	0.971	0.954	0.113	0.999	0.954	0.788	—	—	—	—	—	—	—	—
České Budějovice	—	—	—	—	—	—	—	—	0.291	0.387	0.613	0.910	0.994	0.395
Hradec Králové	0.954	0.954	0.605	0.981	0.989	0.867	0.212	0.806	0.788	0.726	0.910	0.910	0.910	0.500
Jihlava	—	—	0.997	0.709	—	—	—	—	—	—	—	—	—	—
Karlovy Vary	0.971	0.967	—	—	0.971	0.212	0.500	0.887	0.500	0.172	0.887	0.788	0.212	0.967
Kladno	—	—	—	—	—	—	0.927	0.971	—	—	0.613	0.605	0.989	0.500
Liberec	0.291	0.910	0.999	0.867	0.887	0.954	0.927	0.500	0.709	0.291	0.887	0.709	0.613	0.910
Litvínov	0.709	0.709	0.971	0.613	0.867	0.500	0.994	0.709	0.212	0.605	0.387	0.395	0.981	0.927
Mladá Boleslav	0.709	0.887	0.395	0.910	0.887	0.387	0.927	0.927	0.989	0.500	0.849	0.849	0.788	0.945
Olomouc	0.709	0.387	0.613	0.994	0.613	0.500	0.274	0.806	0.613	0.033	0.910	0.709	0.994	0.613
Pardubice	0.954	0.726	0.867	0.867	0.867	0.981	0.910	0.172	0.605	0.788	0.709	0.867	0.709	0.029
Plzeň	0.500	0.927	0.806	0.981	0.500	0.788	0.726	0.999	0.613	0.887	0.806	0.709	0.709	0.605
Sparta Praha	0.613	0.500	0.806	0.387	0.387	0.613	0.726	0.981	0.989	0.500	0.395	0.788	0.971	0.867
Třinec	0.806	0.967	0.954	0.133	0.806	0.500	0.981	0.090	0.867	0.500	0.605	0.927	0.788	0.887
Vítkovice	0.967	0.887	0.709	0.971	0.954	0.998	0.113	0.806	0.613	0.887	0.806	0.788	0.999	0.194
Zlín	0.726	0.927	0.274	0.806	0.788	0.994	0.073	0.867	0.395	0.994	0.605	0.971	—	—

The symbol — is used in the half-seasons in which the team did not participate.

