Video Assistant Referee and home field advantage: implications for referee bias

Abstract

Previous research has highlighted referee bias as a potential contributor to home field advantage in soccer. In order to shed light on the importance of referee bias, we exploit the staggered implementation of Video Assistant Referee (VAR) using data from the top domestic league in 16 countries between 2009 and 2019 to estimate the effect of objective review systems on home field advantage in soccer. Surprisingly, the implementation of VAR had negligible effects on home field advantage and various crucial match statistics despite decreased total offsides and yellow cards. These results provide suggestive evidence regarding the mechanisms through which referee bias might contribute to home field advantage and highlight how scope may limit the effectiveness of review processes in general.

Keywords: soccer, home field advantage, referee bias, social pressure, review systems

JEL Codes: Z2, L83, D91

Abbreviations: IFAB, International Football Association Board; VAR, Video Assistant Referee

1 Introduction

Many economically meaningful situations rely on arbiters to make decisions. Despite their supposed impartiality, these arbiters sometimes exhibit bias. This bias is often studied in a legal context and typically depends on individual, firm, or judge characteristics (Cahuc et al., 2022; Alesina & La Ferrara, 2014). However, social pressure has also been shown to impact behavior and decision-making, such as through differences in sentence length based on newspaper coverage (Lim et al., 2015). One economic setting that is particularly susceptible to influence by social pressure is sports, which features large economic stakes, biased crowds, and arbiters (e.g., referees) who evaluate play based on a set of rules. Previous work has shown that the referees in these settings are not immune to the social pressure from the biased crowd. For example, Reade et al. (2022) exploit the fact that soccer games were played without fans early in the COVID-19 pandemic and conclude that fans cause referees to favor home teams in their officiating.[1] Many sports organizations around the world have turned to technology to minimize incorrect decisions by referees, but questions remain regarding the effect these technologies have on outcomes.

This paper analyzes the implementation of Video Assistant Referee (VAR) systems on refereeing and home field advantage in soccer. Although the existence of home field advantage is well-established, the exact causes and contributions remain unclear. Recent literature has emphasized the role of the fans in home field advantage (Ponzo & Scoppa, 2018; Cross & Uhrig, 2023), with some researchers suggesting that fans apply social pressure to the referee who, in turn, provides favorable treatment to the home team (Reade et al., 2022; Scoppa, 2021; Endrich & Gesche, 2020; Bryson et al., 2021). VAR was introduced to improve referee decisions by utilizing video replay to correct "clear and obvious" errors and had the desired effect; VAR significantly improved decision accuracy on reviewed calls from 92.1% to

[1] Specifically, Reade et al. (2022) document that the home-away difference in yellow cards decreased when fans are not present, suggesting that the fans cause the initial difference when they are in attendance.

98.3% (Spitz et al., 2021).[2] If referee bias affects outcomes primarily through clear errors on important decisions, then the implementation of impartial technology such as VAR could mitigate this channel and thus reduce the observed home field advantage.

We exploit differences in VAR implementation timing across various top domestic soccer leagues as a source of identifying variation to estimate the effect on match outcomes. Specifically, we employ a staggered adoption difference-in-differences specification with two-way fixed effects to control for level differences in home field advantage across countries (i.e., leagues) and seasons. We find no evidence of a decrease in home field advantage in response to the implementation of VAR. Estimated coefficients are statistically insignificant and suggest only an 8.2% increase in home field advantage, as measured by the average difference in goals for the home team compared to the away team. The 95% confidence interval rules out a 16.8% decrease relative to the baseline home field advantage, suggesting a precise null effect of VAR. Results are qualitatively similar when using an indicator for a home team win as the outcome of interest: the estimated coefficient is approximately 0 and statistically insignificant with a 95% confidence interval that rules out a 3.1 percentage point decrease in home win probability, which is equivalent to 6.8% of the baseline probability. We thus find no evidence that the implementation of VAR decreases home field advantage, counter to expectations by some news articles and gambling services (Petty, 2018).

Although we find no effect of VAR on home field advantage, one would expect that the implementation of review technology impacted referee decisions. We document negative effects on total yellow cards and offsides, but we do not estimate statistically significant effects on potentially game-changing decisions, such as penalty kicks, which are directly reviewed by the Video Assistant Referee. Moreover, despite evidence that a slight majority of VAR decisions in the English Premier League during the 2019-2020 season favored the away team

[2] 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.

over the home team (Johnson, 2020),[3] we find no evidence that VAR significantly decreased the gap between home and away teams for any refereeing outcomes. Overall, our results show that improved referee decision accuracy did not lead to a decrease in home field advantage in either match outcomes or referee decisions.

