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Article

Ghost Games: Crowds, Referee Bias, and Home Advantage in European Football Leagues

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Abstract: Using a five-year data set including the crowd-less games in the 2020 English, Spanish, Italian, and German first division football leagues and multivariate regression analysis, this paper estimated how fans influence home field advantage. Consistent with previous studies, the estimates showed that in games with crowds, referees gave fewer fouls, yellow cards, and red cards but more penalty kicks to the home team than to the away team. Removing the fans from the stadium eliminated these home advantages coming through referee decisions. Removing fans reduced yellow and red cards given to away teams but did not change cards given to home teams. There was not a similar asymmetry for fouls and penalty kicks. These results suggest that crowds influenced referee judgments about how severe an infraction was more than they influenced decisions about whether a foul occurred. The addition of VAR had little impact on referee decisions and no effect on the home advantage in goal differential. Despite the home bias in referee decisions when crowds were in the stadium, fouls, cards, and penalty kicks played a relatively small role in determining home advantage in game outcomes and most of the home advantage remained after fans were removed.

Keywords: home advantage; referee bias; COVID-19; natural experiments; social pressure; video assisted referee

"Home advantage gives you an advantage."
Sir Bobby Robson

The advantages of playing at home have been well-established across a variety of sports, including football. One of the key advantages is having a large vociferous crowd supporting the home team. The COVID-19 pandemic removed this advantage by causing the latter part of the 2019-2020 football season, and much of the next, to be played before empty stadiums. These games were dubbed "geisterspiele" or ghost games (Dilger & Vischer, 2020). The ghost games provided a natural experiment in which the impact of crowd noise relative to other benefits of home play could be examined. Researchers have begun to take advantage of this natural experiment, and early indications in the literature were that the home advantage in goals and in points won per game had been reduced by about one-half when the fans were removed (Dilger & Vischer 2020; Ferraresi and Gucciardi 2020; McCarrick et al. 2021; Fischer and Haucap 2021). In addition, some studies examined the impact of removing the crowds on referee decisions and showed that the referee bias in favor of the home team was eliminated when fans were excluded from the stadiums (Endrich and Gesche 2020; McCarrick et al. 2021).

The purpose of this study was to use the data on empty stadiums to examine the link between crowds, referee decisions, and game outcomes. In doing so, the analysis added to the burgeoning literature on home advantage in several ways. First, while studies have shown that crowds affect referees, research using data from ghost games has not quantified how large of an impact crowds have on home advantage through their influence on referee decisions. The analysis of the matches in this study provided estimates of the impact of home crowds on outcomes channeled through referee decisions. Using data from the 2015/2016 through 2019/2020 seasons from four of the top five European leagues, the empirical models measured the impact of empty stadiums on home and away fouls, yellow cards, red cards, and penalty kicks to provide estimates of home bias on the part of referees. These models controlled for changes during this time period such as the introduction of video assistant referee systems. The estimates revealed that referees gave more fouls, yellow cards, and red cards to the away team (and more penalty kicks to the home team) in games with fans but that the removal of crowds in 2020 eliminated these biases in favor of the home team. Using the estimated impact of fouls, cards, and penalty kicks on game outcomes, the empirical analysis quantified how much of the reduction was related to referee decisions. The estimates indicated that only 15% of the advantage that home teams have in goal difference can be explained by the crowd's influence on referee decisions.

A second contribution of this paper was to present and test a theory that the effect of the crowd on referees may be asymmetric so that crowds had a larger impact on fouls and cards given to the away team than on those given to the home team. The data provided mixed evidence on this theory. While fouls called against home teams rose more than those called against away teams when crowds were removed, yellow cards and red cards fell significantly for away teams but remained unchanged for home teams. These results suggested that crowd noise may have had a larger impact on referee opinions about the severity of infractions than on opinions about whether an infraction occurred.

Literature Review

A home advantage has been shown to be prevalent in many sports. Gomez, Pollard, and Luiz-Pascual (2011) examined nine sports in Spain and confirmed that the home team had an advantage over the visitors in all nine. Jamieson (2010) performed a meta-analysis of studies on ten sports and concluded that the home team can expect to win around 60% of contests on average. Interestingly, football, basketball, and rugby had the largest and baseball, golf and cricket the smallest home advantages. Across the top ten European football leagues, teams won about 58% of their total points at home (Leite, 2017). This

estimate of the recent home advantage in football was smaller than that in previous studies, which is consistent with evidence from Pollard (1986) and Smith (2003) of a declining home advantage over time. Previous research has identified a number of reasons why the home team is more likely to win including greater familiarity with the stadium and the field, travel fatigue for the away team, and the impact of the crowd on the players and the referee (Pollard & Pollard 2005).

