Video Assistant Referee and Home Field Advantage: Implications for Referee Bias*

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Abstract

Until recently, soccer referees operated with minimal technology assistance. Following the successful introduction of communication devices and goal-line technology, as well as the use of video review systems in various other athletic competitions, soccer leagues around the world implemented Video Assistant Referee (VAR) technology to further reduce mistakes and improve referee performance. This paper investigates the effect of Video Assistant Referee systems on home field advantage in soccer using a staggered adoption difference-in-differences framework and data from 16 leagues between 2009 and 2019. We find that the implementation of VAR had negligible effects on home field advantage despite impacting various match statistics for both home and away teams. These results have important implications for the impact of referees on home field advantage, especially in light of recent literature.

Keywords: soccer, home field advantage, video assistant referee

JEL Codes: Z2

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1 Introduction

Home teams generally outperform away teams in a wide variety of sports. This stylized fact is well-established and known as home field advantage. Over the course of the 2009-2010 through 2016-2017 season in five top European soccer leagues, home teams outperformed away teams in goal difference by 0.40 goals and win percentage by 17 percentage points.[1] This advantage is driven by various factors that are typically broken down into three main channels: travel fatigue, venue familiarity, and crowd support. One subchannel through which crowds may impact soccer outcomes is by influencing referee decisions; this is known as "referee bias." Various researchers have attempted to identify referee bias through match-level analysis (Nevill, Newell and Gale, 1996; Boyko, Boyko and Boyko, 2007; Downward and Jones, 2007; Buraimo, Forrest and Simmons, 2010; Dohmen and Sauermann, 2016) and in experiments that show higher crowd noise levels lead to harsher judgements by referees (Nevill, Balmer and Williams, 2002; Unkelbach and Memmert, 2010); this large literature establishes that home teams are more likely to be awarded fouls and penalty kicks and are less likely to receive yellow and red cards. However, it remains unclear to what extent this relationship is causal and contributes to the overall home field advantage as measured by goal difference per game and home win percentage.[2] This paper investigates the implementation of Video Assistant Referee (VAR) systems to improve referee decisions in 16 soccer leagues around the world. We estimate a precise null effect of this technology on home field advantage and thus find no evidence of referee bias as a contributing factor to observed home field advantage in the professional game.

The role of technology in sports has increased over time. Instant replay systems were implemented in various other sports since at least 1986 and are now ubiquitous in professional leagues and international competitions of American football, basketball, baseball, tennis, hockey, cricket, rugby, and fencing. In soccer, the adoption of goal-line technology to determine if the ball crossed the line

[1] Home teams win approximately 46% of the time, draw 25% of the time, and lose 29% of the time

[2] Some research attributes the decrease in home field advantage in response to COVID-19 mitigation policies entirely to referee bias (Bryson et al., 2021; Endrich and Gesche, 2020; Reade, Schreyer and Singleton, 2021; Scoppa, 2021), but this should only be interpreted as the total effect of fans on home field advantage (Cross and Uhrig, 2022; Fischer and Haucap, 2021). This may be partially driven by referees, but the complexity of soccer matches make it impossible to decompose the effects observed in response to no-fans policies (Lago, 2009).

in 2011 (testing) and 2012 (approval) followed a Frank Lampard goal against Germany in the 2010 World Cup not being awarded. Other referee gaffes include a third yellow card being awarded to Josip Simunic of Croatia in the 2006 World Cup[3] and the "Hand of God" goal by Maradona against England in the 1986 World Cup semifinal.[4] The use of video replay systems to review decisions presumably would have corrected these mistakes and led to a more fair outcome.

Soccer leagues around the world have experimented with Video Assistant Referee systems since the 2012/2013 season (Holder, Ehrmann and König, 2022). Top leagues eventually implemented VAR starting in the 2017/2018 season, and the International Football Association Board (IFAB) formally included Video Assistant Referees in the Laws of the Game starting in 2018 (IFAB, 2018; FIFA, 2022; Holder, Ehrmann and König, 2022). After a referee makes a decision, a match official with access to match footage reviews the events and informs the referee if there has been a "clear and obvious error" or "serious missed event." Reviews are automatically initiated, rather than requested by the teams. Under the "minimum interference - maximum benefit" philosophy, the scope of VAR is limited to only major match events to ensure that time is not spent re-litigating insignificant missed calls, (IFAB, 2018). Only incidents involving goals, penalty kicks, direct red cards, and cases of mistaken identity are reviewed (IFAB, 2022). The video assistant referee provides information, sometimes including replays, to the center referee for review to inform the final decision (IFAB, 2022). VAR significantly improved decision accuracy on reviewed calls from 92.1% to 98.3% (Spitz et al., 2021).[5]

It is difficult to predict ex-ante what effect the implementation of VAR might have on home field advantage. On the one hand, VAR might diminish referee bias towards the home team in major match events and therefore level the playing field. Although referee bias is not explicitly mentioned, the overall goal of VAR was to "reduce unfairness" in referee decisions, suggesting that bias may be an implicit target of VAR implementation (IFAB, 2018). News articles and gambling services

[3]Under the Laws of the Game, a player should be sent off after two yellow cards and thus cannot receive a third: https://www.givemesport.com/1484708-on-this-day-in-2006-graham-poll-showed-three-yellow-cards-to-josip-simunic-at-world-cup.

[4]Diego Maradona deliberately used his hand to punch the soccer ball into the goal: https://www.youtube.com/watch?v=-ccNkksrfls.

[5]This closes 78% of the gap between the initial correct decision rate and the upper bound of 100% accuracy. This finding, along with the fact that VAR does not disproportionately favor home teams (Johnson, 2020), suggests that VAR is a more "objective" judge than referees.

predicted that home field advantage would decrease in response to VAR (Petty, 2018), and various papers have found changes in match statistics based on referee actions (Lago-Peñas, Rey and Kalén, 2019; Lago-Peñas, Gómez and Pollard, 2021; Kubayi, Larkin and Toriola, 2022), especially shifting from favoring home teams towards a balanced treatment (Han et al., 2020; Holder, Ehrmann and König, 2022). Johnson (2020) finds that a slight majority of VAR decisions in the English Premier League during the 2019-2020 season favored the away team over the home team, suggesting that the initial referee decisions were biased towards the home team.[6] On the other hand, there may be no change in home field advantage either because referee bias itself does not significantly contribute to home field advantage,[7] due to the limited scope of VAR, or the distinction between rules and norms and the difficulty in enforcing the latter (Zglinski, 2022).[8] This is the first paper to directly analyze the effect of Video Assistant Referees on home field advantage in various leagues around the world.

In this paper, we exploit the variation in implementation of Video Assistant Referee systems across various leagues throughout the world. We employ a staggered adoption difference-in-differences specification with two-way fixed effects to control for differences in home field advantage across leagues and seasons and find no evidence of a decrease in home field advantage in response to VAR. Estimated coefficients are statistically insignificant and suggest only a 3.5% decrease in home field advantage as measured by goals per game. The 95% confidence interval rules out a 20.7% decrease relative to the baseline home field advantage, suggesting a precise null effect of VAR. These results are robust to various specifications, including controls for team quality and alternative definitions of the season fixed effects, as well as alternative methods of constructing confidence intervals through either robust standard errors or the wild bootstrap. Results are qualitatively similar using home win probability as the outcome of interest: the estimated coefficient is close to zero and statistically insignificant, and the 95% confidence interval rules out a 4.2 percentage point decrease in home win probability, which is equivalent to 9.1% of the baseline probability.

[6] 68 (62%) of 109 overturned decisions favored the away team over the home team.

[7] It may be the case that the gap in referee actions is driven entirely by home field advantage with respect to quality of play, rather than actual referee bias. Buraimo, Forrest and Simmons (2010) discusses the challenges in identifying true referee bias.

[8] The effect of VAR should also be no greater than the effect of fans on home field advantage, since referee bias as a whole is a subchannel of the fans channel.

This paper contributes to the literature on referee bias and home field advantage in soccer. The precise null effect of Video Assistant Referee implementation on home field advantages suggests one of two possible explanations. It may be the case that referee bias does not contribute to home field advantage, in which case the observed differences in various referee statistics between home and away teams are driven by differences in play rather than differences in treatment under the Laws of the Game. On the other hand, referee bias may exist and contribute to home field advantage in ways that are unaffected by VAR under its current structure. As it stands, only clear and obvious errors on major match events are re-litigated, but either marginally incorrect major decisions or many minor decisions may contribute to the observed home field advantage in soccer if those slight differences add up over the course of a match. Although these results cannot be interpreted as the full effect of referees on match outcomes, they do have important implications for the use of Video Assistant Referee and the mechanisms through which referee bias may contribute home field advantage.