Our paper contributes to the literature analyzing review processes in sports. Although previous research has documented various changes in response to VAR implementation, it is an open question to what extent these changes may have mitigated home field advantage and promoted fairness in soccer. We extend the understanding of VAR in two dimensions. First, we employ a staggered adoption difference-in-differences design. This is possible due to the expanded sample of our dataset; by including matches from many countries and seasons, the empirical strategy is able to control for average differences in outcomes across countries and over time. This stands in contrast to the existing literature, which focuses on two or fewer leagues and is therefore unable to account for the gradual decline in home field advantage that has been documented in soccer (Pollard & Pollard, 2005; Strauss et al., 2014; Roeder & Curley, 2014; Filippo, 2021).

Second, we directly investigate the effect of VAR on home field advantage rather than only referee outcomes. Only two other papers consider home field advantage, as measured by either goal difference or win percentage, as an outcome of interest. Han et al. (2020) and Dufner et al. (2023) investigate the immediate effects of VAR implementation in China and Germany, respectively, and find statistically insignificant effects. However, Han et al. (2020) and Dufner et al. (2023) each rely on data from only two seasons and one country. This paper is the first to provide quasi-experimental evidence on the potential direct effect of Video Assistant Referee systems on home field advantage in top soccer leagues around the world.

The null effect of VAR on home field advantage also provides insights about the mechanism

[3] 68 (62%) of 109 overturned decisions favored the away team over the home team. This is similar to the result in cricket that "home and away teams are equally likely to win a 3rd umpire reversal" (Shivakumar, 2018).

through which referee bias impacts outcomes in soccer. Previous work leveraging variation in fan loyalties (Ponzo & Scoppa, 2018) or constraints on fan attendance (Reade et al., 2022) has documented that referees provide favorable treatment to home teams. If referee bias contributes to home field advantage in soccer through major, blatantly incorrect decisions, then the implementation of Video Assistant Referee systems would reduce the observed advantage by reversing these decisions and leveling the playing field. However, the precise null effect of VAR on home field advantage suggests that referee bias impacts match outcomes through either marginally incorrect decisions that are not overturned by VAR or through minor decisions, which are not reviewed by VAR at all, rather than major ones. These results narrow the scope of possible mechanisms through which referee bias might affect match outcomes and can therefore inform future interventions designed to promote fairness in sports.

More generally, we contribute to the literature on arbiter bias and decision review. Critics of the current United States judicial system have highlighted that implicit bias has been documented among both judges (Rachlinski et al., 2008) and jurors (Sommers & Ellsworth, 2001), but the scope for appeals based on implicit bias is non-existent (Pollis, 2022). Instead, similar to VAR, the focus of the appeals system is correcting for blatant errors, particularly procedural transgressions, and reviews for evidentiary sufficiency tend to confirm the initial decision, in part due to affirmation bias (Edwards, 2018). Our findings provide additional evidence that, when reviews are limited in scope and the null hypothesis is the initial decision, review systems are ineffective at reducing arbiter bias.

2 Background

2.1 Home Field Advantage

Home field advantage has been observed in soccer for decades (Dowie, 1982) and is typically broken down into three main channels: travel fatigue, venue familiarity, and crowd support (e.g., Sutter & Kocher, 2004). Previous work has attempted to causally estimate how much each of these factors contribute to home field advantage by leveraging exogenous variation in each of these three components (Pollard, 2002; Belchior, 2020; Pradhan et al., 2022). With the absence of fans induced by COVID-19, recent work has been particularly focused on identifying the effect of crowd support in many different contexts such as baseball (Losak & Sabel, 2021), basketball (Gong, 2022; Ganz & Allsop, 2024), and hockey (Thrane, 2023). The literature often notes that one way crowds impact match outcomes is by influencing referee decisions, which is commonly referred to as "referee bias."

Given the key role of referees on the flow of matches and the focus of fans on referee decisions, it is not surprising there is a rich literature focused on identifying how referee bias impacts match outcomes in sports. For example, home field advantage in cricket dropped from 16% to 0.7% when neutral umpires replaced umpires from the host country (Sacheti et al., 2015).[4] In the context of soccer, home teams receive fewer yellow and red cards and are awarded more penalty kicks (Ponzo & Scoppa, 2018; Reade et al., 2022), which is likely driven by social pressure exerted by fans on the referee. This social pressure may be driven by the attendance of home fans (Downward & Jones, 2007; Boyko et al., 2007), the animosity of home fans (Singleton et al., 2023), or the literal noise home fans generate in response to controversial acts (Nevill et al., 2002).