Familiarity with the Home Stadium

The home team has much greater experience playing on the field and in the stadium compared to the visiting team. Pollard (2002) presented evidence that this familiarity influences match results by showing that the home advantage was reduced by 24% for basketball, baseball, and hockey teams in the first year after a move to a new stadium relative to the last year in the previous stadium. Other research disputed this conclusion, however. Loughead, Carron, Bray and Kim (2003), for instance, found that the home advantage did not change after teams relocated to a new venue.

Familiarity with the stadium may give teams with fields that are very different from their opponents a greater home advantage. Barnett and Hilditch (1993) found that the four English football teams who used an artificial turf pitch at times during the 1980s had a significantly larger home advantage than did the other football teams using the much more common natural grass fields. Pollard (1986) investigated whether variation in field size gives the home team an advantage but found no difference in home advantage based on pitch dimensions.

Travel Fatigue

Fatigue for the away team is another factor that could influence match results and referee decision making. While Pollard (1986) found no difference in home advantage between teams more/less than 200 miles apart, Clarke and Norman (1995) found a larger home advantage when English Premier League teams were located farther apart. Pollard (1986) and Clarke and Norman (1995) also showed that home advantage was smaller in local derbies. When the away team traveled a greater distance, the home team scored more goals in the German league (Oberhofer, Philippovich, & Winner 2010), had a larger goal differential in the Brazilian league (Pollard, Silva, and Medeiros 2008), and had a larger home advantage in international matches (Brown et al. 2002).

Crowd Influence on Game Outcomes

Crowd support is the best-documented source of home advantage. Inan (2020) showed that both the number of spectators and the crowd density significantly affected game outcomes. Pollard (2006) noted that home advantage was similar across the top four levels of competition in England despite very different crowd sizes, but that home advantage was about five percentage points smaller in the English leagues below these top four levels. These results suggest that there may be a cutoff number of fans above which home advantage increases. Pollard and Gomez (2014) showed that, while a home advantage existed in women's football leagues, the home advantage was smaller for women than for men in all 26 countries in their research. One possible explanation for this disparity was the smaller crowds at women's matches (Pollard and Gomez, 2014).

Van de Ven (2011) and Ponzo and Scoppa (2018) examined same-stadium derbies, which eliminate travel fatigue and familiarity differences with the stadium as sources of home advantage. Crowd differences remained, however, as the designated home team had more

fans in the stadium due to attendance by season ticket holders. Van de Ven (2011) concluded that despite superior crowd support the home team did not have a home advantage in same-stadium derbies. Van de Ven (2011, p. 2785) also presented evidence that crowd support was "not a necessary condition for a home advantage" by showing that the home team remained the favorite even in games played without fans. The results in Ponzo and Scoppa (2018), on the other hand, indicated that 60% of the home advantage remained even when teams shared the same home stadium, which suggested that most of the home advantage was due to crowd support.

Crowd Influence on Players

The impact of crowds on home advantage is theorized to work through several different mechanisms, one of which is through direct impacts on the players. Reade, Schreyer, and Singleton (2020), for example, argued that home fans may have motivated home team players because the fans were directly monitoring individual performances. Clarke and Norman (1995) suggested that players performed better with crowds providing social support. Neave and Wolfson (2003) posited that humans respond more aggressively when defending a home territory. Data gathered by these researchers demonstrated that football players' testosterone levels were higher before home games than before away games. Since higher testosterone has been linked to more aggressive behavior in animals (Monaghan and Glickman, 1992), the Neave and Wolfson (2003) results suggest that chemical responses induce different behaviors between home and away players. Ponzo and Scoppa (2018) also showed that the home team did better even after controlling for the referee decisions, so the crowds must have directly affected player performance.

Crowd Influence on Referee Decisions

A second mechanism by which crowds may generate a home advantage is through their influence on referees. Dohmen and Sauermann (2016) documented a number of studies showing that the home team received more favorable amounts of stoppage time awarded, received fewer yellow and red cards, and was awarded more penalty kicks. These studies are based on observational or experimental data rather than on surveys of referees. Ponzo and Scoppa (2018) demonstrated that the referee gave more red and yellow cards to the visiting team and more penalty kicks to the home team even in matches in which the two teams shared the same stadium.

Buraimo, Forrest, and Simmons (2010) and Buraimo, Simmons, and Maciaszczyk (2012) cleverly noted a difference between stadiums that could moderate the impact of crowds on referees. These studies found that having a running track in the stadium, which moved the fans farther away from the pitch, reduced the referee bias against the away team.

Referees can influence the outcome of games through more than just their decisions on calling fouls and giving cards. In the past, referees were able to apply their discretion on when to blow the final whistle at the end of the game. Garicano et al. (2005) showed that referees in LaLiga tended to lengthen the game when the home team was losing by one goal and to shorten it when the home team was ahead by one goal. While there was no bias in referee stoppage time decisions unless the game was close, the bias in close games was larger when there were more fans in the stadium and smaller if the crowd contained more supporters of the visiting team (Garicano et al., 2005). Sutter and Kocher (2004) found that referees in the Bundesliga also added more time at the end of the game in close matches if the home team was behind than if it was ahead.