The rest of the paper proceeds as follows: Section 2 discusses the data used in the analysis. Section 3 describes the empirical strategy employed. Section 4 highlights the key findings. Section 5 concludes.

2 Data

The primary specification uses match data from the soccer statistics website FBref.[9] Our unbalanced panel starts with the 2009-2010 season with top leagues from England, Germany, Italy, and Spain. Additional countries are included starting in later years as their data become available via FBref. The last year included is the 2018-2019 season,[10] as home field advantage during the 2019-2020 season was diminished due to the COVID-19 mitigation strategies that artificially limited fan attendance (Cross and Uhrig, 2022). The full primary specification includes 35,183 matches from 16 top leagues around the world.

[9]FBref.com launched in June 2018 with league coverage for six nations: England, France, Spain, Italy, Germany, and the United States. The website has since expanded to include historical data from various other leagues.

[10]The 2019 season in Brazil, Japan, and Korea is also included, as these leagues play schedules opposite of the standard European schedule.

In addition to the goals scored by the home and away team, we also consider various other match statistics that reflect referee decisions. Information on fouls, penalty kicks, offsides, yellow cards, and red cards at the season-by-team-by-home/away level are collected from WhoScored.com for the same leagues in the primary specification, where available.

Table 2 shows summary statistics, comparing different regions and levels across various dimensions related to home field advantage. All regions and levels exhibit similar home field advantages as measured by goal difference, ranging from 0.33 to 0.39 goals per game, and win probability at 46%.[11] Home teams also experience a slight advantage as measured by various match statistics affected by the referee. Specifically, home teams are called for fewer fouls and penalty kicks and given fewer yellow cards and red cards than away teams.

Figure 1 displays the distribution of goal differences, shown as home goals minus away goals, with and without the use of Video Assistant Referee. The two distributions are overlaid on top of each other and are qualitatively similar; the Kolmogorov-Smirnov test statistic is 0.0063, which indicates a failure to reject the null hypothesis for equality of distribution ($p = 0.999$). This suggests that home field advantage was largely unaffected by the introduction of VAR. In addition, Figure A.3 shows the home field advantage, as measured by goal difference, for each league during the sample period. Figure A.4 and Figure A.5 show the same with leagues grouped by region and timing of VAR adoption, respectively. Although the home field advantage fluctuates over time, these changes do not appear to be driven by the implementation of VAR.

3 Empirical Strategy

We exploit variation in VAR implementation with the following staggered-adoption difference-in-differences specification:

$$y_{ijct} = \alpha + \beta Post_{ct} + \gamma X_{ijct} + \lambda_c + \delta_t + \epsilon_{ijct} \tag{1}$$

[11] The win probability and draw probability are all the same in each region, so the difference between the probability for a home win and a home loss is also the same.

where the dependent variable y_{ijct} is the goal difference between home team i and away team j, α is the baseline level of home field advantage, β is the coefficient of interest for the effect of VAR on home field advantage, $Post_{ct}$ is an indicator variable equal to 1 if country c utilizes VAR during season t and 0 otherwise, X_{ijct} is a vector of controls to account for differences in team quality, λ_c is a country fixed effect,[12] δ_t is a season fixed effect,[13] and the error term ϵ_{ijct} is clustered at the country level to account for correlation in the treatment variable (Bertrand, Duflo and Mullainathan, 2004). Given the low number of clusters, critical values are taken from the t-distribution with $G - 1 = 15$ degrees of freedom.[14] For a 95% confidence interval, this gives a critical value of 2.131, somewhat greater than the 1.960 from a normal distribution. Lastly, we implement the wild bootstrap with Rademacher weights to construct a 95% confidence interval for the effect of VAR on home field advantage (Cameron, Gelbach and Miller, 2008; Lee and Steigerwald, 2018; Roodman et al., 2019). This may lead to improvements in statistical size; if anything, the confidence intervals from the wild bootstrap are too conservative in the effects they can rule out (MacKinnon and Webb, 2017).

In addition to the primary specification with home field advantage as measured by goal difference as the outcome of interest, we also consider both home field advantage as measured home win probability and various other referee statistics that have been shown to favor home teams. These statistics include fouls, yellow cards, red cards, offsides, and penalty kicks.

The key identifying assumption for a causal interpretation of β in Equation (1) is that, absent the introduction of VAR, there are parallel trends in the outcome for leagues that introduced VAR compared to those that did not. To explore the validity of this assumption, we estimate an event study design that will show if trends appear to be similar in the months leading up to the introduction of VAR. For each match, we define V_{ijct} as an indicator that is equal to 1 if the match is played in a league that introduces VAR. Using the following specification:

[12] This is equivalent to a league fixed effect because only the top league from any given country is used.

[13] Season fixed effects are assigned such that countries with inverted schedules are considered separately. For example, Brazil and Japan are assigned a fixed effect for the 2017 season, whereas the other countries receive a fixed effect for the 2017-2018 season. Results are robust to alternative considerations of the inverted schedules: estimated coefficients and confidence intervals are qualitatively similar if, for example, the 2017 season is considered along with either the 2016-2017 season or with the 2017-2018 season.

[14] Results are qualitatively similar with robust standard errors.

$$y_{ijct} = \alpha + \sum_{e=-A}^{2} \beta_e V_{ijct} \mathbb{1}[E_{ijct} = e] + \lambda_c + \delta_t + \epsilon_{ijct} \tag{2}$$

we identify a separate coefficient, β_e, on each event-time indicator E_{ijct} that captures the differences in match outcomes between the leagues for A seasons before through two seasons after the VAR change, relative to the omitted event period which we set equal to -1. Specifically, we set A equal to 9 so that we estimate a separate β_e for every season before VAR is first introduced. Our primary dependent variables, y, is the goal difference between the home and away teams. We control for baseline average differences between leagues with country fixed effects, λ_c, and also include season fixed effects δ_t. We also consider alternative event study specifications with the outcome of interest as the probability of a home win. Lastly, we estimate the effect of VAR on various referee statistics such as red cards and penalty kicks.

4 Findings

4.1 Main Results

Column 1 of Table 3 shows the raw differences in home field advantage before and after the introduction of Video Assistant Referees without the inclusion of various fixed effects or other controls. It is important to note that the baseline home field advantage is similar to that in Cross and Uhrig (2022). The estimated coefficient suggests a decrease in home field advantage of only 0.013 goals per game. This result is statistically insignificant and only represents a 3.5% decrease in the baseline home field advantage. The 95% confidence interval, using critical values from the t-distribution with 15 degrees of freedom, rules out a 0.092 goals per game decrease in home field advantage.

Columns 2 through 4 of Table 3 show the same results with the inclusion of various fixed effects and controls.[15] Estimated coefficients remain statistically insignificant and close to zero. In the full model presented in Column 4, the 95% confidence interval rules out a 0.078 goals per game decrease

[15] Columns 3 and 4 have slightly smaller sample sizes because the earliest season in league is dropped due to missing data from the previous season.

in home field advantage, which would only represent a 20.7% change from the baseline. Confidence intervals from the wild bootstrap are shown in brackets under standard errors, where applicable, and are quantitatively similar to the confidence intervals using critical values from the t-distribution with $G-1$ degrees of freedom. These results reaffirm the conclusions from Figure 1, which highlights the similarity between the distribution of goal differences, shown as home goals minus away goals, before and after the implementation of Video Assistant Referee.

Columns 1 and 3 of Table 4 show the raw effects of VAR implementation on the probability of a home win and a home draw, respectively. Columns 2 and 4 of Table 4 show the same after the inclusion of various fixed effects and controls. Estimated coefficients are close to zero and statistically insignificant regardless of the inclusion of controls. The 95% confidence intervals rule out a 4.2 percentage point decrease in the probability of a home win, representing only 9.1% of the baseline win probability.

Figure 2 shows the results of an event study evaluating the impact of VAR implementation on home field advantage as measured by goal difference. Figure 3 shows the same on home field advantage as measured by the probability of a win for the home team.[16] These figures graphically replicate the results from Table 3 and Table 4, respectively. Results from the event study designs are qualitatively similar to those from the staggered adoption difference-in-differences specification.

4.2 Effect of VAR on Other Match Outcomes

Various articles have found changes in match statistics after the implementation of VAR. Table 5 documents the effect of VAR on various statistics associated with referee actions. Some of these outcomes are less prevalent after VAR implementation; there is a statistically significant decrease in the number of yellow cards and offsides, as has been found in the literature. The estimated coefficients represent a decrease of 8.1% and 11.3% of the baseline, respectively. However, there is no statistically significant effect on level of home field advantage as measured by any of these various statistics.

[16]Figure A.1 also shows the effect of VAR on probabilities for a home win, draw, or home loss using an ordered logit model.