[4] Interestingly, this home field advantage actually decreased further during the COVID-19 pandemic, during which home umpires were reinstated, presumably due to the awareness of the previous bias towards home teams and a desire to appear impartial (Chowdhury et al., 2023).

2.2 Video Assistant Referee

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 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[5] and the "Hand of God" goal by Maradona against England in the 1986 World Cup semifinal.[6] 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 et al., 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 et al., 2022). After a referee makes a decision, an 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). Video Assistant Referee provides information, sometimes including replays, to the center referee for

[5] 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.

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

review to inform the final decision (IFAB, 2022).

Given the limited scope of VAR, it was unclear ex-ante how the implementation of a review system would impact soccer in general and home field advantage specifically. Zglinski (2022) emphasizes the difference between enforcing objective rules and subjective norms, the latter of which is presumably unaffected by VAR. However, Shivakumar (2018) documents changing norms in cricket in response to the implementation of the Decision Review System (DRS), specifically finding, among other results, that officials were much less likely to give the benefit of the doubt to the batsman. Non-academic sources expected a reduction in incorrect calls to diminish home field advantage in soccer (Petty, 2018). Although Spitz et al. (2021) finds that the decision accuracy on reviewed calls increased from 92.1% to 98.3%,[7] it is an open question to what extent the increased decision accuracy translated to changes in home field advantage.

Previous research has found that VAR implementation is associated with lower total fouls (Han et al., 2020; Lago-Peñas et al., 2019; Meneguite et al., 2022; Dufner et al., 2023), offsides (Lago-Peñas et al., 2021; Kubayi et al., 2022; Lago-Peñas et al., 2019; Meneguite et al., 2022), yellow cards (Lago-Peñas et al., 2019; Meneguite et al., 2022), and longer games (Errekagorri et al., 2020; Han et al., 2020; Kubayi et al., 2022; Lago-Peñas et al., 2019, 2021). On the other hand, research has found null or inconclusive effects of VAR on two outcomes that are eligible for review: penalty kicks and red cards (Holder et al., 2022; Kubayi et al., 2022; Meneguite et al., 2022; Dufner et al., 2023). Holder et al. (2022) also document minor heterogeneous effects on added time, depending on the state of the game in the 90th minute. Although the methods vary slightly across these previous papers, all of them focus exclusively on samples of treated countries and examine how outcomes changed from the seasons before implementation of VAR compared to the seasons after implementation of VAR.

[7]This closes 78% of the gap between the initial correct decision rate and the upper bound of 100% accuracy.

3 Data

The primary specification uses match-level data from the soccer statistics website FBref.[8] 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, which we present in Table 1. The last year included is the 2018-2019 season, as home field advantage was diminished starting in 2019-2020 due to the COVID-19 mitigation strategies that artificially limited fan attendance (Cross & Uhrig, 2023).[9] The full sample includes 35,183 matches from 16 top domestic leagues around the world.

In addition to the goals scored by the home and away team and the match outcome (home win, draw, home loss), 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 countries in the primary specification, where available.[10]

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 home win probabilities of approximately 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.

[8] 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.

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

[10] These data are not consistently and easily available from FBref.com at the match level.

[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.

Graphical evidence suggests that the implementation of VAR did not affect home field advantage. 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 initial evidence suggests that home field advantage was unaffected by the introduction of VAR.[12]

4 Empirical Strategy

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

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

where the dependent variable y_{mct} is the goal difference in match m,[13] α is the constant term, 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, λ_c is a country fixed effect,[14] and δ_t is a season fixed effect.[15] The error term ϵ_{mct} is clustered at the country level to account for correlation in the treatment variable (Bertrand et al., 2004). Given the low number of clusters, critical values are taken from the t-distribution with $G - 1 = 15$ degrees of freedom.[16] For a two-sided 95% confidence interval, this gives a

[12] Figure B.1 shows that, even when we group countries by timing of VAR adoption, there is no clear impact of VAR on home field advantage.

[13] Since the changes to VAR occur at the start of each season in our sample, one could conduct a similar analysis where the unit of observation represents season averages for each country. As we discuss in Appendix A, we find similar results with this alternative approach.