Balmer et al. (2007) explored reasons why referees favor the home team and posited that crowd noise leads to increased anxiety and mental effort for the referee. Referees may

cope with this increased anxiety by giving more favorable calls for the home team, which is the popular decision. Nevill, Balmer, and Williams (2002) randomly assigned qualified referees to watch matches with and without sound. In the study, the referees awarded 15.5% fewer fouls against the home team when there was crowd noise in the video. This result suggests that crowds influence referee decisions during matches.

While this study takes advantage of the large number of games played in empty stadiums during the COVID-19 pandemic, previous researchers have used similar natural experiments when fans were banned from stadiums due to corruption or fan violence. Pettersson-Lidbom and Priks (2010) examined 21 games in the top two Italian leagues played with no crowds following an incident of hooligan violence in Sicily. The data from this study showed no evidence that players played differently in the matches with crowds compared to without crowds. In matches where crowds were present, however, referees were biased in favor of the home team in terms of fouls, yellow cards, and red cards (Pettersson-Lidbom and Priks, 2010).

Similarly, Reade, Schreyer, and Singleton (2020) examined 160 matches played with no fans since 2002 compared to over 33,000 matches with fans. The home team won 36% of the matches without fans compared to 46% of the matches when fans were present. When the researchers accounted for team quality in closed-door games, the effect of playing without fans declined and was not statistically significant, though the point estimate showed that the home win probability was 5 percentage points lower without fans (Reade, Schreyer, and Singleton, 2020). The effect of removing fans from the stadium came through referee decisions (away players were cautioned significantly less in games without fans) rather than through an impact on players, as there was no significant change in the home team's ball possession when fans were removed (Reade, Schreyer, and Singleton, 2020).

Reade, Schreyer, and Singleton (2020) and Pettersson-Lidbom and Priks (2010) examined matches in which fans had been removed from the games because of fan violence, racist abuse, and corruption (including referee payoffs). It is possible that those games were different from the typical football match. If the crowds that were banned were more passionate, violent, or abusive than the average crowd, for instance, then the results of this type of study could overestimate the average impact of crowds on referee decisions. Indeed, Anders and Rotthoff (2014) showed that the prospect of fan violence contributed to the referee bias in favor of the home team. The ghost games played without fans due to COVID-19 included all teams in the leagues and thus this natural experiment avoids that concern, although other rule changes (discussed below) were also instituted at this time that may have introduced confounding factors. Preliminary evidence using the COVID-19 crowd-less games in the first and second divisions of the Bundesliga found that the gap in fouls and yellow cards awarded between the home and away teams was completely eliminated (Endrich & Gesche 2020).

The impact of crowds on referee bias may be asymmetric. The presence of home crowds should result in more rule violations called against the away team and fewer against the home team due to this bias, but the impact on the latter may be smaller than on the former. The logic is that when home fans perceive a violation on the part of the away team, crowd noise is present prior to the referee decision. Unkelbach and Memmert (2010) posited that referees have learned to use crowd noise as a cue for gauging the severity of fouls since more severe fouls generate a larger crowd reaction. Nevill, Balmer, and Williams (2002), on the other hand, suggested that referees want to avoid making calls that displease the home crowd, which would predict that crowds led to fewer home yellow cards rather than more away yellow cards. Unkelbach and Memmert (2010) showed that greater crowd density was positively correlated with away yellow cards in the Bundesliga but was not

correlated with home yellow cards. The ghost games in the pandemic provide an opportunity to revisit the question of whether home bias in referee calls emerges due to cue learning (which would mean a greater positive effect of crowds on calls against the away team) or to referee motivations to avoid displeasing home fans (which would mean a greater negative effect of crowds on calls against the home team). The data set also allows these propositions to be tested using foul, red card, and penalty kick decisions as well as yellow cards.

Video Assisted Review and Referee Bias

In recent years European football leagues began using a video assistant referee (VAR) system in which a current or former official watches video replays during the match and notifies the referee if a call or non-call involving a goal, penalty kick, or red card should be reconsidered. Germany and Italy began using this system in the 2017-18 season, followed by Spain in 2018-19 and England in 2019-20. Kolbinger and Lames (2017) noted that arguments for this assistance fall into two categories: to help minimize human error, and to correct for biases on the part of officials such as the home crowd effect. It is possible, despite this justification, that the crowd's potential reaction to the decision in the review influences the VAR official. Preliminary evidence from the German and Italian leagues indicated that fewer fouls and yellow cards were given after VAR was implemented (Carlos, Ezequiel, & Anton, 2019). Han et al. (2020) found similar results in the Chinese Super League.