Previous research has used two-season comparisons to draw conclusions about the effect of VAR on home-away differences in some match statistics, especially yellow cards. This empirical strategy relies on the assumption that the home-away differences would remain unchanged in the absence of VAR implementation. Figure 4 shows the results of Equation 2 with the difference between yellow cards awarded to the home team and yellow cards awarded to the away team as the outcome of interest. As has been found in the literature to date, there is a statistically significant decrease in this difference after the implementation of VAR. However, there is also evidence for pre-trends that may lead to identification questions. The same is shown in Figure A.2,[17] which highlights the downward trend well before the implementation of VAR. Therefore, any empirical strategy should carefully consider how these changes over time may affect the conclusions about home-away differences in various match statistics

4.3 Heterogeneity Analysis

One might expect VAR to have different effects on home field advantage depending on the level of experience for the main referee. Specifically, it may be the case that experienced officials exhibit less bias that VAR might correct, but inexperienced referees could make decisions that require the oversight of VAR. Table A.2 shows the results of Equation 1 estimated on referees with and without high-level international experience, respectively. Referees are considered to have a high level of experience if they have refereed matches in prestigious international competitions during the time period.[18] Approximately 14.0% of referees have high experience by this metric, and those individuals account for 11.2% of games in the main sample.

Estimated coefficients for those two subsamples are qualitatively similar to those for the entire sample. This suggests that VAR does not have heterogeneous effects by referee experience. These results are unsurprising given that the referees without high-level international experience, for whom

[17]For clarity, the number of Away Yellow Cards minus Home Yellow Cards is shown to illustrate the downward trend in the absolute difference between the two outcomes.

[18]Specifically, the international competitions here are the following: 2014 World Cup, 2018 World Cup, 2013 Confederations Cup, 2017 Confederations Cup, 2015 Asian Federation Cup, 2019 Asian Federation Cup, or any season of the CONMEBOL Copa Libertadores or the UEFA Champions League.

an effect would be more likely, make up the vast majority of the overall sample. An effect on home field advantage in games officiated by inexperienced referees would presumably be observed in the overall sample as well, albeit somewhat attenuated by the inclusion of experienced referees.

4.4 Robustness Checks

We consider various alternative specifications in order to differentially account for the fact that Japan and Brazil play an inverted schedule relative to the other countries in the sample. Season fixed effects in the primary specification are assigned such that the 2017 inverted schedule is considered different from the 2016-2017 season and the 2017-2018 season in the European schedule. Results are qualitatively similar if the inverted schedule seasons are grouped with the European schedule on either side. Column 2 of Table A.3 shows the results when inverted leagues are included with the previous European schedule, and Column 3 of Table A.3 shows the results when inverted leagues are included with the following European schedule. Column 4 of Table A.3 shows the results when Japan and Brazil are excluded entirely from the sample. In all case, coefficients are similar to each other as well as those in the primary specification.

Lastly, Table A.4 shows the results from the primary equation estimated separately for each treatment cohort. We again focus on those countries with a European schedule. Although results are somewhat noisier than in Table 3, they remain statistically insignificant for the cohorts that implement in 2017-2018 and in 2018-2019. This suggests that the staggered adoption difference-in-differences design does not threaten inference through potential heterogeneous treatment effects and negative weights.[19]

[19]This result is unsurprising given the fact that no leagues adopt VAR prior to beginning of the sample period and the large number of leagues that adopt in the 2019-2020 season or later and are thus considered fully-untreated.

5 Conclusion

We estimate a precise null effect of Video Assistant Referee implementation on home field advantage, finding a statistically insignificant result that specifically rules out effects of 0.078 goals per game and 4.2 percentage points. This upper bound would represent only either 20.7% (goal difference) or 9.1% (win probability) of home field advantage overall and 44.7% of the effect of no-fans policies implemented to mitigate the spread of COVID-19 in 2020 (Cross and Uhrig, 2022). Figure 5 highlights the disparity between the relative effects of VAR and no-fans policies on home field advantage.

Although these results suggest that VAR systems did not lead to a decrease in home field advantage, this does not necessarily indicate that referees and their decisions do not contribute to home field advantage. It is important to note that, given the limited scope of VAR, many referee decisions were unaffected by the implementation of these systems. It is therefore possible that referees contribute to home field advantage not through a few high-leverage decisions but instead through many smaller decisions that add up over the course of a match. In addition, it may be the case that major decisions are slightly more likely to favor the home team such that they are marginally incorrect but do not rise to the level of a "clear and obvious error" that would be overturned by VAR.

However, the estimated precise null effect of VAR on home field advantage calls into question the importance of any referee bias in favor of the home team. Although the scope of VAR is limited, the events that are checked are those most likely to affect match outcomes. One must consider the possibility that the observed disparities in various outcomes, from goal difference to win probability to the number of yellow cards awarded, between home and away teams are driven by the direct effect of fans on players rather than the referee. In light of these results, further research should attempt to determine if and how referee bias contributes to home field advantage.

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6 Tables

Table 1: VAR Adoption by Country

Country	Schedule Type	First Year Included	Year VAR Adopted
Italy	European	2009/10	2017/18
Germany	European	2009/10	2017/18
Portugal	European	2010/11	2017/18
Australia	European	2013/14	2017/18
France	European	2010/11	2018/19
Spain	European	2009/10	2018/19
The Netherlands	European	2010/11	2018/19
Turkey	European	2013/14	2018/19
Brazil	Inverted	2014	2019
England	European	2009/10	2019/20
Switzerland	European	2014/15	2019/20
Russia	European	2014/15	2019/20
Greece	European	2014/15	2019/20
Japan	Inverted	2014	2020
Denmark	European	2014/15	2020/21
Scotland	European	2014/15	2022/23

Sources: Holder, Ehrmann and König (2022), J.League (2020), Meneguite et al. (2022), Business (2019), and Conroy and Jaidka (2022).

Notes: VAR was technically implemented in the second half of the 2019/20 season in Russia, but that league can nonetheless be considered a never-treated unit for this analysis because the first season with any VAR intervention is after the time period used here. Similarly, Japan initially implemented VAR during the 2020 season. However, that implementation was postponed to 2021 due to the COVID-19 pandemic. The Japanese J-League is regardless considered a never-treated unit for this analysis.

Table 2: Summary Statistics

Panel 1: Match Level Data	Europe (Top 5)	Europe (Other)	Asia/South America
Home-Away Goals	0.39	0.37	0.33
	(1.80)	(1.84)	(1.63)
Total Goals	2.72	2.73	2.54
	(1.68)	(1.68)	(1.63)
Pr(Home Win)	0.46	0.46	0.46
	(0.50)	(0.50)	(0.50)
Pr(Draw)	0.25	0.25	0.25
	(0.44)	(0.43)	(0.43)
Total Matches	17,880	12,377	4,926
Control Leagues	1	5	1
Early Treated (2018) Leagues	2	1	1
Late Treated (2019) Leagues	2	2	1
Panel 2: Team-by-Season Level Data			
Home-Away Yellow Cards per Game	-0.30	-0.30	-0.29
	(0.43)	(0.48)	(0.50)
Home-Away Red Cards per Game	-0.04	-0.03	-0.06
	(0.11)	(0.12)	(0.12)
Home-Away Fouls per Game	-0.47	-0.41	-0.23
	(1.33)	(1.44)	(1.46)
Home-Away Offsides per Game	0.23	0.16	0.18
	(0.55)	(0.56)	(0.47)
Home-Away Penalty Kicks per Game	0.06	0.08	0.06
	(0.12)	(0.14)	(0.11)
Total Team-Seasons	980	348	140

Notes: This table shows various summary statistics from the leagues used in the analysis over the relevant sample period. Home teams on average score more goals than away teams, win more frequently than away teams, are awarded fewer yellow cards and red cards, are awarded more fouls and penalty kicks, and are called for more offsides. This pattern is consistent across the three different groups of leagues detailed here.

Table 3: Home Field Advantage - Goal Difference

	(1)	(2)	(3)	(4)
	G_{H-A}	G_{H-A}	G_{H-A}	G_{H-A}
Baseline	0.376***	0.371***	0.378***	0.377***
	[0.023]	[0.005]	[0.022]	[0.005]
VAR	-0.013	0.031	-0.005	0.007
	[0.037]	[0.041]	[0.037]	[0.040]
		(-0.063,0.126)		(-0.080,0.095)
Points Diff. (Cumulative)			0.023***	0.023***
			[0.002]	[0.002]
Points Diff. (Last 4)			0.019***	0.020***
			[0.003]	[0.003]
Points Diff. (Prev. Season)			0.022***	0.022***
			[0.001]	[0.001]
Team Quality Controls	No	No	Yes	Yes
Season FE	No	Yes	No	Yes
League FE	No	Yes	No	Yes
Observations	35,183	35,183	30,563	30,563
Clusters	16	16	16	16

Notes: This table shows the change in home minus away goals after the implementation of Video Assistant Referee systems. The first row shows the home field advantage prior implementation and the second row shows the change in response to VAR. Each column shows a separate specification. The first column has no controls. The second column includes season and league fixed effects. The third column includes various controls for team quality. differences in the home field advantage across each of the five leagues. The last column includes both season and league fixed effects as well as various controls for team quality. Standard errors in brackets are clustered at the league level. Wild bootstrap confidence intervals are shown in parentheses. Results from the same specification with robust standard errors are presented in Table A.1 and are qualitatively similar. Significance: *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$.

