Westfälische Wilhelms-Universität Münster

Institut für Organisationsökonomik

Diskussionspapier des
Instituts für Organisationsökonomik

6/2022

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Discussion Paper of the
Institute for Organisational Economics

Diskussionspapier des
Instituts für Organisationsökonomik
6/2022

Juni 2022

ISSN 2750-4476

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Abstract

We analyse changes in the National Football League (NFL) due to ghost games in 2020. The home bias disappears as expected. However, referee decisions do not seem to be relevant for this. There are also no significant results for semi-ghost games with a reduced number of spectators.

JEL Code: Z20

Veränderung des Heimvorteils durch Geisterspiele in der NFL

Zusammenfassung

Wir analysieren Veränderungen in der National Football League (NFL) aufgrund von Geisterspielen im Jahr 2020. Der Heimvorteil verschwindet wie erwartet. Schiedsrichterentscheidungen scheinen dafür aber nicht relevant zu sein. Auch für partielle Geisterspiele mit reduzierter Zuschauerzahl gibt es keine signifikanten Ergebnisse.

Im Internet unter:

http://www.wiwi.uni-muenster.de/io/forschen/downloads/DP-IO_06_2022

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Change in Home Bias Due to Ghost Games in the NFL

1. Introduction

“Practice,” that was New England Patriots head coach Bill Belichick’s succinct answer to the question of how he could describe the atmosphere without fans in the stadium and whether it was comparable to anything in his 45-year coaching career in the NFL (Sphigel 2020). A day earlier, his team won the season opener at home against the Miami Dolphins but had to play in front of an empty crowd at home in Gillette Stadium, which has a capacity of 66,000 under normal conditions.

The global corona pandemic affects the reality of life for all of us, for example through adherence to distance and hygiene rules, reduction of social contacts or simply the worry of falling ill ourselves. In addition, the economic and cultural impact of the prevailing situation is immense. However, the world’s top sports have managed to hold games and complete competitions despite strict regulations. Depending on the political measures, the number of spectators on site has been greatly reduced to the point of holding ghost games in front of completely empty stands. The US professional football league NFL also completed its 2020 season under the influence of the pandemic. While the draft in May, i.e. the allocation of college talent to the teams, and numerous training sessions in the spring and summer took place exclusively digitally, the league was able to hold its games completely and with only a few postponements in the time frame of a corona-free season.

What is a bitter loss for the sport and its fans gives academia the opportunity to gain new insights based on changed conditions. The games can be interpreted as quasi-experiments in which the spectators, or their absence, are understood as a treatment and thus the influence of (absent) spectators on various aspects can be measured. In the medium term, the question of whether fans have an influence on the game and how strong it is can be answered for each sport observed. In addition, comparisons can be made between the disciplines, the influences of spectators can be classified and thus facets of the sports can be explained. In the NFL, spectators in the stadium are encouraged to actively intervene in the game. Through acoustic and visual motivation of the stadium announcer, the behaviour is established that during plays of the home offense the fans keep quiet in order not to disturb the communication of their own team. However, when the visiting team’s offence is on the field, spectators are encouraged to be as loud as possible, making tactical instructions difficult for the opponent to understand and implement. In addition, the typical football game, in which a few seconds of action

are followed by a longer break for substitutions and tactical discussions, does not require the spectators to be engaged throughout, but rather to provide support at specific moments of the game. For example, an NFL stadium typically becomes particularly loud on extremely important plays, such as third downs or a close score at the end of the game, as external fan influence is to be maximised on crucial plays and spectators take a more passive role in other situations. This is a clear contrast to football, for example, in which fans support their own team loudly throughout a half.

Even though in 2021 spectators at the screens have already become accustomed, the training atmosphere Belichick spoke of can be recreated. The lack of noise in the stands, for example, allows unfamiliar insights into the communication between players on the field. But how much are NFL football games really shaped by the sharp reduction in crowd size? Conversely, how much do NFL teams benefit from their fans in home games? We use econometric methods to shed light on and answer these questions in this paper.

2. Theoretical Background

Much research has been conducted on home bias in the NFL and other sports. Early studies showed that home teams in the NFL enjoy an advantage over visiting teams, but that this advantage is smaller than in the other three major US sports, baseball, basketball and hockey (cf. Schwartz/Barsky 1977). Vergin and Sosik (1999) showed a significant home bias in the NFL, which the betting market takes into account in 67% of all games with a favourite role of the host. The results in Albert and Koning (2007) confirm the hypothesis of a significant cross-league home bias in the overall sport of American football by analysing data from the NFL, US college football and the Australian professional league AFL. Nevertheless, the NFL is considered the most balanced in a comparison of the big four US sports leagues NBA, NHL, NFL and MLB (cf. Gratton/Solberg 2008, p. 14). This is due in particular to the significantly lower number of games in the NFL compared to other competitions. The results of individual games thus play a much more important role in deciding the season in the NFL, with 16 regular-season games annually, than they do in professional baseball (162 games), basketball or hockey (82 games each). Due to the significantly smaller sample size, randomness plays a greater role (cf. Alwell 2020).

Because of this statistical difference, the annual home bias in the NFL is also significantly less constant than in the other sports leagues (cf. Pollard/Pollard 2005, pp. 341 et seq.). This incoherent character between successive NFL seasons can also be found in other variables (cf.

Puopolo 2018) and can be understood as an attractive factor of the league for the viewer. Welki and Zlatoper (1999) conclude that NFL games are better attended if a close or uncertain game outcome can be expected beforehand. Spenner, Fenn and Crooker (2010) support these results and find that the success of the competing teams, the age of the stadium and previous attendance figures also have a significant influence on the number of spectators. Watson and Krantz (2003) do not find an increased probability of victory for the home team in a newly built stadium.

Despite the erratic nature of game results, a long-term increase in home bias can be identified between the years 1980 and 2005, which has since regressed in a slower form (cf. Jones 2016). Injuries cannot explain the recent downward trend in home bias, as they do not differ significantly between home and visiting teams but appear more frequently in all teams as the season progresses (cf. Jones 2016, p. 5).

Research on external factors influencing game outcomes in the NFL is also extensive. For example, Borghesi (2007) demonstrates a significant impact of weather conditions on the outcome of games. Furthermore, his analysis shows that visiting teams in colder locations suffer a greater impairment of their probability of winning than visiting teams in warmer locations, which in turn reflects sports psychology findings. Data from the NFL seasons 1981 to 2004 also show that visiting teams with a longer travel distance have a lower probability of winning than teams with a shorter travel distance. This effect is amplified when the visiting team has to travel from west to east for the game and therefore 'loses' daylight hours due to the early sunset (cf. Nichols 2012).