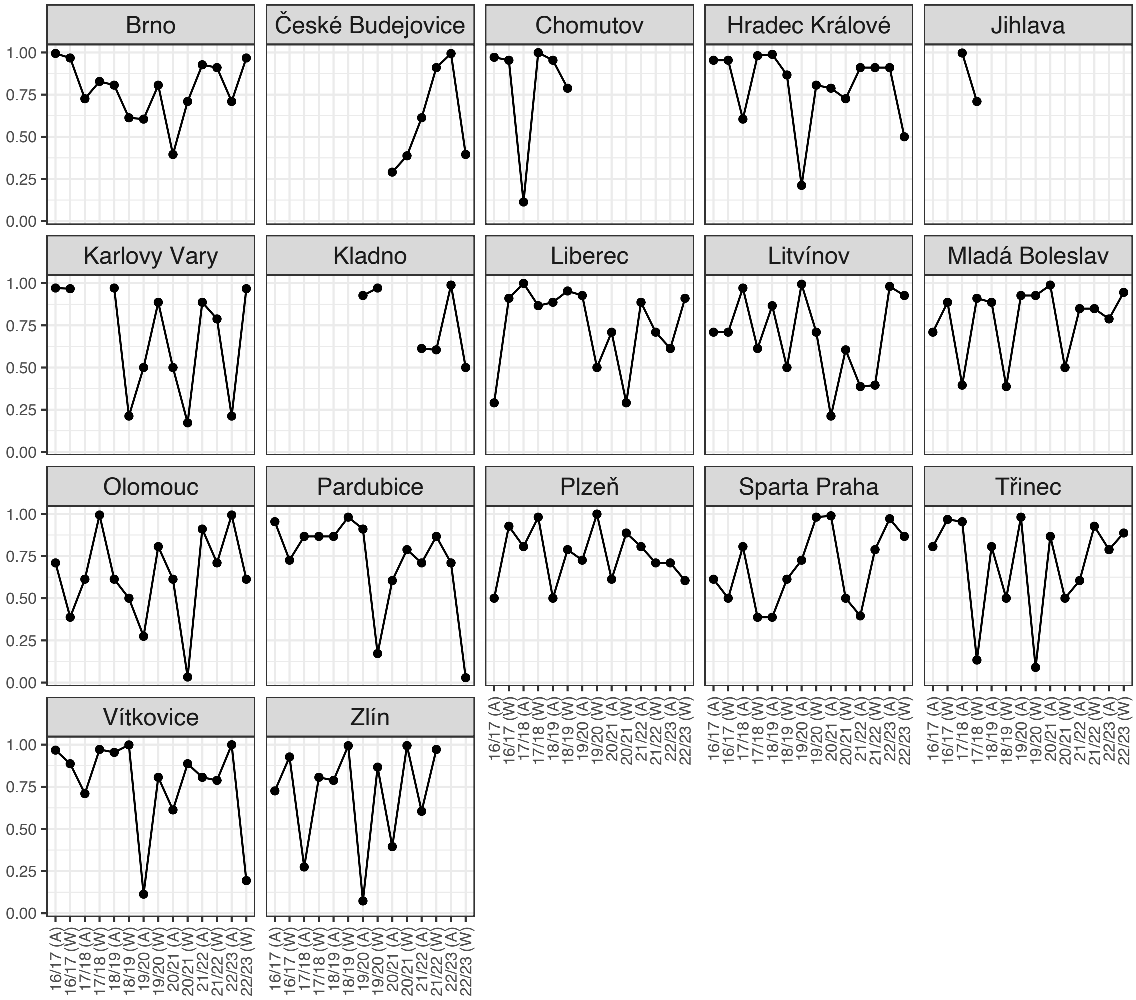

Figure 3: Evolution of $P(p_1 > p_{-1})$ of the individual teams in analysed half-seasons

one team that maintained $P(p_1 > p_{-1}) \geq 0.5$ in all half-seasons – Plzeň. An interesting result is that some teams retained high home advantage, e.g., $P(p_1 > p_{-1}) \geq 0.8$ was recorded in winter 2020–2021 half-season for Plzeň, Vítkovice, and Zlín. On the other side are Olomouc, Karlovy Vary, and Liberec with very low values of $P(p_1 > p_{-1})$.

Mixed results of the autumn and winter 2020–2021 half-seasons, suggest that the influence of home advantage across the teams was different, and some maintained their home advantage while others recorded very low values.

5. Discussion

Strictly speaking we are not able to prove home advantage in four of the analysed half-seasons. However, if we accept $P(p_1 > p_{-1})$ as a measure of home advantage (see Marek and Vávra (2020b)) then we can indicate situations where the home results seems to be better, i.e. $P(p_1 > p_{-1}) > 0.5$, and situations where the away results seems to be better, i.e. $P(p_1 > p_{-1}) < 0.5$. We will use this in the later text and when home advantage was not proven we will distinguish whether the value of $P(p_1 > p_{-1})$ was above or below 0.5.

Obtained results show that the absence of spectators affected home advantage in ice hockey. The two lowest values of $P(p_1 > p_{-1})$ were recorded in both of the 2020–2021 half-seasons. As can be seen from Table 2 and Figure 1, home advantage did not fully disappear, but it was reduced. That is very likely connected with the fact that — unlike in football —

the home team has advantage based on ice hockey rules, i.e. the home team has the right of "last change", i.e. the right to change players after the visiting team has completed the players change during stoppage. Furthermore, the advantage that results from the knowledge of home stadium, the dimensions of rink — which may vary slightly for each team —, and the advantage that the home team does not have to travel far for the match, is retained.