Table 4: Home Field Advantage - Game Outcomes

	(1) P(Win)	(2) P(Win)	(3) P(Draw)	(4) P(Draw)
Baseline	0.459***	0.461***	0.251***	0.247***
	[0.006]	[0.002]	[0.004]	[0.002]
VAR	-0.001	-0.012	-0.003	0.014
	[0.011]	[0.014]	[0.012]	[0.015]
		(-0.038,0.027)		(-0.021,0.052)
Points Diff. (Cumulative)		0.005***		-0.000
		[0.001]		[0.000]
Points Diff. (Last 4)		0.005***		-0.001
		[0.001]		[0.001]
Points Diff. (Prev. Season)		0.005***		-0.001***
		[0.000]		[0.000]
Team Quality Controls	No	Yes	No	Yes
Season FE	No	Yes	No	Yes
League FE	No	Yes	No	Yes
Observations	35,184	30,563	35,184	30,563
Clusters	16	16	16	16

Notes: This table shows the change in home win probability and draw probability after the implementation of Video Assistant Referee systems. The first row shows the relevant probability prior implementation and the second row shows the change in response to VAR. The first and second columns show the effect on home win probability with and without controls, respectively. Similarly, the third and fourth columns show the same except with draw probability as the outcome of interest. Standard errors in brackets are clustered at the league level. Wild bootstrap confidence intervals are shown in parentheses. Results from the same specification with robust standard errors are presented in Table A.1 and are qualitatively similar.

Significance: *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$.

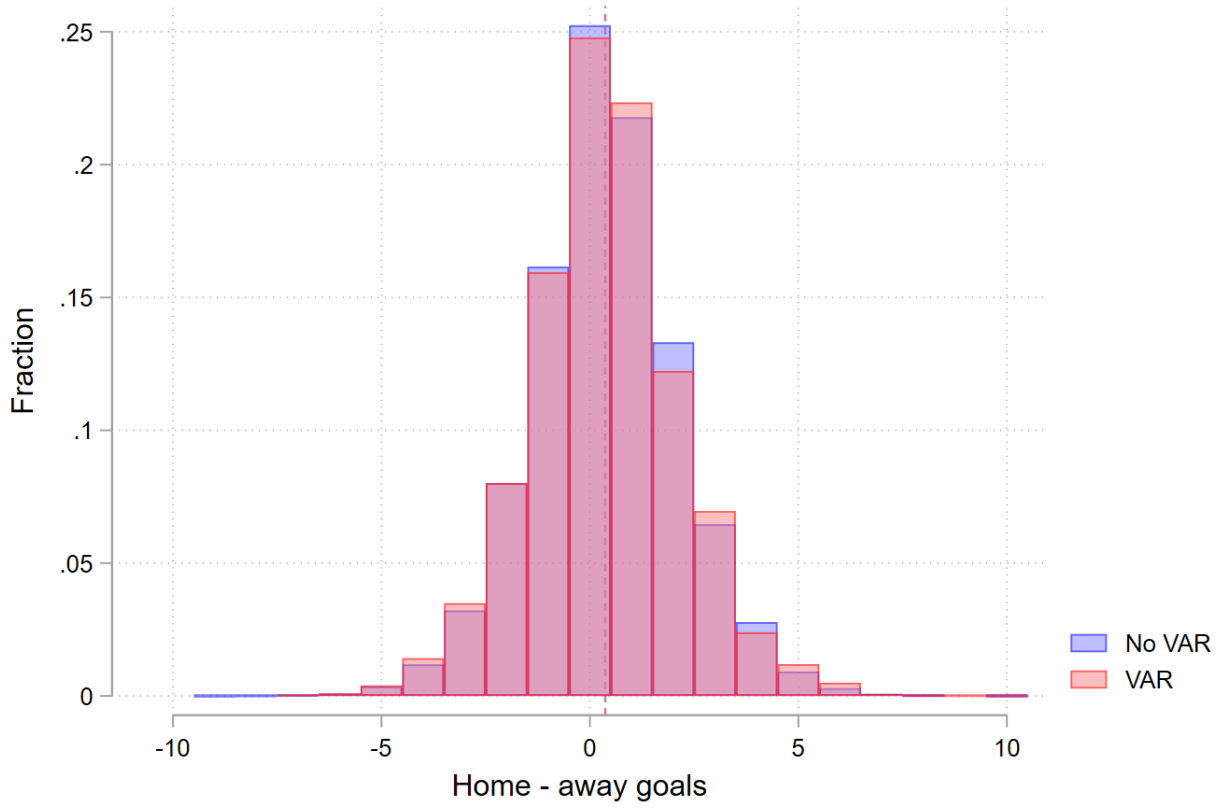
Table 5: All Referee Statistics

	(1)	(2)	(3)	(4)	(5)
Panel 1: Home-Away Diff	Fouls	Yellow Cards	Red Cards	Offsides	Penalty Kicks
Baseline	-0.428***	-0.289***	-0.036***	0.218***	0.062***
	[0.019]	[0.007]	[0.002]	[0.008]	[0.003]
VAR	-0.048	-0.065	-0.015	-0.090	0.021
	[0.133]	[0.052]	[0.013]	[0.057]	[0.019]
Panel 2: Match Total	Fouls	Yellow Cards	Red Cards	Offsides	Penalty Kicks
Baseline	14.271***	2.069***	0.125***	2.217***	0.142***
	[0.041]	[0.010]	[0.002]	[0.014]	[0.001]
VAR	-0.444	-0.167**	0.018	-0.251**	0.012
	[0.290]	[0.072]	[0.011]	[0.101]	[0.008]
Season FE	Yes	Yes	Yes	Yes	Yes
League FE	Yes	Yes	Yes	Yes	Yes
Observations	1,468	1,468	1,468	1,468	1,468
Clusters	10	10	10	10	10

Notes: This table shows the change in various match statistics after the implementation of Video Assistant Referee systems. The first panel shows differences between the home and away team, while the second panel shows match totals. The first row of each panel shows the baseline value prior implementation and the second row shows the change in response to VAR. Each column shows the results from a different outcome and includes both season and league fixed effects. These data are at the team-by-season level, so it is impossible to include more granular controls in this specific analysis. Standard errors in brackets are clustered at the league level. Significance: *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$.