Research on home bias and its roots is also pronounced in other sports. Boyko et al. (2007) show that in football a home bias does not only exist per se, but also correlates positively with increasing spectator numbers. This home bias is reflected in goal difference and referee decisions (yellow cards, red cards, penalties given). Among the referees, an individual home preference could additionally be identified. The two-year ban on visiting fans in the Argentinian Primera Division, the highest national division, which was enacted in 2013, demonstrated that the home bias is more pronounced with a decreasing number of visiting fans than with an average number of supporters of the visiting team (cf. Colella et al. 2018).

Rickman and Witt (2008) show that the home bias of referees can be reduced with increased pay. External material influences, such as bribery, can also change the advantage in both directions. In individual sports, home bias has only been shown to a limited extent to date. In

tennis, for example, statistically significant results were only found for the men's competition, while no clear picture could be drawn for the women's competition (cf. Koning 2011).

Research on ghost games has proven difficult to conduct in the past, as the number of ghost games was hardly sufficient for an academic analysis. Reade et al. (2020), using data from 2003 until shortly before the outbreak of the global corona pandemic, show that home football teams win significantly fewer games and score fewer goals in ghost games while visiting teams win more often. The pandemic permanently changed the data situation, as large crowds were banned in large parts of the world due to massive contact reductions and games of various sports were nevertheless held in front of empty stands for economic reasons. The first empirical results of the effects of ghost games in the pandemic seasons are already available, especially in football. For example, a significant reduction to the point of negating the home bias in front of empty stands could be shown for the 1st Bundesliga in Germany, which can be explained at least in part by my more equal decisions of the referees (cf. Dilger/Vischer 2022). The results of this work are supported by most other publications on the effects of ghost games in football. Scoppa (2021) shows a significant decline in home bias with simultaneous equalisation of the visiting team by the referee in his analysis of the two highest football leagues in Germany, England, France and Italy as well as the first Portuguese league. While Fischer and Haucap (2020) cannot establish a statistically significant change in home bias in the 2nd and 3rd German Bundesliga, their results also confirm the findings for the 1st Bundesliga. In the NBA playoffs, Price and Yan (2021) find a negation of the home bias. However, the tournament took place within the framework of a player bubble on neutral ground in Orlando and was not played in the respective home venues of the teams. For the MLB playoffs it can only be assumed that ghost games have a negative impact on the offensive performance of home teams (cf. Currea 2021).

An academic analysis of change in game results and the home bias in the NFL in the context of ghost games has not yet been published to the best of our knowledge. Only well-known sports journalism websites have published rudimentary analyses and forecasts (Jones 2020; Princiotti 2021). Furthermore, a strong increase in injuries could be measured in the 2020 NFL season (Blumenthal 2021). However, a statistical significance test is also lacking there, so that this paper can be understood as a first attempt to close this research gap.

3. Hypothesis

We consider the largely spectatorless NFL season 2020 (see Chapter 4) as a natural experiment, assuming that the lack of spectators is the most important difference between this season and the regular seasons 2011 to 2019. This is the first hypothesis, based on the research already presented on other sports:

H_1: Ghost games reduce the home bias in NFL.

In addition to the game decision, the difference in points is also taken into account in the analysis. Moreover, other statistical indicators are checked for significant changes between the groups under consideration. In particular, the behaviour of referees is a recurring focus of research. Accordingly, the second hypothesis is as follows:

H_2: The preference given to home teams by NFL referees is negated by ghost games.

A variety of game statistics are used to examine the impact of the lack of spectators on the game at the micro level, so that a statement can be made whether ghost games favour NFL offenses and thus favour higher-scoring games or more efficient ball movement.

Finally, we analyse whether home teams with limited spectator capacity had an advantage in the 2020 season over teams that could not welcome spectators to their games due to local or US state regulations.

H_3: Teams that held 2020 games with some spectator participation enjoyed an advantage over teams that had to operate in front of empty crowds.

4. Data

For the empirical analysis of the ghost games, we compare data from the ten NFL seasons from 2010 to 2019, which took place under normal audience conditions, with those from 2020. Only the annual 256 regular season games are taken into account, as the seeding mode of the NFL playoffs rewards strong teams with home games, which would distort the data set for this study. The NFL preseason, on the other hand, has too little sporting value to be included in the analysis due to the high injury risk of the sport and the resulting large number of deployments of actual substitute players. Because we are interested in the impact of the home bias in the NFL, we exclude games executed on neutral ground from our data set. There are three ghost games that took place on neutral ground due to Covid-19 regulations. In the 2010-

2019 seasons, this affects a total of 34 matches, of which a few were not played at their home stadium due to weather conditions and most due to internationalisation. Thus, we have 2,526 games in the control group.

Ghost games are generally defined as games played in front of no audience. However, due to the highly federal nature of the NFL's audience regulations during the pandemic, a distinction must be made. Of the 256 games in the 2020 season, 149 were held in front of exclusively empty stands, three of them on neutral ground. 107 games were played with greatly reduced crowds. The Pittsburgh Steelers game against the Dallas Cowboys in Week 9 represented the peak attendance with 31,700 spectators. This represents 32 % of the total capacity of AT&T Stadium, the Cowboys' home venue. On average, these semi-ghost games were attended by 11,256 spectators, equivalent to 15.4 % stadium occupancy. When visiting the stadium, fans had to adhere to strict hygiene guidelines and were therefore not allowed to exceed a volume of 70 decibels, among other things, while fan sounds recorded in ghost games were also allowed to be played over the loudspeakers at up to 70 decibels (cf. NFL Football Operations 2020). Thus, players compared the atmosphere in semi-ghost games with that in training sessions (cf. Mahomes 2020). We initially apply the statistical analyses exclusively to real ghost games in order to shed light on the differences between ghost games and semi-ghost games in a further step.

For the evaluation, the following data was collected, each for home and visiting team and, if meaningful, as a difference of both teams: Score, points scored, pass attempts, passes completed, pass yards, pass touchdowns, interceptions, sacks allowed, sack yards allowed, passer rating, runs, run yards, run touchdowns, penalties, penalty yards, 1st downs, 1st downs by runs, 1st downs by pass and 1st downs by penalty. A large part of the data was aggregated via the paid statistics portal stathead.com. In addition, data from nflpenalties.com for penalties and penalty yards are included. Furthermore, the freely available spectator numbers per game from espn.com are used. All these variables are available for each of the 2,779 games from the 2010 season onwards. The analysis is supported by the statistical data and analysis software SPSS.