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

[15] Season fixed effects are assigned such that countries with inverted schedules are considered separately.

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

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 two-sided 95% confidence interval for the effect of VAR on home field advantage (Cameron et al., 2008; Lee & 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 & 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 home field advantage as measured by an indicator equal to 1 if the home team wins 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. For all of these referee statistics, we consider match totals and home-away differences. In addition, to ensure the robustness of our results, we estimate additional specifications where we include center referee and home team or home-by-away team fixed effects as well as a vector of team form controls that include the point difference in the most recent four games, in the full season to date, and the previous season.[17] These controls account for common factors that impact home field advantage in a specific match. For example, referee fixed effects control for how a specific center referee tends to favor the home team and home-by-away team fixed effects (e.g., Lazio at home against Napoli) account for time-invariant factors, such as travel distance. It is unlikely that these factors are correlated with VAR implementation, but it will be reassuring if the estimates from these specifications mirror the findings from estimating Equation (1).[18]

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 countries that introduced VAR compared to those that did not. Our estimates are unbiased as long as

[17]For recently promoted teams, the previous season's points are set to the lowest points total in the top division from the previous season.

[18]It is also reassuring that when we do the season-level analysis shown in Appendix A, which abstracts from factors that impact specific match outcomes, we find results that mirror the match-level findings.

the gap between average outcomes for VAR implementing countries compared to non-VAR implementing countries would have remained constant absent VAR. This is in sharp contrast to previous work, which examines within-country differences before and after the implementation of VAR so any trends over time would bias the estimated effect of VAR.[19]

To explore the validity of the parallel trends assumption, we estimate an event study design that will show if trends appear similar in the months leading up to the introduction of VAR. For each match, we define V_{mct} as an indicator that is equal to 1 if the match is played in a country that introduces VAR. Using the following specification:

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

we identify a separate coefficient, β_e, on each event-time indicator E_{mct} that captures the differences in match outcomes between the countries 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, but we estimate similar event studies for each of the alternative outcomes of interest. We control for baseline average differences between countries with country fixed effects, λ_c and average changes by season with season fixed effects δ_t.

[19] This is particularly important since there is clear evidence of baseline trends in some of the referee related outcomes. For example, Figure B.2 highlights a clear downward trend in the gap between home and away yellow cards well before the implementation of VAR.

5 Findings

5.1 Main Results

The key identifying assumption for our estimates to be unbiased is that absent the implementation of VAR the treated and control groups would have been on parallel trends. The assumption is fundamentally not testable, but we explore its validity by estimating the event study specification shown in Equation (2) to identify how the gap between the two groups (treated and control) changes in the pre-period. Figure 3 and Figure 4 show the event study results from estimating Equation (2) for home field advantage measured by goal difference and an indicator for a home win, respectively. Both figures show no evidence that the gap between the treated and control groups changes during the pre-period, and there is no obvious effect of VAR on either measure of home field advantage.

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 previous work on home field advantage (e.g., Cross & Uhrig, 2023). The estimated coefficient suggests a decrease in home field advantage of only 0.013 goals per game in response to the implementation of VAR. 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 G - 1 = 15 degrees of freedom, rules out a 0.092 goals per game decrease in home field advantage.

Column 2 of Table 3 shows the same results with the inclusion of season fixed effects and country fixed effects. This specification is preferred due to the fact that it controls for differences in baseline home field advantage, absent the implementation of VAR, across countries and over time. The estimated coefficient of interest is slightly positive but statistically insignificant, and the 95% wild bootstrap confidence interval, shown in parentheses under the standard error, rules out a 16.8% decrease in home field advantage.[20] 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. To put these results in context, Figure 2 compares our results on the effect of VAR to previous work estimating the effect of fans on home field advantage. This figure highlights the null effect of VAR relative to other factors that may affect home field advantage.

We also investigate the effect of VAR on match results. We explore these alternative outcomes in Table 4, which presents our estimates when the outcome of interest is either an indicator for a home win or an indicator for a home draw. For both outcomes, our estimated coefficients are close to zero and statistically insignificant, regardless of the inclusion of controls. For example, focusing on the results shown in Column 2, which includes both season fixed effects and country fixed effects, the 95% wild bootstrap confidence interval rules out a 3.1 percentage point decrease in the probability of a home win, which represents only 6.8% of the baseline win probability.