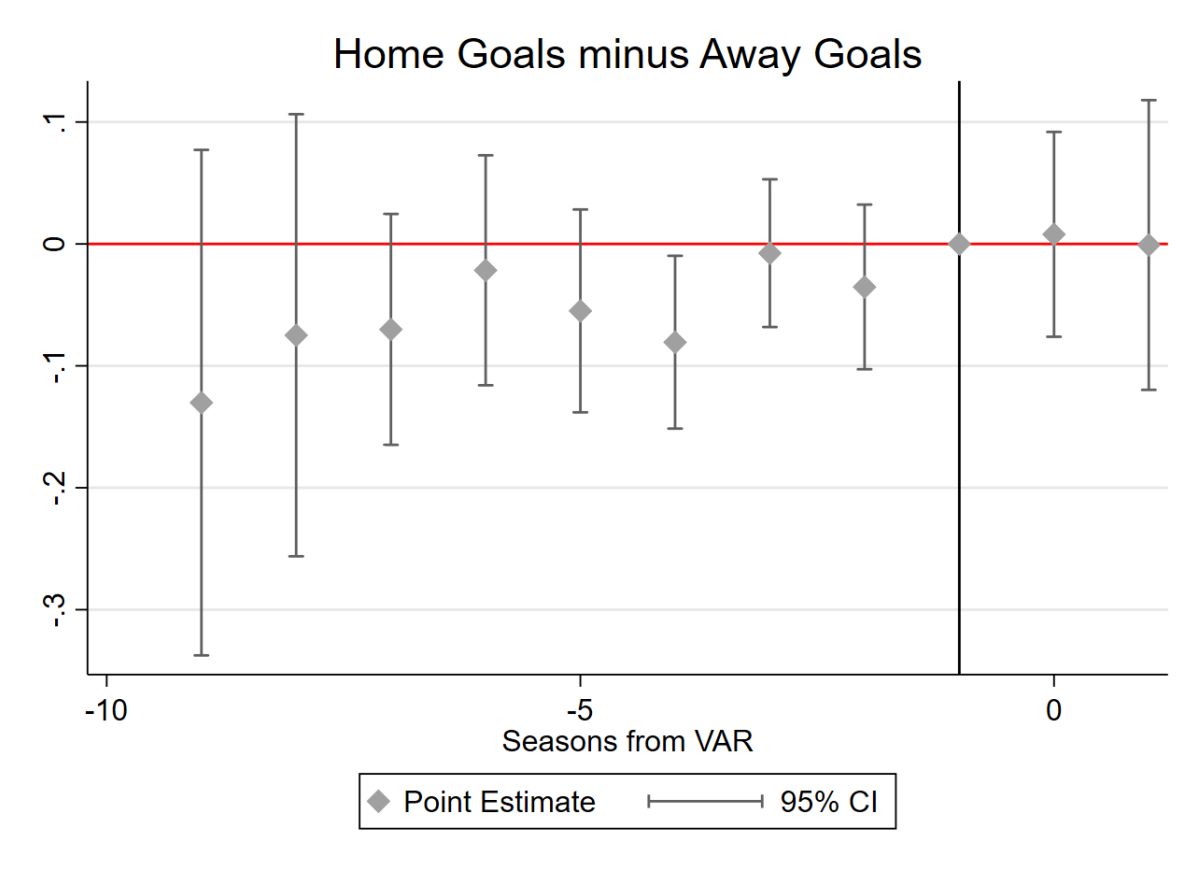
7 Figures

Figure 1: Home Field Advantage - Goal Difference Histogram



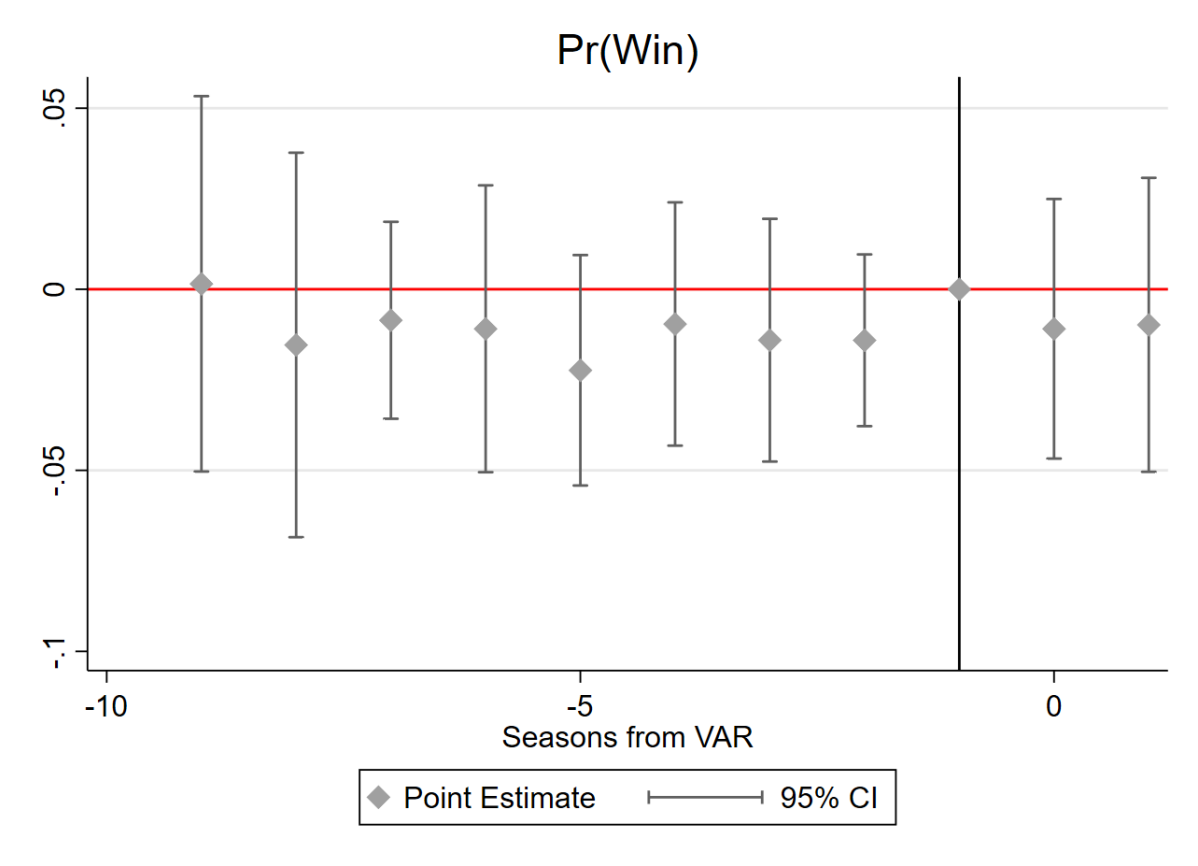
Notes: This figures shows the distribution of goal differences (home goals minus away goals) with and without Video Assistant Referees. The Kolmogorov-Smirnov test statistic is equal to 0.0063. The resulting p-value is 0.999, and we therefore fail to reject the null hypothesis that the distributions are equal.

Figure 2: Home Field Advantage by Season Relative to VAR Implementation - Goal Difference



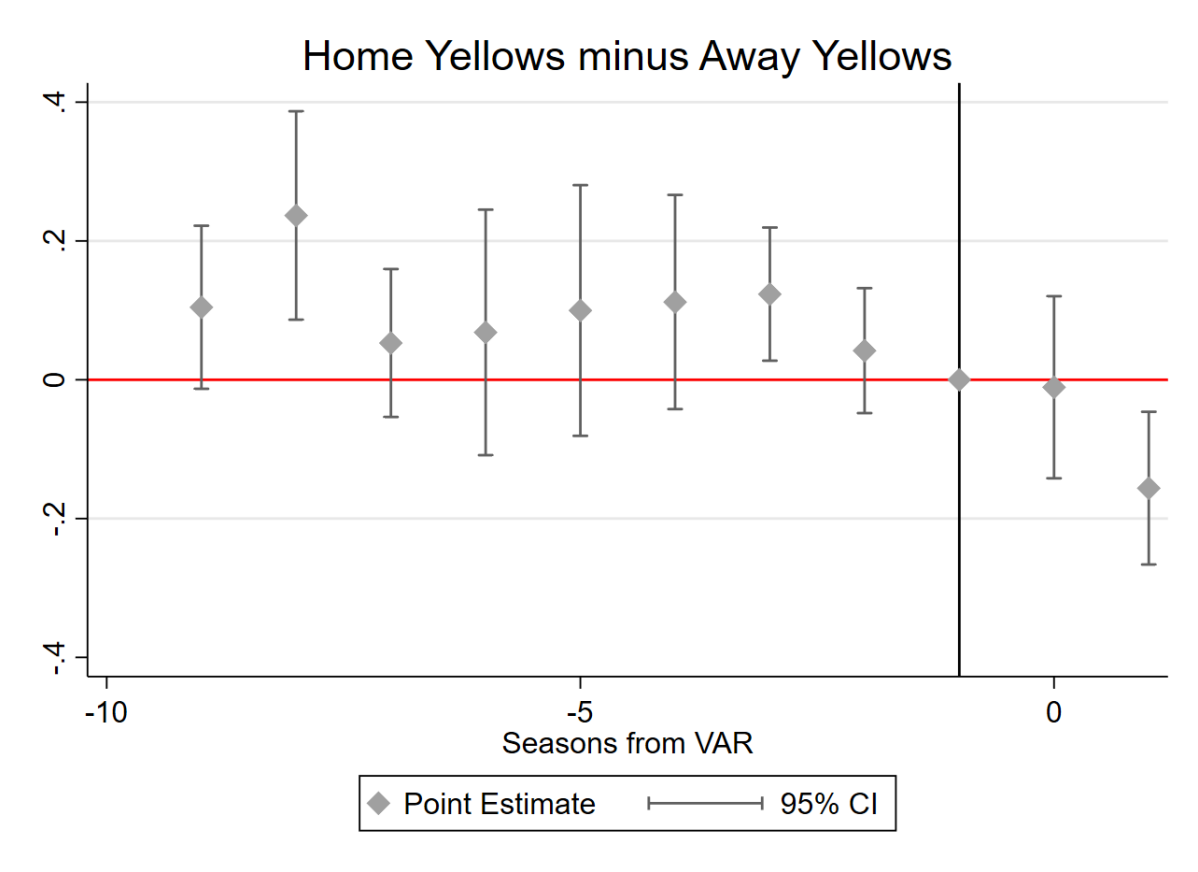
Notes: This figure shows the results of the event study specification described in Equation 2, where the outcome of interest is the home field advantage as measured by goal difference. These results suggest that home field advantage did not significantly change in response to Video Assistant Referee, reaffirming the results presented in Table 3.