Schwartz and Barsky (1977) analysed home advantage in NHL and found that the main reason for home advantage is the social support of the home spectators. They did not find connection between home advantage and visitor fatigue, or the lack of familiarity with the rink. We did not analyse which factors affect the rest of home advantage after removing spectators but we see that home advantages probably still exist even in matches without spectators. The results in Table 1 indicate that the change of home advantage in matches without spectators results in better scoring of the visiting teams rather than a change of the goals scored by the home team.

Agnew and Carron (1994) found that home advantage is significantly related to the crowd density in junior ice hockey and our results are in line with these findings. Unlike these authors, however, we now have the entire half-season without spectators, and we are able to determine that the elimination of spectators probably did not completely erase home advantage[1].

Our results of home advantage of individual teams suggest that home advantage is not very stable, and it changes over the time. However, this seems to be true for all teams and we are not able to connect the quality of a team with a home advantage. This is in line of findings of Bray (1999) who showed that home advantage in NHL was consistent across teams in the league. However, this was not part of our analysis and it would require deeper psychological analysis to confirm these hypothesis that we base on the results presented in Table 4 and Figure 3.

Pollard (2002) offers a view on home advantage when the team moves to a new stadium. He analysed 13 NHL teams that moved to a new stadium in the same city. He found that home advantage was significantly reduced in the season after the moving. Again, this is in line with our results that show some home advantage after exclusion of spectators, and it seems that even familiarity of home rink has some influence on home advantage. Lopez, Matthews, and Baumer (2018) also mention that the home advantage is affected by the altitude of the stadium and the need for the visiting team to acclimatise. This is unlikely in the Czech *Extraliga*, as the stadiums are located at similar altitudes.

Leard and Doyle (2011) found that rules have a significant role in home advantage in ice hockey. They state that the advantage can be caused by the rule that during face-offs, the player from the visiting team have to place his stick on the ice first, therefore the player is at a disadvantage, and he is more likely to lose the face-off. However, we do not see this as a main cause as this rule only applies when the face-off is on the centre-line dot. We would attribute this advantage to the rule of "last change" as stated before. However, this does not change the fact that our results suggest that even after the elimination of the spectators, some home advantage probably remained, and these two rules could contribute to the advantage of the home team.

Effects of rule changes in NHL between the 1979–1980 season and the 2014–2015 was studied by Marek (2017) and he showed that rules can significantly affect scoring in matches, i.e. rules have a significant role for the match outcome. These results support the assumption that there may be home advantage that can be caused by rules.

We showed that home advantage was reduced in matches without spectators. If we use $P(p_1 > p_{-1})$ as a measure of home advantage, as suggested by Marek and Vávra (2020b), we can conclude, that part of home advantage was still preserved. Based on findings mentioned by authors, we can attribute the rest of home advantage to rules of ice hockey and familiarity

[1] Attendance in the Czech *Extraliga* in normal seasons varies between 3,000 and 10,000 spectators depending on the team. The stadiums have a minimum capacity of 5 000 and a maximum capacity of 17 360 spectators.

with the rink. However, we cannot distinguish these influences.

6. Conclusion

The method based on combined measure of home advantage was applied to data from ice hockey and we used it to demonstrate how much home advantage was reduced in the matches without spectators.

We found that we were unable to demonstrate the presence of home advantage in four of the 14 half-seasons analyzed, including both half-seasons in 2020–2021, the autumn 2019–2020 half-season, and the winter 2022–2023 half-season. Notably, two of these half-seasons occurred during the period of COVID-19 restrictions. Further analysis using $P(p_1 > p_{-1})$ as a measure of home advantage revealed that the lowest value was observed in the winter 2020–2021 half-season when spectators were completely excluded from matches.

Although the value of $P(p_1 > p_{-1})$ was still above 0.5 in the four half-seasons without demonstrated home advantage, indicating the presence of some influence of home advantage, its statistical significance could not be confirmed. This result was expected because the home team in ice hockey has a certain advantage that the rules give it. At the same time, the home team can benefit from knowing the home rink and not having to travel far for the match.

Next, we examined home advantage of individual teams in half-seasons, and we found that the results can be very unstable between half-seasons and teams. Nevertheless, from the point of view of the analysis of individual teams, we found that home advantage was reduced when spectators were not present.

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