The VAR system adds time to the games, slowing the action (Carlos et al., 2019; Han et al., 2020), and it may have introduced other biases by allowing slow motion replays. Experimental evidence in Spitz et al. (2018) showed that subjects reviewing the slow-motion footage were more likely than those watching game speed videos to classify the same foul as a red card, likely due to an increased perception of the severity of the action.

Methods

Data on goals, fouls, yellow cards, and red cards were obtained from football-data.co.uk from the 2015/2016 season to the 2019/2020 season for English, German, Italian, and Spanish leagues. The latitude and longitude of each stadium were used to calculate the distance between the two teams' stadiums. Data on penalty kicks in each game were collected from transfermarkt.us. For the 2019/2020 season, data on the timing of goals were used to examine whether referee decisions regarding stoppage time gave home teams an additional advantage.

Table 1 shows the average number of home and away fouls, yellow cards, red cards, and penalty kicks with and without crowds. Interestingly, there was no statistically significant change (at the 5% level) in the number of fouls, yellow cards, red cards, or penalty kicks given to the home team when the fans were removed (though home yellow cards rose at the 10% significance level). Away teams received significantly fewer yellow cards and more penalty kicks, at the 1% significance level, in the ghost games. Away teams were also called for fewer fouls and were given fewer red cards in ghost games, though those differences were statistically significant only at the 10% level.

Table 1. Descriptive Statistics.

	With crowds		Ghost games	
Home	Fouls:	12.606	Fouls:	12.904
	Yellow cards:	1.974	Yellow cards:	2.093 *
	Red cards:	0.083	Red cards:	0.093
	Penalty kicks:	0.174	Penalty kicks:	0.194
Away	Fouls:	12.969 γγγ	Fouls:	12.561 *
	Yellow cards:	2.230 γγγ	Yellow cards:	1.922 γ, ***
	Red cards:	0.111 γγγ	Red cards:	0.083 *
	Penalty kicks:	0.125 γγγ	Penalty kicks:	0.189 ***
Observations	6,822		408	

Notes: *, **, *** indicate that the ghost games means are statistically significantly different from the means for games with crowds at the 10%, 5%, and 1% levels, respectively; γ, γγ, γγγ indicate that the away team means are statistically significantly different from the home team means at the 10%, 5%, and 1% levels, respectively

While the results for fouls, yellow cards, and red cards were consistent with the cue learning theory that removing crowds would have a greater impact on referee actions toward the away team, an empirical model is needed to determine if the results still emerge when other factors affecting referee decisions are controlled for. The model used in the analysis assumed that match outcomes depend on the relative strength of the two teams, any advantage that the home team has, and other factors. In order to measure the relative strength of the teams, the data set included information on the Elo rating for the two teams. The Elo rating system was initially designed by Arpad Elo to rank chess players but since 2018 it has been used by FIFA to rank international teams, and it has been used in previous studies as a control for team quality (Reade, Schreyer & Singleton 2020).

Conditions of the Natural Experiment/Confounding Factors

There were variations in the time gap between regular play and post-COVID conditions across the leagues, but the time gap in between the league cessation and resumption of play should have affected home and away teams equally. In addition, the analysis included controls for the league in the multivariate regressions.

Because of the compressed schedule with less time between games, all four leagues amended their substitution rules, increasing the number of substitutions from three to five. Water breaks were also added and LaLiga expanded the number of match-day squad members from 21 to 23.

Finally, the games played in empty stadiums included the last few matches of the season, and teams may have had very different incentives to compete depending on where the team was in the league table. These considerations were randomly distributed across home and away teams, however, so they would not have affected the key variable of interest.

Results

Referee Decisions

Table 2 shows the results of Poisson regressions estimating the determinants of fouls, yellow cards, red cards, and penalty kicks given to a team in a particular game. The technical

appendix provides details about the estimation. The key variables of interest are the home team variable, the crowd-less game variable, and the interaction term between those two variables. The coefficient on the home team variable reveals the difference between home and away teams in the period prior to the COVID pandemic. The first column of Table 2 shows that when fans were in the stadiums, the referee called about 0.37 fewer fouls per game against the home team than against the away team. In the average game, a team had 12.8 fouls called against it, so the estimate indicates that the referee called slightly under 3% fewer fouls against the home team. This estimate is statistically significant at the 1% level. When crowds were removed, the number of fouls called against the away team fell by 0.26 (the coefficient on the crowd-less game variable) while the number of fouls called against home teams rose by 0.50 (the sum of the coefficients on the crowd-less game variable and the interaction term). The increase in home team fouls was statistically significant at the 5% level while the fall in away team fouls was not statistically significant. The interaction term coefficient (0.76) represents the difference between those two changes. Overall, the removal of crowds reversed the home bias in foul calls. While away teams were called for 0.37 more fouls per game with crowds in the stands, home teams were called for 0.37 more fouls per game in ghost games.