5. Empirical Results

For an initial overview, Figure 1 shows the annual course of the home win rate in the NFL for the seasons under consideration, 2010 to 2020. In the ten years before the pandemic, home teams won 56.5 % of the games. Due to decisive overtime rules (cf. Martin et al. 2018), draws

occur extremely rarely in the NFL. In the eleven seasons considered, nine games ended without a winner (including one in 2020), which corresponds to a share of 0.3% of all games. Therefore, this paper focuses on the home win percentage as a measure of home field advantage. Figure 1, like every other figure and table in this paper, is based on our own representation of the merged and econometrically researched data.

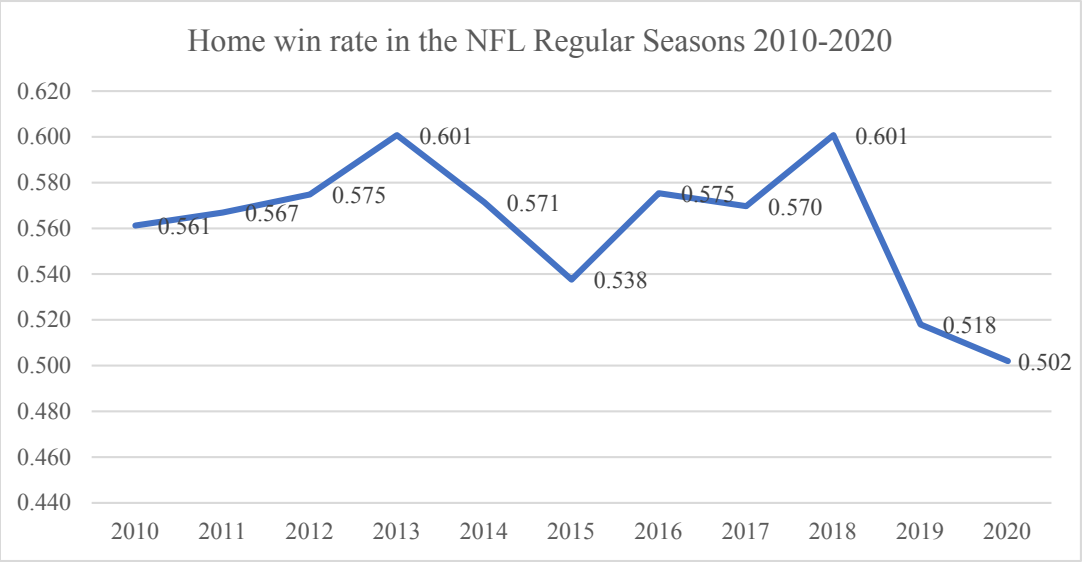
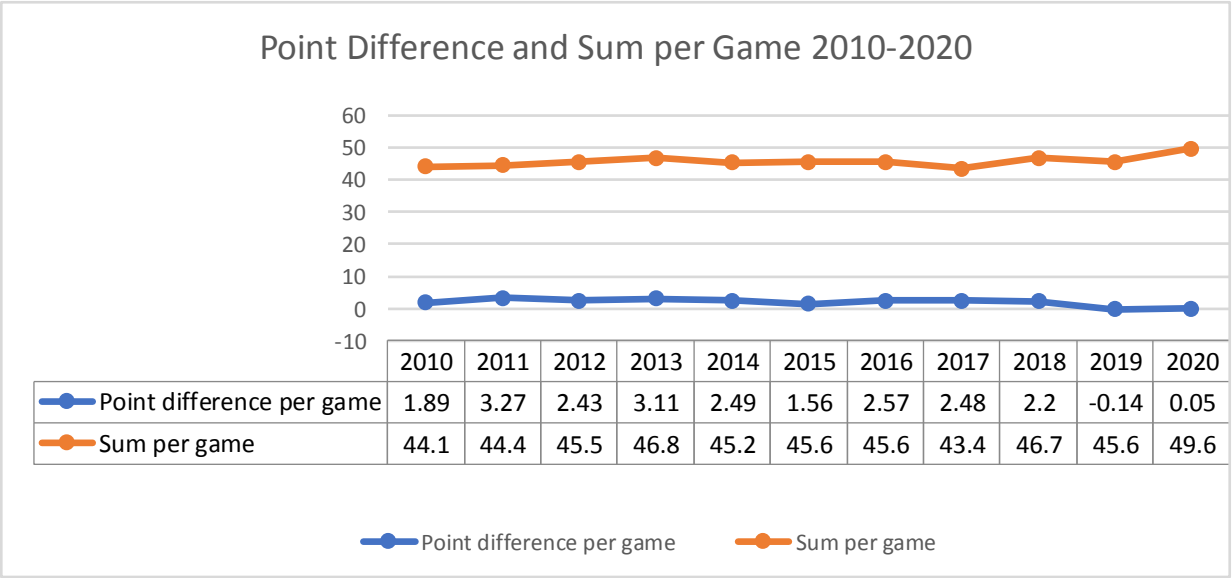


Figure 1: Home Win Rate in NFL Regular Seasons 2010-2020

Figure 2 shows the difference in points between the teams and the combined points scored by both teams per game. Like every difference statistic in this paper, the point difference is calculated by subtracting the points scored by the visiting team from those of the home team (H – A). If the points difference is positive, the home team scored more points per game than the visitors on average in the season under consideration, and vice versa. In the ten seasons before corona, home teams scored on average 2.19 points more than their visiting rivals in the regular season (home 23.74 vs. visiting 21.55). During this period, an average of 45.29 points per game was scored. Between 2010 and 2019, the correlation between year and combined points is positive (0.28). This shift in the balance of power between offenses and defences is also perceived in current sports journalism and is primarily attributed to new rules that make the game higher-scoring and thus more spectacular (cf. Clark 2019; Sphigel/Pennington 2019). In the corona season, even more points were scored (49.6 on average), while the average point difference can be described as almost neutral (0.05).



	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020
Point difference per game	1.89	3.27	2.43	3.11	2.49	1.56	2.57	2.48	2.2	-0.14	0.05
Sum per game	44.1	44.4	45.5	46.8	45.2	45.6	45.6	43.4	46.7	45.6	49.6

Figure 2: Point Difference and Sum per Game 2010-2020

Figure 3 presents the average number of spectators per regular season game. In the seasons 2010 to 2019, an average of 67,806 spectators attended the games. The figure shows a slight decrease between 2016 and 2019, but an overall fairly stable picture of stadium attendance before the pandemic. The games of the 2020 season are to be subdivided. The 107 semi-ghost games were held with an average of 11,255 spectators, while the 146 genuine ghost games were held in front of empty stands by definition.