5.2 Effect of VAR on Other Match Outcomes

Table 5 presents our results from estimating Equation (1) where the outcomes of interest are various statistics associated with referee actions. Panel 1 presents our estimates when the dependent variable is the home-away difference in various referee actions (e.g., fouls), while Panel 2 shows our results when the dependent variable is the match total. Focusing on the match totals shown in Panel 2, we find that some outcomes are less prevalent after VAR

[20] Results are qualitatively similar if various controls for team quality are also included, as is shown in Column 3 (without fixed effects) and Column 4 (with fixed effects) of Table 3. Moreover, we find a similar pattern of results when controlling for average differences in home field advantage by referee, home team, and matchup through referee, home team, and home-by-away team fixed effects, which we show in Table B.2.

implementation; there is a statistically significant decrease in the total number of yellow cards and offsides. These results are mirrored by our event study estimates shown in Figures 5 and 6, which show a sharp decrease following the implementation of VAR. For the other three outcomes (red cards, fouls, and penalty kicks) we are not able to reject the null hypothesis of no effect, but the signs of the coefficients are similar to previous research (Han et al., 2020; Spitz et al., 2018).

Although we find some effects of VAR on total yellow cards and offsides, Panel 1 of Table 5 shows no evidence that the implementation of VAR impacted the difference between referee actions for the home team relative to the away team. Specifically, we find that there is no statistically significant effect of VAR on the level of home field advantage as measured by fouls, yellow cards, red cards, offsides, or penalty kicks. Interestingly, these results highlight that, although the presence of fans has been shown to significantly impact the home-away difference in yellow cards (Reade et al., 2022), the implementation of VAR did not affect the home-away differences in referee decisions examined here.

5.3 Heterogeneity Analysis

One might expect heterogeneous effects of VAR on home field advantage depending on the level of experience for the main referee. Specifically, it may be the case that experienced officials make fewer errors and exhibit less bias for VAR to correct, but inexperienced referees could make decisions that require the oversight of VAR. Table B.4 shows the results of Equation (1) where we split the sample based on whether or not the referee has high-level international experience. Referees are considered to have a high level of experience if they have refereed matches in prestigious international competitions during the time period.[21] Approximately 14.0% of referees have high experience by this metric, and those individuals

[21] 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.

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 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.

5.4 Robustness Checks

We consider various alternative specifications to 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 both 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 B.5 shows the results when inverted countries are included with the previous European schedule, and Column 3 of Table B.5 shows the results when inverted countries are included with the following European schedule. Column 4 of Table B.5 shows the results when Japan and Brazil are excluded entirely from the sample. In all cases, coefficients are similar to those in the primary specification.

Our empirical strategy leverages the staggered nature of VAR adoption by countries over time, which introduces concerns associated with treatment effect heterogeneity and negative weights (Goodman-Bacon, 2021). To address this, we show the results from the primary equation estimated separately for each treatment cohort, which alleviates concerns about using already treated units as controls for later treatment cohorts. Table B.6 shows the results from the primary equation estimated separately for each treatment cohort.[22] 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.[23]

5.5 Discussion and Limitations

Although we document a null effect of Video Assistant Referee systems on home field advantage, the implications for referee bias are ambiguous due to the limited scope of VAR. On the one hand, it may be the case that biased decisions that fall outside of the purview of VAR are the primary channel that referee bias contributes to home field advantage.[24] If referee bias manifests through many minor decisions over the course of 90 minutes, then this could contribute to home field advantage in such a way that is completely unaffected by the implementation of VAR due to the limited scope of what is eligible for review. On the other hand, VAR systems also only correct for "clear and obvious" errors. If referee bias contributes to home field advantage through marginally incorrect calls, then home field advantage may remain unchanged simply because VAR would not necessarily reverse calls that only slightly favor the home team.[25]

Alternatively, our results are consistent with the possibility that referee bias does not

[22] For simplicity, only countries with a European schedule are included. There are insufficient countries with an inverted schedule to conduct the analysis separately, and the quantitative similarity between estimated coefficients in Column 1 and Column 4 of Table B.5 suggests that the exclusion of countries with inverted schedules does not affect the results.

[23] This result is unsurprising given the fact that 1) no countries adopted VAR prior to the beginning of the sample period, and 2) a large number of countries implemented VAR in the 2019-2020 season or later and are thus considered fully-untreated in the primary specification.

[24] To illustrate this point, Titman et al. (2015) jointly models bookings and goals in soccer and documents the complex relationships between various statistics and the final result of a match.