Figure 3: Home Field Advantage by Season Relative to VAR Implementation - Home Win Probability



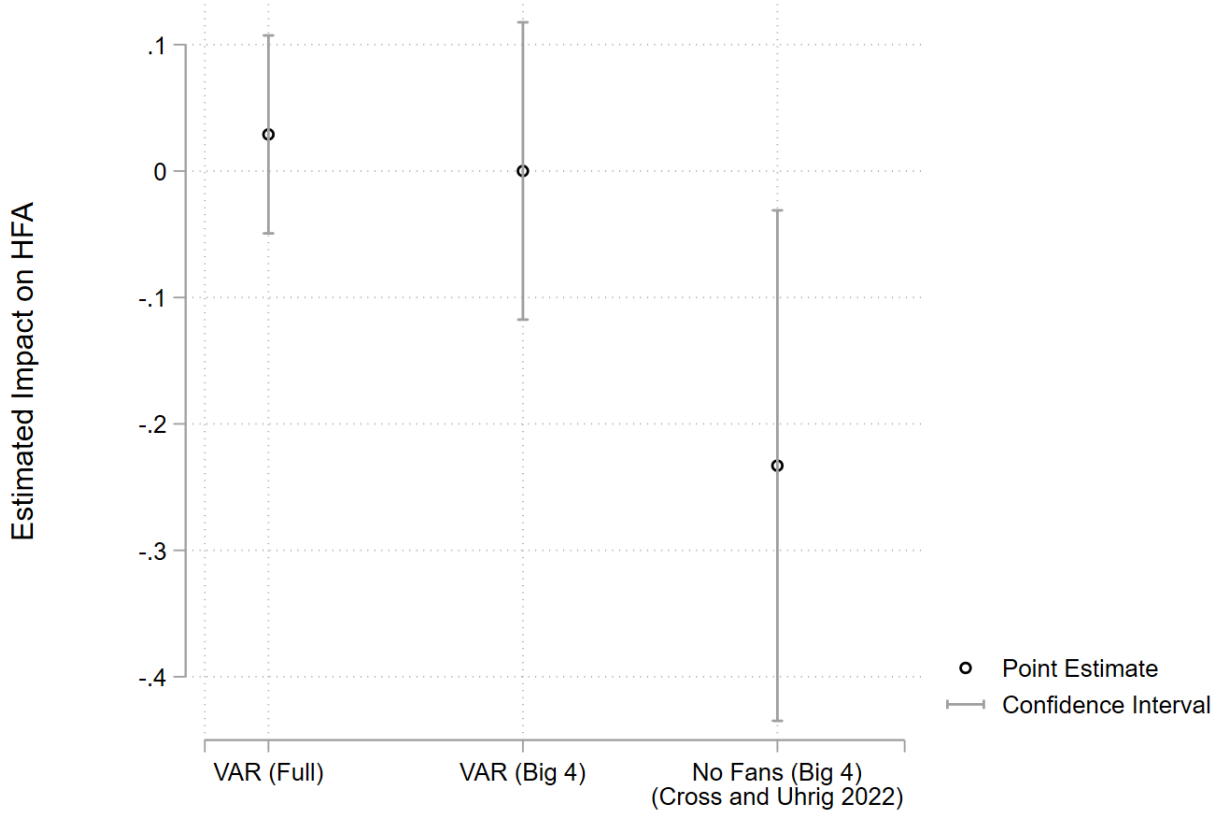
Notes: This figure shows the results of the event study specification described in Equation 2, where the outcome of interest is the home field advantage as measured by win probability for the home team. These results suggest that home field advantage did not significantly change in response to Video Assistant Referee, reaffirming the results presented in Table 4. In addition to the staggered adoption differences-in-differences specification and the event study shown here, Figure A.1 shows the qualitatively similar results of an ordered logit model.

Figure 4: Home Field Advantage by Season Relative to VAR Implementation - Yellow Cards



Notes: This figure shows the results of the event study specification described in Equation 2, where the outcome of interest is difference between the number of yellow cards awarded to the home and the number of yellow cards awarded to the away team. There is significant evidence of pre-trends: multiple coefficients in periods prior to treatment are positive and statistically significant. This suggests that the negative and statistically significant coefficient in the event study may be driven by underlying trends in the difference between home yellow cards and away yellow cards rather than the implementation of Video Assistant Referee systems, as has been found in the literature.

Figure 5: Home Field Advantage Comparison



Notes: This figure compares the estimated effect of Video Assistant Referee implementation and no-fans policies adopted in 2020 to mitigate the spread of COVID-19 (Cross and Uhrig, 2022). The left coefficient and confidence interval is derived from the full-sample estimates in this paper. The middle coefficient and confidence interval shows the estimates on only the top four leagues in Europe (the English Premier League, German Bundesliga, Spanish La Liga, and Italian Serie A) to mirror the sample used in Cross and Uhrig (2022). The right coefficient and confidence interval show the negative, statistically significant effect of the no-fans policies on home field advantage. The stark contrast between the effects in Cross and Uhrig (2022) and the precise null estimates in this paper highlight the lack of any effect of Video Assistant Referee implementation on home field advantage.

A Additional Tables and Figures

Table A.1: Home Field Advantage - Goal Difference (Robust SE)

	(1)	(2)	(3)	(4)
	G_{H-A}	G_{H-A}	G_{H-A}	G_{H-A}
Baseline	0.376***	0.371***	0.378***	0.377***
	[0.010]	[0.011]	[0.010]	[0.011]
VAR	-0.013	0.031	-0.005	0.007
	[0.031]	[0.048]	[0.028]	[0.044]
Points Diff. (Cumulative)			0.023***	0.023***
			[0.001]	[0.001]
Points Diff. (Last 4)			0.019***	0.020***
			[0.003]	[0.003]
Points Diff. (Prev. Season)			0.022***	0.022***
			[0.001]	[0.001]
Team Quality Controls	No	No	Yes	Yes
Season FE	No	Yes	No	Yes
League FE	No	Yes	No	Yes
Observations	35,183	35,183	30,563	30,563

Notes: This table shows the change in home minus away goals after the implementation of Video Assistant Referee systems. The first row shows the home field advantage prior implementation and the second row shows the change in response to VAR. Each column shows a separate specification. The first column has no controls. The second column includes season and league fixed effects. The third column includes various controls for team quality. differences in the home field advantage across each of the five leagues. The last column includes both season and league fixed effects as well as various controls for team quality. Robust standard errors are in brackets. Significance: *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$.

Table A.2: Home Field Advantage - Referee Experience

	(1) All G_{H-A}	(2) High G_{H-A}	(3) Low G_{H-A}
Baseline	0.377***	0.384***	0.373***
	[0.005]	[0.035]	[0.005]
VAR	0.007	0.070	0.006
	[0.040]	[0.153]	[0.044]
Points Diff. (Cumulative)	0.023***	0.019***	0.024***
	[0.002]	[0.003]	[0.002]
Points Diff. (Last 4)	0.020***	0.029***	0.018***
	[0.003]	[0.009]	[0.003]
Points Diff. (Prev. Season)	0.022***	0.020***	0.022***
	[0.001]	[0.003]	[0.001]
Team Quality Controls	Yes	Yes	Yes
Season FE	Yes	Yes	Yes
League FE	Yes	Yes	Yes
Observations	30,563	3,754	26,809
Clusters	16	15	16

Notes: This table shows the change in home minus away goals after the implementation of Video Assistant Referee systems. The first row shows the home field advantage prior implementation and the second row shows the change in response to VAR. The first column shows the results estimated on the full sample. The second column includes only matches officiated by referees with experience in major international tournaments. The third column includes only matches officiated by referees without experience in major international tournaments. All columns include both season and league fixed effects as well as various controls for team quality. Standard errors in brackets are clustered at the league level. Significance: *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$.

Table A.3: Home Field Advantage - Schedule Differences

	(1)	(2)	(3)	(4)
	G_{H-A}	G_{H-A}	G_{H-A}	G_{H-A}
Baseline	0.377***	0.378***	0.378***	0.380***
	[0.005]	[0.005]	[0.005]	[0.006]
VAR	0.007	0.000	0.000	0.015
	[0.040]	[0.040]	[0.038]	[0.044]
Team Quality Controls	Yes	Yes	Yes	Yes
Season FE	Yes	Yes	Yes	Yes
League FE	Yes	Yes	Yes	Yes
Observations	30,563	30,563	30,563	27,133
Clusters	16	16	16	14

Notes: This table shows the results from various specifications checking the robustness given differences in schedule type across leagues. Column 1 shows the results of the primary specification. Column 2 shows the results from the specification in which inverted seasons are included with the previous European season. Column 3 shows the same with inverted seasons included in the following European season. Column 4 shows the results from the primary specification estimated on the sample excluding leagues that use an inverted schedule. Results are similar to those in Table 3.