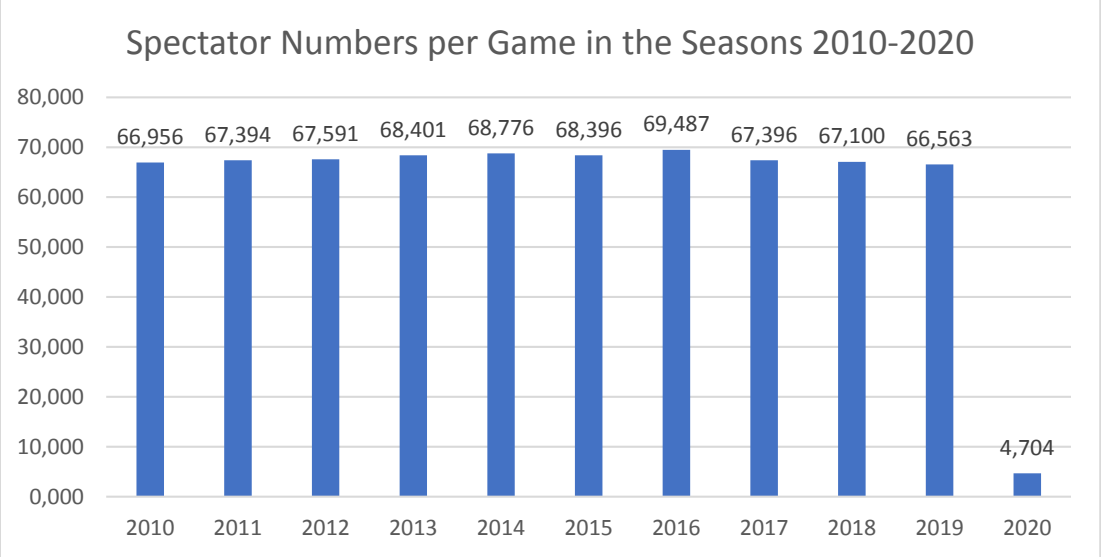


Figure 3: Spectator Numbers per Game in the Seasons 2010-2020

5.1 Descriptive Analysis

Table 1 shows the descriptive data of ghost games in the 2020 season compared to games held under regular conditions between 2010 and 2019. Semi-ghost games are included later in Tables 7 and 8. The number, minima, maxima, mean values and standard deviations of the respective statistics are shown and the variables are explained in the text below.

	Ghost Games in 2020					Regular Games in 2010-2019				
Variables	N	Min.	Max.	M	SD	N	Min.	Max.	M	SD
h_win	146	0	1	.48	.501	2526	0	1	.57	.495
h_points	146	0	56	23.76	9.125	2526	0	62	23.78	10.326
a_points	146	3	48	24.11	9.742	2526	0	59	21.52	9.851
Margin	146	-45	37	-.35	13.968	2526	-49	58	2.26	14.587
points_comb	146	23	82	47.87	12.699	2526	6	105	45.30	13.948
d_Cmp	146	-21	27	-.84	9.395	2526	-31	30	.22	8.865
d_pAtt	146	-31	33	-1.00	13.067	2526	-43	52	-.29	13.169
d_Cmp%	146	-.452	.417	-.912	.138	2526	-.416	.481	.012	.133
d_pYds	146	-364	195	-18.98	103.937	2526	-330	302	7.75	100.486
d_pY/A	146	-8.557	6.077	-.370	2.621	2526	-11.110	9.822	.275	3.547
d_pTD	146	-6	4	.08	1.692	2526	-7	5	.12	1.511
d_Int	146	-4	3	.02	1.251	2526	-6	5	-.03	1.473
d_Sk	146	-6	7	-.18	2.519	2526	-9	11	-.13	2.539
d_sYds	146	-51	54	-.54	19.659	2526	-87	77	-1.04	18.475
d_Rate	146	-107.100	93.300	.460	38.392	2526	-125.800	123.000	5.743	38.939
d_rAtt	146	-28	28	-.75	12.030	2526	-44	46	1.03	13.590
d_rYds	146	-179	195	4.73	71.809	2526	-263	296	6.29	79.946
d_rY/A	146	-3.580	5.860	.251	1.830	2526	-6.980	6.430	.073	1.833
d_rTD	146	-4	4	-.08	1.345	2526	-6	4	.15	1.283
d_Pen	146	-10	7	-.55	2.980	2526	-17	13	-.35	3.632
d_penYds	146	-59	116	5.62	31.089	2526	-128	138	3.22	35.640
CombPen	146	3	20	11.35	3.638	2526	2	29	13.05	4.230
CombPenYds	146	15	222	97.43	39.024	2526	10	292	111.06	41.085
d_1stD	146	-20	16	-.75	7.117	2526	-24	31	.93	7.389
d_1stDrush	146	-10	12	.02	4.287	2526	-18	17	.95	4.762
d_1stDpass	146	-18	15	-.93	5.992	2526	-16	22	1.47	6.315
d_1stDpen	146	-6	4	.16	1.845	2526	-7	10	.37	2.007

N = Sample Size. Min. = Minimum. Max. = Maximum. M = Mean. SD = Standard Deviation.

Table 1: Descriptive Statistics for Ghost Games 2020 and the Seasons 2010-2019

The binary variable h_win indicates whether the home team won (1) or not (0) in the game under consideration. The points scored by both teams are shown as h_points and a_points.

The difference between them shows the variable margin, the sum of both scores the variable PC. In addition to these variables, statistical difference values of both teams are shown. For this purpose, the respective value of the visiting team is subtracted from that of the home team (H – A). These difference variables are identified by the prefix d_. The respective statistics for home and visiting teams are also available and can be used for analysis if necessary.

At first glance, a decline in the home advantage of about ten percentage points can already be seen. The visitors' offences in particular seem to benefit from ghost games, scoring on average 2.59 points more than under regular conditions.

5.2 Significance Tests

In order to test the first hypothesis whether the home advantage is reduced by ghost games a chi-squared tests are first carried out. The variables h_win, h_points, a_points and margin are considered. Table 2 shows the results, where the usual significance levels are marked by * (< 0.1), * * (< 0.05) and * * * (< 0.01). Unless explicitly described otherwise, two-sided significance is used in this paper. The control group consists of the 2,526 games played in the 2010 to 2019 seasons, while the experimental group consists of the 146 ghost games played in 2020.

The home win probability in ghost games thus decreases significantly compared to games under normal audience conditions. Thus, the first hypothesis can be confirmed on the error level $\alpha = 0.05$. A first indicator of what causes this shift in the balance between the teams can also be found in the results. While the points scored by the home team show no significant change, the points scored by the visiting team increase by an average of 2.59 points per game. This change is even significant at the $\alpha = 0.05$ level. Due to the different changes in points, the difference in points also decreases significantly.