[25] This possibility is slightly mitigated by the fact that decision accuracy on reviewed calls increased dramatically in response to VAR (Spitz et al., 2021), but it is still feasible that marginally incorrect decisions by referees contribute to home field advantage even in the presence of review systems.

contribute to home field advantage.[26] Conventional wisdom suggests that fans of home teams exert social pressure on referees who, in turn, favor home teams. However, it may instead be the case that fans affect the performance of home teams directly in such a way that leads to observed discrepancies in both match outcomes and disciplinary outcomes such as yellow cards, red cards, and penalties (Fischer & Haucap, 2021; Ferraresi & Gucciardi, 2021, 2023; Colella et al., 2023). For example, home team managers may opt for more offensive and courageous playing tactics (Staufenbiel et al., 2015) and the absolute performance of players is higher when playing in front of a home crowd (Ferraresi & Gucciardi, 2021). Removal of the direct effect of fans on managers and players could thus lead to relatively worse home team performance and fewer disciplinary actions called on the away team. For example, recent work using a ban on away fans in Argentina documents that the visiting team is less likely to win the match, suggesting that away fans positively impact away teams, but there is no impact on referee behavior (Colella et al., 2023). Despite experimental evidence that has shown referees respond to crowd noise (Nevill et al., 2002), we thus cannot rule out that referees bias does not contribute to home field advantage, which is consistent with the precise null effects documented in Section 5.1.

More broadly, the implications of our analysis are limited by key features of our setting. First, our analysis limited to the short-term effects of VAR in the seasons immediately following implementation. Home field advantage was dramatically reduced by COVID-19 mitigation policies starting in early 2020 (Reade et al., 2022; Cross & Uhrig, 2023); each country therefore experiences at most two seasons with VAR before the end of the sample considered in this paper. We are thus not able to identify if the effect of VAR on outcomes are changing over longer periods of time. Second, our analysis is limited to the extensive margin as we do not have the necessary variation in how VAR is utilized to examine how broadening what can be reviewed impacts home field advantage. Our findings are thus able

[26] If referees are worried about being perceived as blatantly biased, then this could actually mitigate the potential impact of fans on referees. That sports referees or umpires are aware of perceptions is evident in Chowdhury et al. (2023), which documents that scrutiny can eliminate (or even reverse) in-group biases.

to speak to the effect of implementing VAR in its current capacity, but we cannot speak to how match outcomes would change if, for example, the scope was modified to include review of fouls and yellow card decisions.

6 Conclusion

Although decisions made by arbiters are often prone to error and bias, the extent to which previous decisions are re-examined is often limited. In sports, these limitations are typically informed by the desire to minimize interference in the action, as is highlighted by the "minimum interference - maximum benefit" mantra for Video Assistant Referee systems. In other contexts, these limitations may be driven by the availability of, for example, appellate court judges or tax auditors. While this targeted approach may eliminate the most egregious errors, it fails to correct all biases due to the limited scope of the review process.

In this paper, we utilize the staggered rollout of a review process focusing on clear errors in a setting where arbiter bias is well-documented to identify if there is any impact on average outcomes. Specifically, we estimate the effect of Video Assistant Referee technology on home-field advantage and various referee statistics. Despite previous evidence of referee bias that would suggest referee errors favor the home team, we find no evidence that improved referee decision accuracy has any impact on home field advantage. Our statistically insignificant results rule out decreases in home field advantage due to VAR of 16.8% (goal difference) or 6.8% (win probability), relative to the baseline averages. The conclusions based on these measures of match outcomes are mirrored by our findings on referee statistics. Although our estimates show that implementing VAR led to decreases in overall yellow cards and offsides, we do not find evidence of changes in the home-away difference in fouls, yellow cards, red cards, offsides, or penalty kicks. Overall, these results indicate that correcting for blatantly incorrect decisions does not affect home field advantage in soccer.

By examining the effect of VAR on home field advantage, we are able to speak to the effect of reviewing obvious errors on match outcomes. In so doing, our findings illustrate that obvious errors are not the primary channel through which referee bias contributes to home field advantage. Future research can build off our analysis in two key ways. First, we are unable to fully isolate the mechanism through which referee bias impacts match outcomes. Determining if referee bias impacts matches primarily through marginally incorrect major decisions or an accumulation of small biased decisions over the course of a match deserves the attention of future work. Second, the context of VAR and soccer are helpful for identification (e.g., staggered rollout), but the public attention that referees face could impact the way through which bias enters decision-making and could limit cases of overt bias. Our results, however, call for future work in other contexts of arbiter bias, such as the legal system, to examine the mechanisms through which bias enters decisions and whether current review processes mitigate bias and promote fairness.