The second column in Table 2 reveals similar results for yellow cards. In matches where spectators were present, the referee gave the home team 0.25 fewer yellow cards than the visitors per game. As teams only received 2.1 yellow cards per game on average, this effect is quite large. Being at home with a crowd meant that the team received about 12% fewer yellow cards than when the same team played its away games. Removing the crowds in 2020 did not cause a significant change in the number of yellow cards the home team received. Removing the crowds drastically reduced the number of yellow cards received by the visiting team, however, with away team yellow cards falling by 0.50. In addition to being a statistically significant change (at the 1% level), the magnitude of this impact was very large. It amounted to roughly a 25% decline in yellow cards relative to the mean.

The conclusions in the first two columns in Table 2 are similar to those in Endrich and Gesche (2020) who estimated that prior to COVID-19, referees in the German first and second divisions gave 0.6 fewer fouls per game and 0.4 fewer yellow cards to the home team than to the away team. After the audience was removed, however, the home team actually received slightly more fouls and yellow cards than the away team (Endrich and Gesche, 2020). The current study extends the analysis in Endrich and Gesche (2020) by including Spanish, English, and Italian league games as well as by considering the impact of removing crowds on red card and penalty kick decisions.

Table 2. Poisson Regression Results: Determinants of Referee Decisions.

	Fouls	Yellow cards	Red cards	Penalty kicks
Home team	-0.3738 ***	-0.2473 ***	-0.0266 ***	0.0579 ***
Crowd-less game	-0.2643	-0.4932 ***	-0.0318 **	0.0414 *
Crowd-less game * Home	0.7595 ***	0.5048 ***	0.0537	-0.0338 *
VAR	-0.2700 *	-0.0912	0.0081	0.0060
Home team * VAR	-0.0020	-0.0295	-0.0045	-0.0172
Derby	0.4690 ***	0.2330 ***	0.0284 **	0.0073
ELO difference	-0.2598 ***	-0.1174 ***	-0.0077 **	0.0046
Observations	14,460	14,460	14,460	14,460
Team, opponent fixed effects	Yes	Yes	Yes	Yes
Season fixed effects	Yes	Yes	Yes	Yes

Notes: *p < .10, **p < .05, *** p<.0; Standard errors are calculated allowing a correlation between observations from the same game

Column 3 shows the effect of crowds on red cards awarded. In games with crowds, referees gave home teams 0.03 fewer red cards per game than they gave away teams. There were less than 0.1 red cards given to the average team in a game, so the difference between home and away teams was about 28% of the mean number of cards given. After crowds were removed from games, away red cards fell significantly, by 0.032 cards per game. Removing crowds increased home red cards slightly, by 0.005 per game. Overall, then, crowds raised away red cards relative to home red cards by a little over 0.05 per game. As with yellow cards, that estimated impact was large in magnitude, amounting to about 45% of the number of cards given to a team in an average game.

The evidence of a crowd influence on penalty kicks is weaker. In games with crowds, the home team received nearly 0.06 more penalty kicks per game than the away team. The average team received about 0.15 penalty kicks per game, so the difference between home and away penalties was about 38% of the mean penalties awarded. Removing the fans did not have a statistically significant impact on the number of penalty kicks received by the home team. The away team was awarded 0.04 more penalty kicks after the crowds were removed, although the coefficient is significant only at the 10% level. As a result of the increase in away penalties, the difference between home and away teams in penalties awarded was only about 35% as large in the summer of 2020 as it had been during the previous four and a half seasons.

Impact of Video Assistant Refereeing

The estimated coefficients on the control variables in Table 2 reveal some interesting results. Video assistant refereeing was introduced in the leagues at various times during the previous five seasons ostensibly to eliminate egregious refereeing errors. In theory, VAR could reduce or eliminate referee home bias. The estimates in Table 2 suggest that VAR did not eliminate home bias. The only significant change in refereeing decisions associated with VAR was 0.27 fewer fouls called on both home and away teams (about a 2.1% drop relative to the mean). That result is somewhat surprising because VAR automatically reviews red cards and penalty kicks but does not review fouls outside the penalty box. Thus, if VAR was to have an impact, one would expect to find it on red card or penalty kick decisions. These

results are consistent with Carlos, Ezequiel, and Anton (2019), who found that fewer fouls were called in the German and Italian leagues after VAR was introduced, and with Han et al. (2020), who concluded that VAR had no impact on yellow cards, red cards, or penalty kicks, but that it reduced fouls called in the Chinese Super League.