	Ghost Games			Regular Games			Chi-Square Test		
	N	M	SD	N	M	SD	Value	Df	Sig. (2-tailed)
h_win	146	.48	.501	2526	.57	.495	4,368	1	.037**
h_points	146	23.76	9.125	2526	23.78	10.326	51.142	56	.659
a_points	146	24.11	9.742	2526	21.52	9.851	75.488	50	.011**
Margin	146	-.35	13.968	2526	2.26	14.587	117.201	90	.029**

N = Sample Size. M = Mean. SD = Standard Deviation. Sig. (2-tailed) = Significance (2-tailed). * p < .10. ** p < .05. *** p < .01.

Table 2: Chi-Square Tests

In the next step, two-tailed t-tests of independent samples are conducted for all existing difference variables of the game. This allows the results already presented to be tested and further variables to be included. To test the second hypothesis, a separate look at the referees' decisions will be made later (see Table 6 below).

Table 3 shows the results of the t-tests of the two independent samples consisting of the ghost games in 2020 and the games under regular conditions in the seasons 2010 to 2019, supporting the findings of the chi-squared tests: The home win probability and the point difference are significantly reduced in ghost games, while the points scored by the visiting team increase strongly and significantly. An effect of the ghost games on the points scored by the home team cannot be found.

The point totals of both teams increase significantly since home teams score at a similar level without spectators as they do when the stadium is full while visitors score significantly more. In almost all related statistics, the average difference (H – A) changes in favour of the visiting team. Pass yards per game (d_pYds), completion percentage (d_Cmp%) and pass yards per attempt (d_pY/A) each show a significant reduction. The difference in the passer rating (d_Rate) and pass touchdowns (d_pTD) has also shifted in favour of the guests although without statistical significance. Sacks allowed (d_Sk) and sack yards allowed (d_sYds) are negative and are thus considered detrimental to player success and should be prevented. Consequently, increasing the differential is desirable for visiting teams. While this can be recorded, the movements in both variables are not significant.

In contrast to the passing game, no significant change in space gained can be observed in the running game. Although the respective difference statistics rush yards per game (d_rYds) and rush yards per attempt (d_rY/A) also decrease, the change is insignificant. The difference between touchdowns scored via the running game (d_rTD) matters. The change from 0.15 rushing touchdowns, which home teams with spectators score more than visiting teams, to -0.08 rushing touchdowns, which home teams without spectators score less than the opponent, is significant at the level of $\alpha = 0.05$.

Overall, a clear trend of an eroding home advantage can be noted. In almost all the difference statistics considered, the respective mean value shifts in favour of the visiting team in the context of ghost games, in many cases significantly. In addition to the variables already mentioned above, the first downs achieved (d_1stD) should also be mentioned. The statistical significance of the difference in means between games under regular conditions and ghost games

is strong at p = 0.008. Furthermore, as already seen in the ratios point differential, passes completed, pass yards per game, completion percentage, pass yards per attempt, interceptions thrown and rushing touchdowns, the difference variable changes sign. Thus, on average, visiting teams score more 1st downs in ghost games than home teams do.

	Ghost Games			Regular Games (2010-2019)			95 % CI		
Variables	N	M	SD	N	M	SD	Sig. (2-tailed)	LV	UV
h_win	146	.48	.501	2526	.57	.495	.037**	.005	.171
h_points	146	23.76	9.125	2526	23.78	10.326	.981	-1.526	1.564
a_points	146	24.11	9.742	2526	21.52	9.851	.002***	-4.235	-.949
Margin	146	-.35	13.968	2526	2.26	14.587	.035**	.182	5.040
points_comb	146	47.87	12.699	2526	45.30	13.948	.030**	.258	4.964
d_Cmp	146	-.84	9.395	2526	.22	8.865	.162	-.425	2.544
d_pAtt	146	-1.00	13.067	2526	-.29	13.169	.525	-1.484	2.910
d_Cmp%	146	-0.009	.1385	2526	.012	.133	.055*	-0.000	.044
d_pYds	146	-18.98	103.937	2526	7.75	100.486	.002***	9.928	43.535
d_pY/A	146	-.370	2.621	2526	0.275	3.547	.031**	.060	1.229
d_pTD	146	.08	1.692	2526	.12	1.511	.750	-.213	.295
d_Int	146	.02	1.251	2526	-.03	1.473	.691	-.293	.194
d_Sk	146	-.18	2.519	2526	-.13	2.539	.500	-.374	.473
d_sYds	146	-.54	19.659	2526	-1.04	18.475	.753	-3.592	2.597
d_Rate	146	.460	38.392	2526	5.743	38.939	.111	-1.211	11.777
d_rYds	146	4.73	71.809	2526	6.29	79.946	.819	-11.721	14.826
d_rY/A	146	.251	1.830	2526	0.073	1.833	.253	-.484	.127
d_rTD	146	-.08	1.345	2526	.15	1.283	.042**	.008	.438
d_1stD	146	-.75	7.117	2526	.93	7.389	.008***	.448	2.909

N = Sample Size. M = Mean. SD = Standard Deviation. Sig. (2-tailed) = Significance (2-tailed). CI = Confidence Interval. LV = Lower Value. UV = Upper Value. * p < .10. ** p < .05. *** p < .01.

Table 3: t-Tests for Ghost Games Compared to Seasons 2010-2019

To take a closer look at the significant changes, we focus in the next step on the indicators of the home and visiting teams for the corresponding variables. Variables for which no change could be detected in the difference will not be examined further. For margin and PC, the two individual components h_points and a_points have already been examined and are therefore also omitted.

Table 4 shows t-tests for equality of means for game statistics whose difference from home and visiting teams proved to be a significant change between the 2020 ghost games and the games under regular conditions in the 2010 to 2019 seasons. Only offensive statistics are rep-

resented, so an increase in values can be interpreted as beneficial for the respective team. Both teams show a significant increase in completion percentage (h/a_Cmp%). Accordingly, more passes were caught by teammates in 2020 in relation to pass attempts than compared to previous years. However, the 3.93 % increase in completion percentage for visiting teams is more than twice as large as for home teams (1.75 %). This not only results in a higher significance level in the statistics but also explains the significant reduction of the difference variable d_Cmp% from Table 3. For passing yards contrasting trends can be observed. Home teams not only achieve significantly fewer yards per game in ghost games but also gain significantly less space per passing attempt. In contrast, the visitors' offence achieves more passing yards per game. The space gain per attempt of the away team increases on average, but only insignificantly. Nevertheless, the results can explain the difference variables, so that the impression already created that visiting teams benefit particularly in the passing game during ghost games is confirmed.