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7 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 et al. (2022), J.League (2020), Meneguite et al. (2022), Business (2019), and Conroy & 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 planned to implement 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. Other competitions that adopted VAR recently, but were not used in the analysis include the following: Copa Libertadores and Sudamericana (2017), Champions League (2018/19 season), Europa League (2019/20 season), World Cup (2018), Copa America (2019) and UEFA Euro (2021).

Table 2: Summary Statistics

Panel 1: Averages at the Match Level	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: Averages at the Team-by-Season Level			
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 countries 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 countries detailed here. Standard deviations in parentheses.

Table 3: Home Field Advantage - Goal Difference

	(1) G_{H-A}	(2) G_{H-A}	(3) G_{H-A}	(4) G_{H-A}
Constant	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
Country 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 country fixed effects. The third column includes various controls for team quality. The last column includes both season and country fixed effects as well as various controls for team quality. Columns 3 and 4 have slightly smaller sample sizes because the earliest season in each country is dropped due to missing data from the previous season. Standard errors in brackets are clustered at the country level. Wild bootstrap confidence intervals are shown in parentheses. Results from the same specification with robust standard errors are presented in Table B.1 and are qualitatively similar. Significance: *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$.

Table 4: Home Field Advantage - Game Outcomes

	(1) Win	(2) Win	(3) Draw	(4) Draw
Constant	0.459***	0.459***	0.251***	0.250***
	[0.006]	[0.002]	[0.004]	[0.002]
VAR	-0.001	-0.002	-0.003	0.008
	[0.011]	[0.014]	[0.012]	[0.015]
		(-0.031,0.036)		(-0.026,0.049)
Season FE	No	Yes	No	Yes
League FE	No	Yes	No	Yes
Observations	35,183	35,183	35,183	35,183
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 to 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 fixed effects, 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 country level. Wild bootstrap confidence intervals are shown in parentheses.
Significance: *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$.