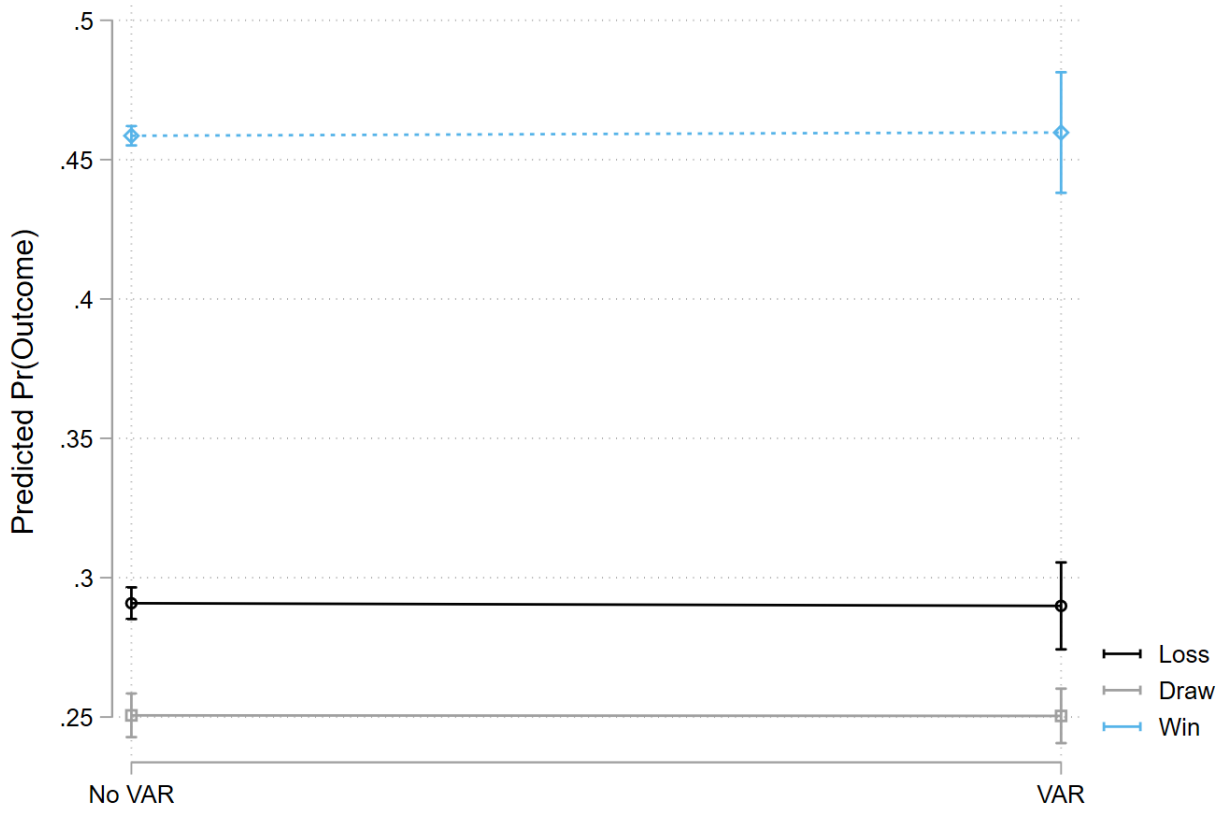
Significance: *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$.

Table A.4: Home Field Advantage - By Treatment Cohort

	(1)	(2)	(3)
	G_{H-A}	G_{H-A}	G_{H-A}
Baseline	0.377***	0.383***	0.394***
	[0.005]	[0.003]	[0.005]
VAR	0.007	0.026	0.009
	[0.040]	[0.062]	[0.067]
Points Diff. (Cumulative)	0.023***	0.024***	0.023***
	[0.002]	[0.002]	[0.002]
Points Diff. (Last 4)	0.020***	0.018***	0.015***
	[0.003]	[0.003]	[0.003]
Points Diff. (Prev. Season)	0.022***	0.022***	0.023***
	[0.001]	[0.001]	[0.002]
Team Quality Controls	Yes	Yes	Yes
Season FE	Yes	Yes	Yes
League FE	Yes	Yes	Yes
Observations	30,563	23,214	18,034

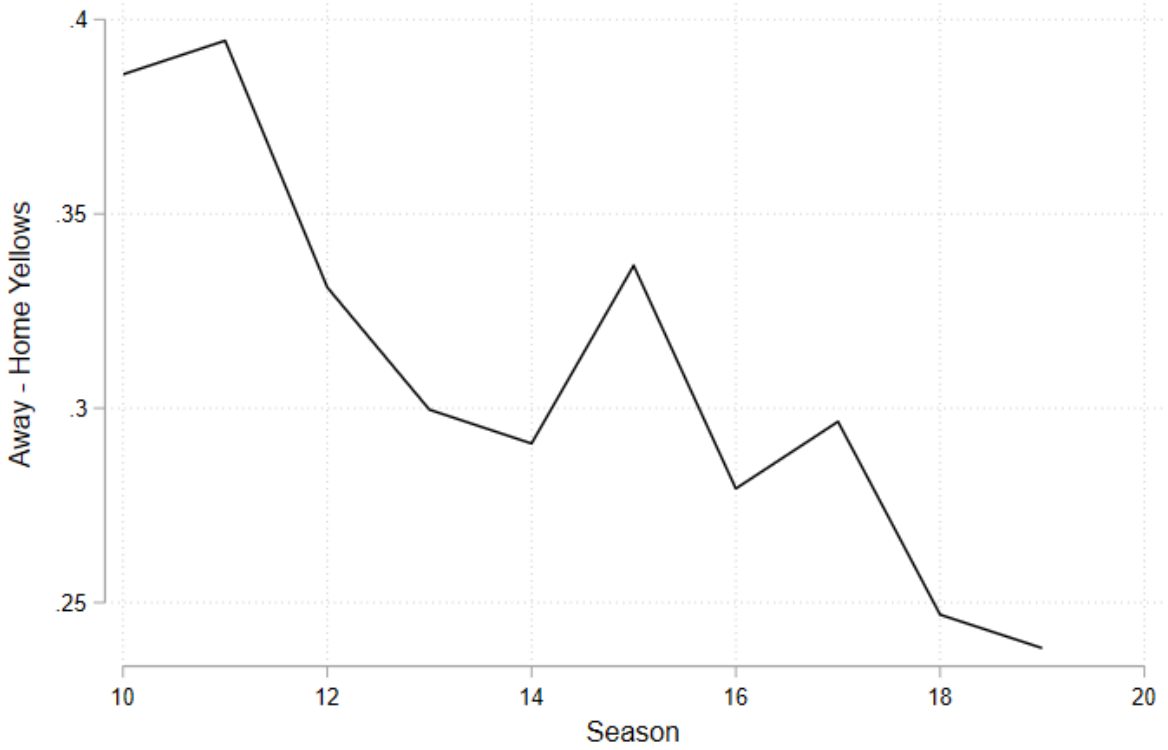
Notes: This table shows the results estimated by treatment cohort level. Column 1 shows the results of the primary specification. Column 2 shows the results of the primary specification through only the 2017-2018 season, using only European schedule leagues, thus only comparing those leagues that become treated in 2017-2018 to untreated leagues. Column 3 shows the results of the primary specification for the full sample of years but excluding those leagues that implement VAR in the 2017-2018 season (and leagues that follow an inverted schedule). This restriction means that no leagues are already treated in this specification; the 2018-2019 treatment cohort is only compared to leagues that had not yet adopted VAR. Results are similar to those in Table 3. Significance: *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$.