Home and away teams scored more passing touchdowns in ghost games than they did in the previous ten seasons. Although both increases are not demonstrably statistically different from the control group, the trend that away teams were more likely to benefit from the circumstances of the corona season is also evident here. The increase for away teams (0.11 passing touchdowns per game) is more than a factor of 1.5 greater than the increase for the hosts (0.07). A similar picture emerges in the statistics of rushing touchdowns. Both teams were able to record more touchdowns via the running game in 2020 than they achieved in previous years. However, the increase is many times (and significantly) higher for the guests than for the hosts.

In terms of 1st downs achieved, the basic tendency of an offensively dominated 2020 season compared to the ten seasons before can also be observed. Here, too, visiting teams generally benefit more from the increase than the hosts. While home teams also register a significant increase of 0.87 first downs per game, away teams achieve almost three times the value with 2.55 additional first downs. The significantly larger increase is indicated by the significance level $\alpha = 0.01$ and is the reason for the reduction of the difference variable d_1stD in favour of the away team in table 3 despite significantly more first downs by the home team.

	Ghost Games			Regular Games			95 % CI		
Variables	N	M	SD	N	M	SD	Sig. (2-tailed)	LV	UV
h_Cmp%	146	.6475	.096	2526	.630	.096	.034**	-.033	-0.001
a_Cmp%	146	.656	.090	2526	.617	.096	.000***	-.055	-.02
h_pYds	146	224.64	75.938	2526	237.62	78.056	.051	-.034	25.984
a_pYds	146	243.62	77.466	2526	229.87	78.125	.039**	-26.790	-.723
h_pY/A	146	6.573	1.895	2526	6.955	1.956	.021**	.056	.708
a_pY/A	146	6.942	1.792	2526	6.680	2.911	.281	-.740	.215
h_pTD	146	1.67	1.244	2526	1.60	1.183	.492	-.268	.129
a_pTD	146	1.59	1.184	2526	1.48	1.140	.255	-.302	.080
h_rTD	146	.97	.871	2526	.86	.935	.146	-.256	.038
a_rTD	146	1.05	.992	2526	.72	.842	.000***	-.497	-.166
h_1stD	146	21.18	4.697	2526	20.31	4.964	.039**	-1.696	-,044
a_1stD	146	21.93	5.062	2526	19.38	4.998	.000***	-3.383	-1.713

N = Sample Size. M = Mean. SD = Standard Deviation. Sig. (2-tailed) = Significance (2-tailed). CI = Confidence Interval. LV = Lower Value. UV = Upper Value. * p < .10. ** p < .05. *** p < .01.

Table 4: t-Tests for Home and Away Variables

In order to examine the strong effect of the ghost games on the 1st downs scored, these are split according to the type of score (passing game, running game or penalty). This also gives a first impression of the change in referee decisions. The results in Table 5 are largely consistent with the conclusions already drawn. Home and visiting teams scored significantly more first downs per game in 2020 than they did in the previous ten years. Each subgroup of 1st downs, i.e. via the running game, passing game or penalties after referee decisions, also increased on average in the 2020 season. Again, visiting teams benefit more from the trend of offensive dominance in ghost games than home teams. The increase in all first downs gained per game is again higher for the visitors than for the hosts. When looking at 1st downs gained through the passing game, the disparity is even higher. The visiting team's increase (2.36) is highly significant, mapping 41 times the minimal and non-significant increase of the home team (0.04). For 1st downs gained by running plays, a significant increase to the error level $\alpha = 0.01\%$ can be demonstrated for both teams. Again, however, visiting teams benefit significantly more from the circumstances than home teams. For 1st downs, which are awarded to punish the opponent's defence by the referee, no significant increase can be found for both teams. However, the increase in the mean per game is again higher for the visiting teams than for the home teams. Thus, it is to be examined whether referees treat the teams less unequally in the context of ghost games in accordance with the second hypothesis.

	Ghost Games			Regular Games			95 % CI		
Variables	N	M	SD	N	M	SD	Sig. (2-tailed)	LV	UV
h_1stD	146	21.18	4.697	2526	20.31	4.964	.039**	-1.696	-.044
a_1stD	146	21.93	5.062	2526	19.38	4.998	.000***	-3.383	-1.713
h_1stDrush	146	6.99	3.124	2526	6.15	2.987	.001***	-1.345	-.346
a_1stDrush	146	6.97	2.809	2526	5.20	3.286	.000***	-2.249	-1.295
h_1stDpass	146	12.15	3.973	2526	12.19	3.983	.914	-.628	.701
a_1stDpass	146	13.08	4.235	2526	10.72	5.166	.000***	-3.22	-1.511
h_1stDpen	146	2.03	1.362	2526	1.97	1.521	.611	-.318	.187
a_1stDpen	146	1.88	1.379	2526	1.60	1.444	.026**	-.514	-.033

N = Sample Size. M = Mean. SD = Standard Deviation. Sig. (2-tailed) = Significance (2-tailed). CI = Confidence Interval. LV = Lower Value. UV = Upper Value. * p < .10. ** p < .05. *** p < .01.

Table 5: t-Tests for First Down Splits

Unlike in European football, personal penalties are rare in American football. The option of a warning is not available and ejections (comparable to a red card, but the team in question is not outnumbered after being given one) are extremely rare and are not listed in the usual statistics portals. Thus, the work concentrates on the statistics penalties and penalty yards, i.e. the number of penalties and the penalty rate, which is quantified by different gradations of space gained for the opponent. In addition to home, away and differential figures, the totals per game are also listed. As before, data from the 2020 season's genuine ghost games are compared with those from 2010 to 2019 on a per-game basis. Table 6 presents the results.

The first thing to note is that under regular conditions, a preference for home teams by referees can be measured. For example, in the last decade, an average of 0.35 penalties and 3.24 penalty yards per game were called more against the visiting team than against the home team. This unequal treatment is considered proven in the NFL, but also in other sports (see Chapter 2). Furthermore, the results show that significantly fewer penalties are called against both teams in ghost games than before. 1.7 fewer penalties per game are equivalent to a highly significant reduction compared to the control value. This also applies to the total penalty yards, which were reduced by 13.63 yards. This trend has not gone unnoticed by attentive spectators and major sports portals are already reporting on it (Seifert 2020).

The reduction in total penalties and penalty yards can also be seen for both teams. Hosts and visitors were each given significantly fewer penalties and penalty yards in ghost games than was previously the case. However, it is striking that the difference in ghost games has an even higher negative amount. Thus, in ghost games, visiting teams have been awarded even more

penalties and penalty yards than home teams. Although the changes in the difference variables are not significant, a reduction or even negation of the referee preference through ghost games cannot be assumed on the basis of the results. The results are somewhat surprising, as it is known from work on other sports that referees' decisions can certainly be influenced by spectators.