Other Factors Affecting Outcomes

Derbies are games between teams from the same city, and they are often fierce rivalries. Derbies are defined in the data set to be games between teams whose stadiums were within 20 miles of each other. Table 2 shows that derbies had significantly more fouls called and more yellow and red cards given than did games between teams from farther apart. There was no significant difference between derbies and non-derbies in the number of penalty kicks awarded.

As the coefficient estimates show, the higher a team's quality as measured by Elo rating relative to their opponent's, the fewer fouls, yellow cards, and red cards they received. Higher quality teams were able either to avoid fouling or to induce their opponents to foul more than lower quality teams could.

Effect of Referee Decisions on Home Advantage

Table 2 shows strong evidence that home crowds influenced referee decisions, but how much do those decisions affect match outcomes? Table 3 presents estimates from several linear regression models of the factors affecting goal difference (home minus away goals). In Model 1, the estimated value of the constant shows that the home team was predicted to win by 0.3 goals on average if there were fans in the stadium, the two teams had identical Elo ratings, and there was no distance between the teams. After crowds were removed, the expected home advantage in goal difference fell to 0.144. The difference in team quality was strongly predictive of the game outcome, as one would expect. In a neutral stadium, the team with the largest Elo advantage over its opponent in the data set was predicted to win by 2.9 goals. Home teams won by larger margins on average if the two teams were located farther apart. Each extra 100 miles of distance between the teams was correlated with an increase of 0.027 in the average home team's goal advantage over the away team.

Model 2 in Table 3 adds four variables related to referee decisions during the game: foul, yellow card, red card, and penalty kick differences (all measured as home minus away). Each of these variables was significantly related to the game outcome. One extra foul committed by the home team raised the home team's goal advantage by about 0.02 goals per game. Each extra yellow card given to the home team reduced the home team's goal advantage by 0.05 goals. A red card given to the home team reduced its goal advantage by 0.56 goals, and a penalty kick awarded to the home team raised its goal advantage by 0.57 goals. Interestingly, even after controlling for the relative quality of the two teams, the distance the away team travels, and the decisions made by the referee, the home team still had a goal advantage of 0.27 goals per game with fans and approximately 0.17 goals per game without fans. Thus, most of the home advantage in goal difference was unrelated to having fans in the stadium. Familiarity with the pitch and chemical responses by players of being in their home stadium are likely candidates to explain this remaining part of the home advantage.

Table 3. OLS Regression Results: Determinants of Goal Difference.

	Model 1	Model 2	Model 3	Model 4
Constant	0.300 ***	0.269 ***	0.327 ***	0.295 ***
Crowd-less game	-0.156 *	-0.103	-0.120	-0.06
ELO difference	0.440 ***	0.416 ***	0.440 ***	0.416 ***
Distance between teams	0.027 **	0.018 *	0.027 **	0.018
VAR			-0.061	-0.062
Foul difference		0.019 ***		0.019 ***
Yellow card difference		-0.052 ***		-0.052 ***
Red card difference		-0.562 ***		-0.562 ***
Penalty kick difference		0.572 ***		-0.572 ***
Observations	7,230	7,230	7,230	7,230
R-squared	0.216	0.268	0.216	0.268

Note: *p < .10, **p < .05, *** p<.01

Combining the impact of playing at home (with fans) on referee decisions in Table 2 with the estimated effect of referee decisions on goal difference in Table 3 gives an estimated referee channel impact of playing at home in front of crowds equal to 0.054. Appendix A includes a description of the calculation of this estimate. Thus, prior to the ghost games, the home team on average received a roughly 0.054 goal difference advantage over the away team as a result of the crowd-induced bias in referee decisions. Interestingly, the referee channel impact amounted to a relatively small fraction (15%) of the pre-COVID 0.35 total home advantage in goal differential. Table 2 shows that the home bias on referee decisions disappeared when crowds were removed from the stadium. Combining the estimated impact of playing at home without fans on referee decisions with the effect of referee decisions on goal difference provides an estimated referee channel impact of playing at home in ghost games equal to -0.001. Thus, removing the crowds completely eliminated any advantage that the home team received through referee decisions.

Overall, Tables 2 and 3 suggest that referee decisions were affected by crowds. The ghost games had no statistically significant differences between calls against home and away teams, which suggests that the crowds were the source of the difference in referee decisions (either through a direct impact of the crowd on the referee or through an indirect effect on player behavior). These differences in referee decisions, however, accounted for a relatively small part of the home advantage in goals. Instead, unmeasured factors were quite important in determining match outcomes, as the regression R-squared statistic indicates that the variables in the model explained only about a quarter of the variation in goal differences across matches.

The last two columns in Table 3 included the VAR indicator to test for the possibility that the introduction of VAR reduced home advantage. The estimates suggest that VAR did not affect home advantage. VAR did not have a statistically significant impact on goal difference, and the impact of the other variables on goal differential was unchanged by its inclusion.