Figure A.1: Home Field Advantage - Game Outcomes: Ordered Logit Model



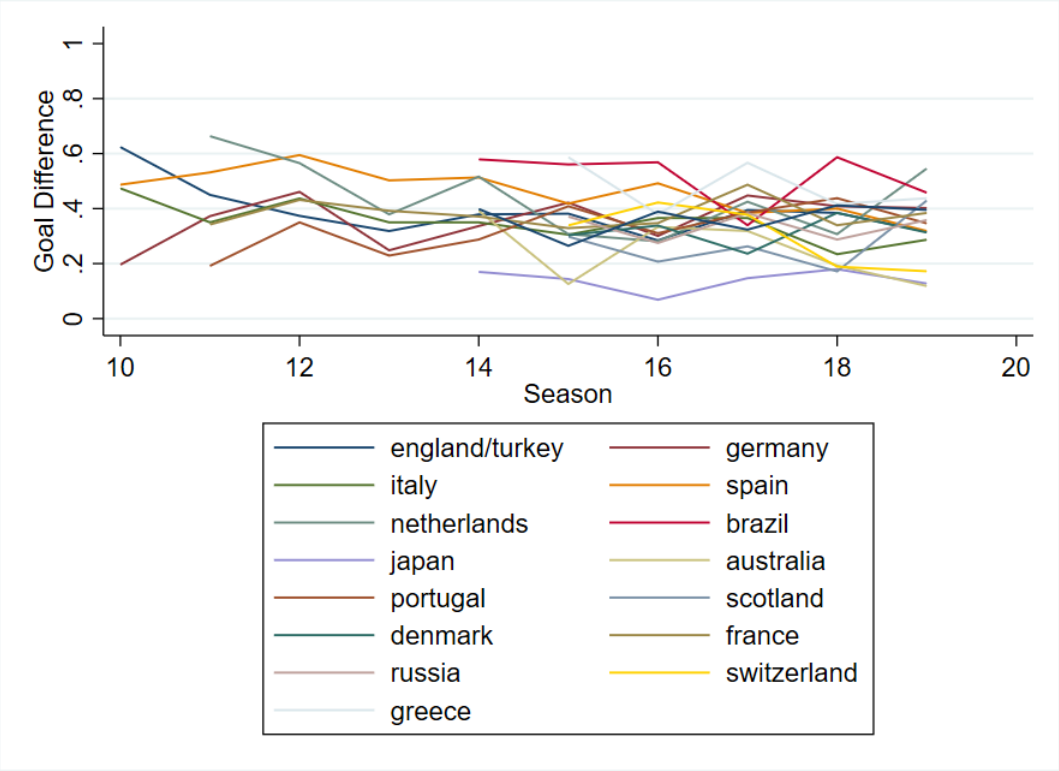
Notes: This figure shows the results of an ordered logit model estimating the effect of Video Assistant Referees on the probability for a home win, a draw, and a home loss. The outcomes are virtually unchanged in response to VAR, mirroring those results shown in Table 4 and Figure 3.

Figure A.2: Trends in Home-Away Yellow Card Differences



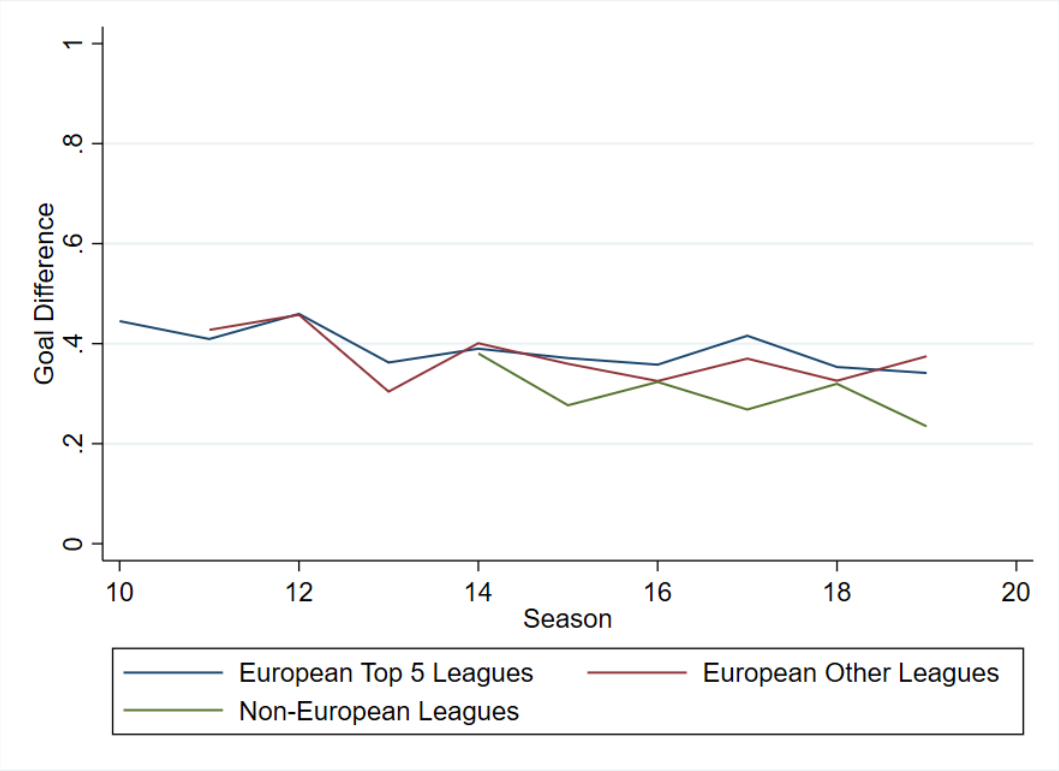
Notes: This figure highlights the decrease in home-away differences in yellow cards awarded over time. This difference has decreased since the early 2010's, well before the implementation of Video Assistant Referee systems. These trends suggest that researchers should take care in analysis of the effect of VAR on home-away differences in yellow cards or other match statistics, as some analyses rely on the assumption that those differences would have remained unchanged in the absence of VAR.

Figure A.3: Home Field Advantage by Season - League



Notes: This figure shows the home field advantage, as measured by goal difference, for each league over the sample time period.

Figure A.4: Home Field Advantage by Season - Region



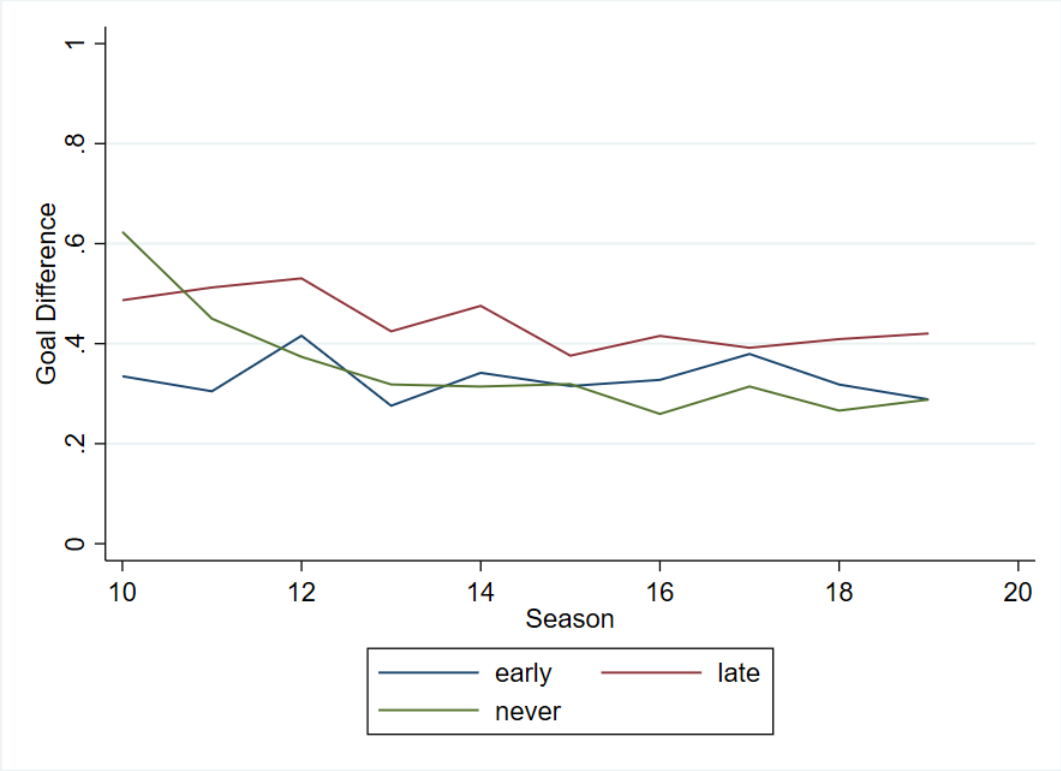
Notes: This figure shows the home field advantage, as measured by goal difference, for each region over the sample time period.

European Top 5: Italy, Germany, France, Spain, England

European Other: Portugal, Netherlands, Turkey, Switzerland, Russia, Greece, Denmark, Scotland

Non-European: Australia, Brazil, Japan

Figure A.5: Home Field Advantage by Season - Adoption Timing



Notes: This figure shows the home field advantage, as measured by goal difference, over the sample time period by groups organized by adoption of Video Assistant Referee.

Early Adopters: Italy, Germany, Portugal, Australia

Late Adopters: France, Spain, Netherlands, Turkey

Never Adopters: Brazil, Japan, Switzerland, Russia, Greece, Denmark, Scotland, England