	Ghost Games			Regular Games			95 % CI		
Variables	N	M	SD	N	M	SD	Sig. (2-tailed)	LV	UV
h_Pen	146	5.40	2.239	2526	6.35	2.737	.000***	.572	1.334
a_Pen	146	5.95	2.459	2526	6.70	2.838	.001***	.328	1.162
d_Pen	146	-.55	2.980	2526	-.35	3.632	.420	-.299	.715
h_penYds	146	45.90	24.132	2526	53.92	26.643	.000***	3.591	12.441
a_penYds	146	51.53	25.735	2526	57.14	27.735	.017**	1.003	10.227
d_penYds	146	5.62	31.089	2526	3.22	35.640	.426	-8.311	3.509
CombPen	146	11.35	3.638	2526	13.05	4.230	.000***	.997	2.399
CombPenYds	146	97.43	39.024	2526	111.06	41.085	.000***	6.792	20.470

N = Sample Size. M = Mean. SD = Standard Deviation. Sig. (2-tailed) = Significance (2-tailed). CI = Confidence Interval. LV = Lower Value. UV = Upper Value. * p < .10. ** p < .05. *** p < .01.

Table 6: t-Tests for Referee Decisions

To test hypothesis 3, semi-ghost games are included in the analysis. Table 7 shows the 95 % confidence intervals of the home win probability by game type. While the significantly lower home advantage between regular and ghost games can be clearly seen, no statistically verifiable statement is possible due to the small sample size of semi-host games and the home win rate of 53 % there.

			95 % CI	
Variables	N	M	LV	UV
Ghost Games	146	.48	.40	.56
Regular Games	2526	.57	.55	.59
Semi-Ghost Games	107	.53	.44	.63

N = Sample Size. M = Mean. CI = Confidence Interval. LV = Lower Value. UV = Upper Value.

Table 7: 95 %-Confidence Intervals for Home Wins by Type of Game

In other indicators already presented in comparison between regular and ghost games, no significant differences between semi-ghost games and ghost games from the 2020 season can be identified. Table 8 shows the home winning percentage, the margin and all available differ-

ence variables in the comparison between ghost and semi-ghost games. No change between the two groups illuminated reaches a statistical significance level.

	Ghost Games			Semi-Ghost Games			95 % CI		
Variables	N	M	SD	N	M	SD	Sig. (2-tailed)	LV	UV
h_win	146	.48	.501	107	.53	.501	.405	-.179	.072
margin	146	-.35	13.968	107	.80	14.770	.527	-4.740	2.434
d_Cmp	146	-.84	9.395	107	-.36	9.076	.680	-2.809	1.834
d_pAtt	146	-1.00	13.067	107	-.38	13.433	.714	-3.931	2.697
d_Cmp%	146	-0.912	13.858	107	-0.499	12.771	.809	-3.773	2.948
d_pYds	146	-18.98	103.937	107	2.75	97.502	.093	-47.109	3.654
d_pY/A	146	-.370	2.621	107	.052	2.434	.194	-1.059	.215
d_pTD	146	.08	1.692	107	-.11	1.556	.351	-.216	.604
d_Int	146	.02	1.251	107	.07	1.439	.750	-.388	.280
d_Sk	146	-.18	2.519	107	-.47	2.332	.364	-.330	.894
d_sYds	146	-.54	19.659	107	-2.63	16.820	.377	-2.555	6.725
d_Rate	146	.460	38.392	107	-.265	37.253	.881	-8.777	10.228
d_rAtt	146	-.75	12.030	107	-1.32	14.546	.741	-2.826	3.969
d_rYds	146	4.73	71.809	107	-3.21	91.887	.459	-13.141	29.018
d_rY/A	146	.251	1.830	107	.179	1.711	.750	-.374	.518
d_rTD	146	-.08	1.345	107	.13	1.505	.253	-.561	.148
d_Pen	146	-.55	2.980	107	-.11	3.085	.251	-1.201	.316
d_penYds	146	5.62	31.089	107	-.98	32.872	.105	-1.379	14.588
d_1stD	146	-.75	7.117	107	-.26	7.293	.592	-2.294	1.311
d_1stDrush	146	.02	4.287	107	-.39	5.379	.513	-.828	1.655
d_1stDpass	146	-.93	5.992	107	.21	5.213	.114	-2.569	.276
d_1stDpen	146	.16	1.845	107	-.08	1.943	.315	-.231	.715

N = Sample Size. M = Mean. SD = Standard Deviation. Sig. (2-tailed) = Significance (2-tailed). CI = Confidence Interval. LV = Lower Value. UV = Upper Value. * p < .10. ** p < .05. *** p < .01.

Table 8: t-Test between Ghost Games and Semi-Ghost Games 2020

5.3 Regressions

In order to verify the significance tests carried out up to this point, several regressions are carried out. Table 9 shows the results of a binary logistic regression based on home wins. This type of regression is appropriate due to the binary nature of the home win variable. In addition to the binary variable ghost games ("yes" = 1; "no" = 0), only difference variables are included whose changes due to ghost games have already been shown to be significant in this work.

The first hypothesis that ghost games reduce the home advantage is confirmed at the significance level $\alpha = 0.1$. The difference variables pass yards, pass yards per attempt, completion

percentage, passing touchdowns, rush touchdowns and 1st downs scored, which were found to be significant in the t-tests, have a highly significant effect on the probability of a home win, with the difference in passing attempts having a negative effect on the home win probability.

Independent Variables	B	Sig.	Exp(B).	95 % CI	
				Lower	Upper
gg_01	-.449	.093*	.638	.377	1.078
d_pYds	-.016	.000***	.984	.982	.987
d_pY/A	.717	.000***	2.047	1.862	2.251
d_Cmp%	.040	.000***	1.040	1.028	1.053
d_pTD	.937	.000***	2.552	2.231	2.918
d_rTD	.951	.000***	2.589	2.211	3.031
d_1stD	.142	.000***	1.152	1.121	1.185
d_penYds	.004	.021**	1.004	1.001	1.008

B = Regression Coefficient. Exp(B) = Exponentiation of B, Odds Ratio. Sig. = Significance. CI = Confidence Interval for Exp(B). LV = Lower Value. UV = Upper Value. * p < .10. ** p < .05. *** p < .01. Cox & Snell R Square = .524. Nagelkerke R Square = .702.