Table 2 provides mixed evidence on whether the crowd had a greater impact on calls against the away team or the home team. Contrary to the cue learning theory, fouls called against the home team rose by more than fouls called against the away team fell when

crowds were removed. Also contrary to the theory, the away team was awarded more penalty kicks (a foul called against the home team in the penalty box) but the home team penalty kicks remained unchanged after crowds were removed. In penalty kick decisions (and to a lesser extent fouls), then, referees appeared to be motivated by a desire to avoid displeasing the fans. The estimates for yellow and red cards, however, supported the cue learning theory. The referees gave significantly more yellow and red cards to away teams when there were crowds in the stadium than when the stands were empty but removing the crowds did not significantly change the number of yellow or red cards given to home teams. The result for yellow cards was similar to a result from Endrich and Gesche (2020), who estimated that removing crowds in the German first and second division reduced away team yellow cards by 0.36 while increasing home yellow cards by 0.12.

An explanation for these results is that in giving out cards, referees were attempting to judge the severity of the infraction. It is plausible that crowd noise had a larger impact on referee opinions about how reckless or dangerous a foul was than on the referee opinion about whether a foul occurred. That interpretation is consistent with the observation that there was a small home bias in overall fouls called (3% more fouls called against the away team) compared to the much larger gap in cards given out (12% more yellow cards and 28% more red cards given to the away team) in games with fans in the stadium. Applying the cue learning theory from Unkelbach and Memmert (2010) to these results indicates that referees used crowd noise as a cue more about the severity of fouls than about whether or not a foul occurred.

Crowds and Stoppage Time

While the estimates imply that the impact of referee decisions on game outcomes was small, one potentially important impact of referees omitted from the regression analysis was the decision about how long to extend stoppage time. Garicano et al. (2005) and Sutter and Kocher (2004) established that when the home team was trailing, referees extended the stoppage time (on average), giving the home team more time to improve their outcome. If home bias in referee decisions on fouls, cards, and penalty kicks had very little impact on game outcomes, could decisions about stoppage time have had a bigger effect?

Table 4 presents evidence on this question by considering cases in the 2019-20 season in which the outcome of the game changed during stoppage time. The table reveals (for the pre- and post-COVID periods) the fraction of home wins and losses achieved by a goal in stoppage time and the fraction of draws that were the result of either a home or away team stoppage time goal. If referee stoppage time decisions were critical to game results and there was a referee home bias because of crowds, there should have been more home wins and draws achieved by stoppage time home goals in the matches with crowds, and away wins/draws from stoppage time away team goals should have been less common with crowds.

Table 4. Home Team Wins, Draws and Losses Determined in Stoppage Time, Pre- and Post-COVID 2019-2020 Season.

	With fans Mean (SD)	**Ghost games** Mean (SD)	**Difference** Fans – ghost (SE)
Home Win	0.44	0.41	0.027
	(0.50)	(0.49)	(0.029)
Home Draw	0.24	0.24	0.0094
	(0.43)	(0.42)	(0.025)
Home win, stoppage time winning goal	0.0270	0.0196	0.0074
	(0.162)	(0.139)	(0.0091)
Draw, home team with stoppage time tying goal	0.0164	0.0196	-0.0032
	(0.127)	(0.139)	(0.0076)
Away win, stoppage time winning away goal	0.0202	0.0147	0.0055
	(0.141)	(0.121)	(0.0079)
Draw, away team with stoppage time tying goal	0.0154	0.0172	-0.0017
	(0.123)	(0.130)	(0.0073)
Number of observations	1,038	408	

Notes: Standard deviation in parentheses for first two columns; Standard error in parentheses for third column

Table 4 shows that there were only small, and not statistically significant, changes in game outcomes during stoppage time with and without fans. When fans were removed, the fraction of games won with a stoppage time goal by the home team declined from 2.7% of games to 2.0% of games, while the fraction of games in which the home team tied the game with a goal in stoppage time increased from 1.6% to 2.0%. The latter change was in the opposite direction of what one would expect. The fraction of games in which the away team scored a stoppage time goal to get a draw slightly increased from 1.5% to 1.7% in ghost games. That change was what one would expect if removing crowds eliminated referee stoppage time bias, but the difference was small and not statistically significant. Furthermore, game-changing goals in stoppage time were almost equally likely to benefit the away team as the home team. These results indicate that the game outcomes were rarely affected by referee decisions regarding stoppage time, which is a conclusion also noted by Garicano et al. (2005).

Limitations of Study

The games played in an empty stadium coincided with a number of other rule changes, including breaks, additional substitutions, and a more compressed schedule, which might also have impacted game outcomes. There is little a priori reason to think that many of these changes would affect home and away teams differently or that they would bias the results in one direction. The compressed schedule may have created more fatigue for the away teams, but the additional breaks and substitutions may have counteracted that fatigue. Future research including games in which leagues resumed play to empty or partially filled stadia but reverted back to prior rules could separately identify these rule changes from crowd-less matches.