Table 9: Binary Logistic Regression for Home Wins

By including the semi-ghost games, i.e. the regular season games that took place in 2020 with limited spectator capacity and under strict hygiene regulations, the sample size of the experimental group increases, but the reduction of the home bias is no longer statistically significant due to a higher home win rate of semi-ghost games. Table 10 shows the results of the logistic binary regression of all existing games on the dependent variable h_win.

Independent Variables.	B	Sig.	Exp(B).	95 % CI	
				Lower	Upper
gg&sgg_01	-.167	.428	.846	.560	1.279
d_pYds	-.015	.000***	.985	.982	.987
d_pY/A	.709	.000***	2.033	1.854	2.229
d_Cmp%	.039	.000***	1.040	1.028	1.052
d_pTD	.944	.000***	2.571	2.253	2.934
d_rTD	.974	.000***	2.648	2.267	3.092
d_1stD	.140	.000***	1.150	1.120	1.182
d_penYds	.004	.034**	1.004	1.000	1.007

B = Regression Coefficient. Exp(B) = Exponentiation of B, Odds Ratio. Sig. = Significance. CI = Confidence Interval for Exp(B). LV = Lower Value. UV = Upper Value. * p < .10. ** p < .05. *** p < .01. Cox & Snell R Square = .525. Nagelkerke R Square = .703.

Table 10: Binary Logistic Regression for Home Wins Including Semi-Ghost Games

6. Discussion

The main intention of this paper is to explore the impact of ghost games due to the corona pandemic on the home bias in the NFL. In order to do this, a series of significance tests are conducted in a first step to measure and rank the differences between regular and ghost games. The results obtained are then tested in a second step using binary logistic regression because of the binary nature of the home win variable. In this way our first hypothesis that the home bias decreases can be confirmed or conversely the null hypothesis that the home bias does not change under NFL ghost games can be rejected at least at the error level $\alpha = 0.1$, while the t-tests allows a corresponding rejection even at the error level of 0.05. However, the influence of other variables are more pronounced. Furthermore, it is not possible to speak of a bias for visiting teams due to ghost games. Of the 146 ghost games, the visitors won 75. This win probability of 51.3 % does not represent a significant difference to the balanced value of 50 %. The corresponding t-test of a sample set yields a two-sided significance value of $p = 0.621$.

In addition to the statistical significance explored, a look at the other results of this paper supports the conclusion that NFL home teams suffered a disadvantage in ghost games in the 2020 season compared to the seasons before. Visiting teams can score significantly more points in ghost games than they did before under regular conditions. At the same time, the insignificant and on average only minimal increase in the points scored by the home teams results in a strong shift in the points difference in favour of the away teams. Furthermore, the trend of the disappearing home advantage can also be seen in the game statistics. The differential variables pass yards per play, pass yards per attempt, passing touchdowns and 1st downs scored all change significantly in favour of the visiting team in ghost games. Basically, the passing game of the visiting team benefits from the absence of the (mainly) opposing fans. Pass yards per game and completion percentage for visiting teams in the 2020 season increase significantly more than the corresponding figures for home teams. Their yards per pass attempt in ghost games even decrease significantly compared to the average from the previous ten years.

Our second hypothesis is that the preference of home teams by referees in the NFL is negated by ghost games. The opposing null hypothesis that there is no difference between regular and ghost games cannot be rejected. The two differential variables determined by the referees (penalties and penalty yards) tended even to change (albeit not significantly) in favour of the home team in the ghost games of the 2020 season. This result is surprising, given that the influence of spectators on refereeing decisions is often highlighted across sports and favours the

home teams. The fact that referees in American football have only limited room for interpretation compared to other sports is a possible explanation for the results obtained. Personal penalties are so rare that there is no valid data collection we know of, and for team penalties there are clear guidelines from the league that the referees have to follow. Furthermore, individual referee actions are less relevant to game decisions. For example, there is no equivalent in American football to the penalty kick in soccer, the penalty corner in hockey or the seven-metre in handball, all of which are very likely to have a direct influence on the respective score.

However, a significant and strong reduction of the total number of penalties and penalty yards can be shown. The extent to which these changes can really be transferred to the ghost games remains open. Several national sports media suggest that the league intentionally had fewer penalties imposed by referees (cf. Farmer 2020; Greenberg 2020; Seifert 2020). Fewer penalties were called against offenses in particular, presumably in order to generate higher-scoring and more spectacular games and to counteract the effect of the pandemic-related shortened practice times and the resulting loss of quality. An analysis of this accusation is only possible through intensive and highly elaborate data collection, in which individual game situations and (non-)decisions of the referees are compared between the seasons.

Our third hypothesis, i.e. that teams that played 2020 games with at least some spectator participation enjoyed an advantage over teams that had to play in front of empty stands, cannot be confirmed either. Thus, although the home win rate in semi-ghost games is lower on average than in games under regular conditions and higher than in ghost games, these differences are not statistically significant in either direction. On the one hand, the sample size of 107 games is possibly too small to really gain statistically verifiable conclusions in such a complex sport. On the other hand, the semi-ghost games are probably too heterogeneous among themselves. For example, the most spectator-rich game of the 2020 season (Cowboys vs. Steelers in week 9) was attended by more than 42 times as many fans (31,700) as the semi-ghost game with the least spectators (Saints vs. Packers in week 3 with 748 spectators). In addition, the rules of conduct for spectators differed greatly from one another, as individual laws in the respective states were also very diverse. Thus, it is hardly possible to speak of uniform semi-ghost games across the league.

A more in-depth analysis of semi-ghost games may be of general research interest. For example, it should be examined whether significant differences in the home win rate can be measured within the group, which can possibly be explained by the strongly differing capacity uti-

lisation of the stadiums or by the different rules of behaviour of the fans during the game (such as the possibility to cheer for the home team). This can also be applied to other sports and thus shed light on the influence of pandemic-related ghost games on various factors of the sport.

7. Conclusion

Our study shows that the home bias in the NFL is significantly reduced by ghost games or even disappears completely, which confirms our first hypothesis. This result is also in line with a large number of analyses of different sports and competitions. However, the shift in favour of the visiting team cannot be explained by a change in referee behaviour and our second hypothesis cannot be confirmed. Rather, it is the visitors' offences in particular that benefit from the unusual conditions. The visiting teams can register a clear increase in points scored, which is mainly rooted in a significant increase in the efficiency of their own passing game. Regarding semi-ghost games with a reduced number of spectators, no change in the home advantage could be demonstrated, neither compared to games under regular conditions nor in comparison to real ghost games without any spectators. There is a lot of heterogeneity within the group of semi-ghost games and the partial effect could be too small for statistically significant results. Thus, our third hypothesis cannot be confirmed, too.

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