Another limitation is that the analysis cannot identify how referee decisions were affected by player actions or referee choices from earlier in the game. Buraimo, Simmons and Maciaszczyk (2012) showed that referee calls during games were influenced by the game score at the time and by prior referee decisions. Future analysis with additional information on the timing of calls could allow these in-game influences on referees to be investigated.

Conclusions

Similar to previous research of crowd-less matches (Endrich & Gesche 2020; Reade, Schreyer, & Singleton 2020; Pettersson-Lidbom & Priks 2010), the empirical estimates in Tables 2 and 3 indicated that referee calls were more favorable for the home team when fans were in the stadium and that referee bias was eliminated when fans were removed. The results also provide evidence that the crowd influence was asymmetric. The presence of crowds raised the number of yellow and red cards given to away teams without affecting the number of cards given to home teams. A potential explanation for this result is that crowd noise may have influenced the referee's judgment about the severity of a foul more than it affected the referee's judgment about whether a foul occurred.

This study also expanded the research on video assistant referees to include additional leagues and seasons and explicitly examined whether VAR changed home bias in referee decisions. The results were consistent with Carlos, Ezequiel and Anton (2019) and Han et al. (2020), who concluded that fouls were reduced when VAR came into use. In contrast to Han et al. (2020), however, the estimates did not indicate that VAR reduced home advantage. VAR also did not affect the number of red cards or penalty kicks given, measures that should theoretically have been impacted by the use of this technology.

While the study results revealed a statistically significant home bias in referee calls, this bias explained very little (more or less 15%) of the total home advantage. Roughly half of the home advantage remained when the crowds were removed, and therefore home advantage must be due at least in part to factors other than the presence of fans. These results confirm the conclusion of van de Ven (2011) that crowds were not required for the home team to have an advantage. Perhaps Jurgen Klopp, manager of Liverpool, captured the essence of this advantage when he stated, on the resumption of play in 2020, "It's still a home game because we have our dressing room, we have all our things around, we know exactly where is what and stuff like this. That feels already good when you walk in the dugout or in the dressing room area" (Egorov 2020). Admittedly, Klopp might feel differently after Liverpool lost six games in a row at home in 2021. Nevertheless, the results in this study suggest that poor home outcomes such as these were almost certainly not due to the removal of home bias on the part of the referee.

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Appendix A

The models in Table 2 were estimated as Poisson regressions since the dependent variables are counts of fouls, cards, and penalty kicks. The data set included two observations for each game (one for each team), and these observations could be correlated with each other. A strict referee, for example, could call more fouls or give out more cards to both the home and away team. Thus, the regression calculated standard errors allowing for a correlation between the residuals in observations coming from the same game. The regressions included fixed effects for each team and opponent, which capture the impact of factors that were specific to a team but were constant over time such as community support, the size of the stadium, and (perhaps) its style of play. Estimates from the tables were similar if fixed effects were included for each pair of teams. For continuous variables, such as the Elo rating difference, Table 2 shows the marginal effects of x on y ($\partial y/\partial x$). For the binary variables, the table shows the change in predicted y when the x variable increases from zero to one.

Table 3 shows OLS estimates of the determinants of the match goal difference. These results can be combined with the results from Table 2 in equation (1) to estimate how much crowds affect referee decisions and how much those decisions affect the goal differential. Let $\hat{\alpha}_{fouls}$, $\hat{\alpha}_{yellows}$, $\hat{\alpha}_{reds}$, and $\hat{\alpha}_{pks}$ be the estimated impact of the home variable in Table 2 on the number of fouls, yellow cards, red cards, and penalty kicks called per game prior to the pandemic. Let $\hat{\beta}_{fouls}$, $\hat{\beta}_{yellows}$, $\hat{\beta}_{reds}$, and $\hat{\beta}_{pks}$ be the estimated impact of fouls, yellow cards, red cards, and penalty kicks on the goal difference in Table 3.

$$Est.Ref\ Impact = \hat{\alpha}_{fouls}\hat{\beta}_{fouls} + \hat{\alpha}_{yellows}\hat{\beta}_{yellows} + \hat{\alpha}_{reds}\hat{\beta}_{reds} + \hat{\alpha}_{pks}\hat{\beta}_{pks}, \qquad (1)$$

Substituting the estimated values from Tables 2 and 3 for each parameter into the equation above gives the estimated referee channel impact of playing at home in front of crowds equal to 0.054. Redefining the $\hat{\alpha}$ terms in equation (1) to be the estimated impact on referee decisions of being at home during ghost games provides an estimated referee channel impact of -0.001.

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