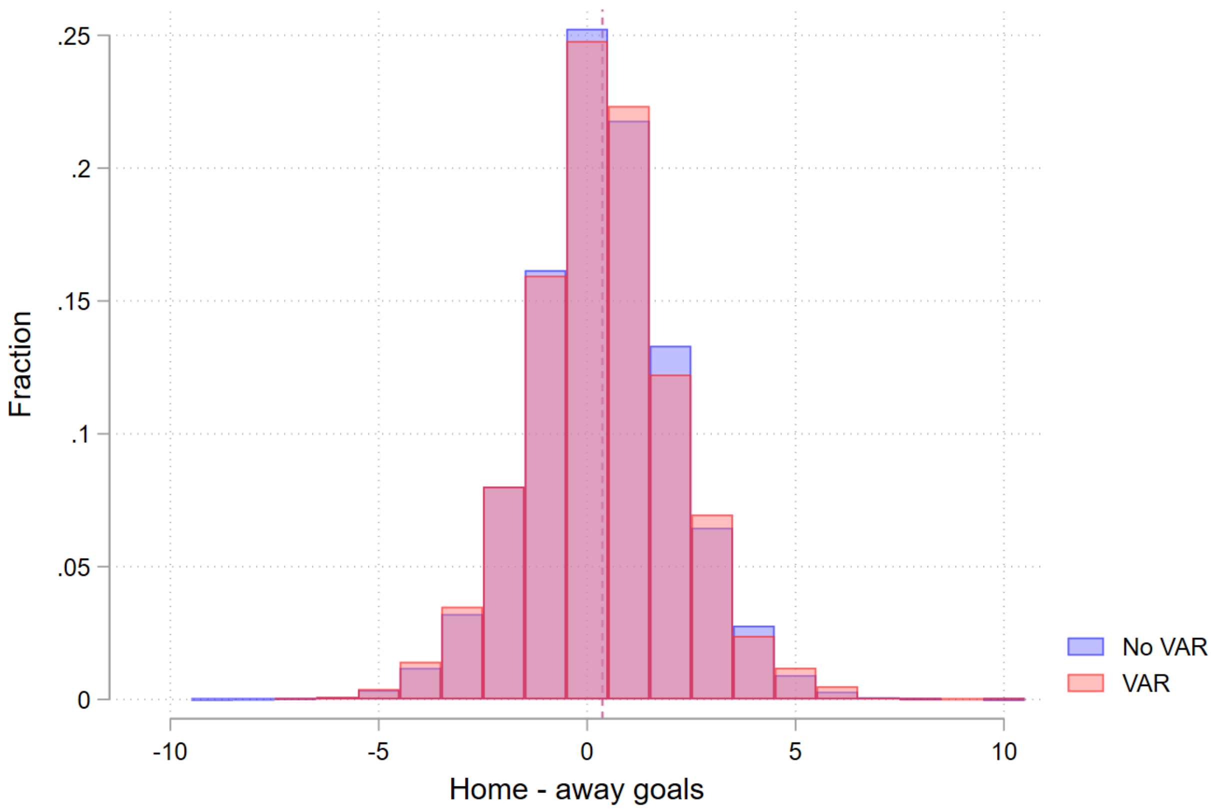
Table 5: Other Outcomes

Panel 1: Home-Away Diff	(1) Fouls	(2) Yellow Cards	(3) Red Cards	(4) Offsides	(5) Penalty Kicks
Constant	-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
Constant	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
Country 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 to 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 country 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 country level. Significance: *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$.

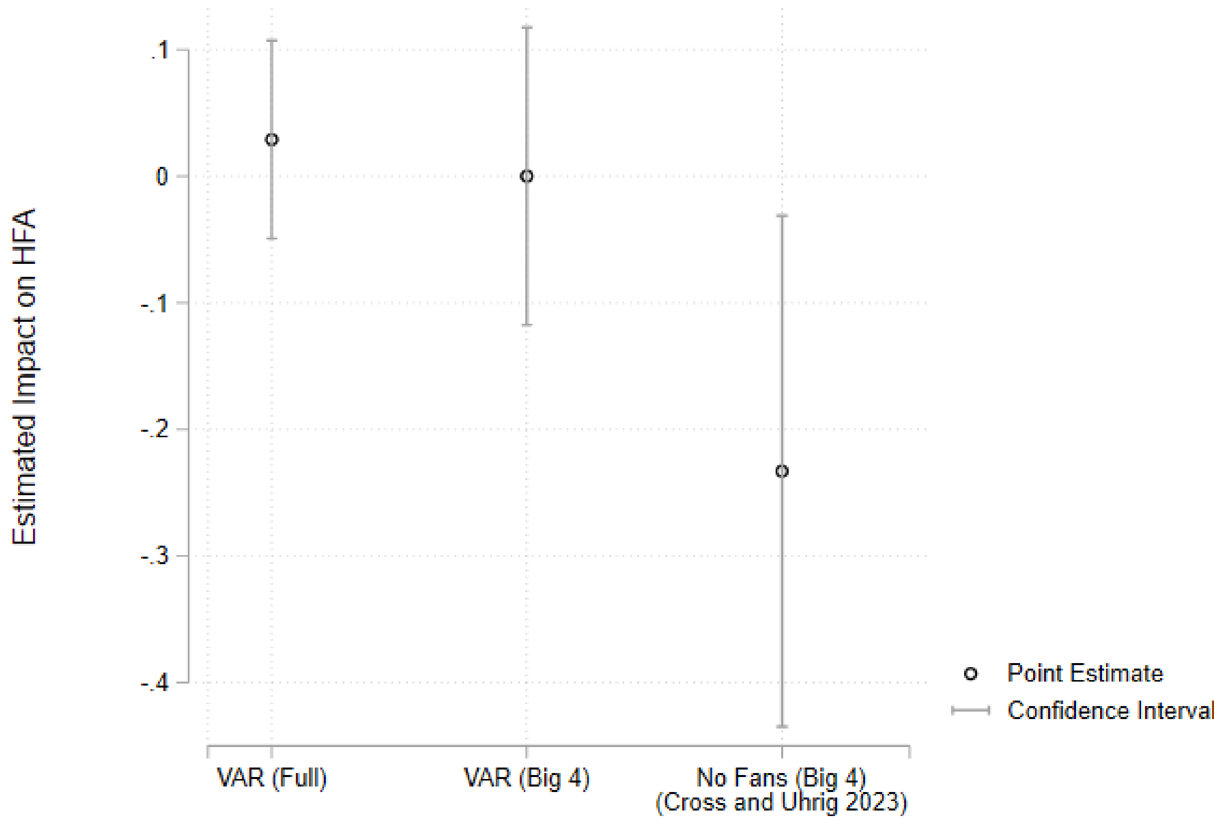
8 Figures

Figure 1: Home Field Advantage - Goal Difference Histogram



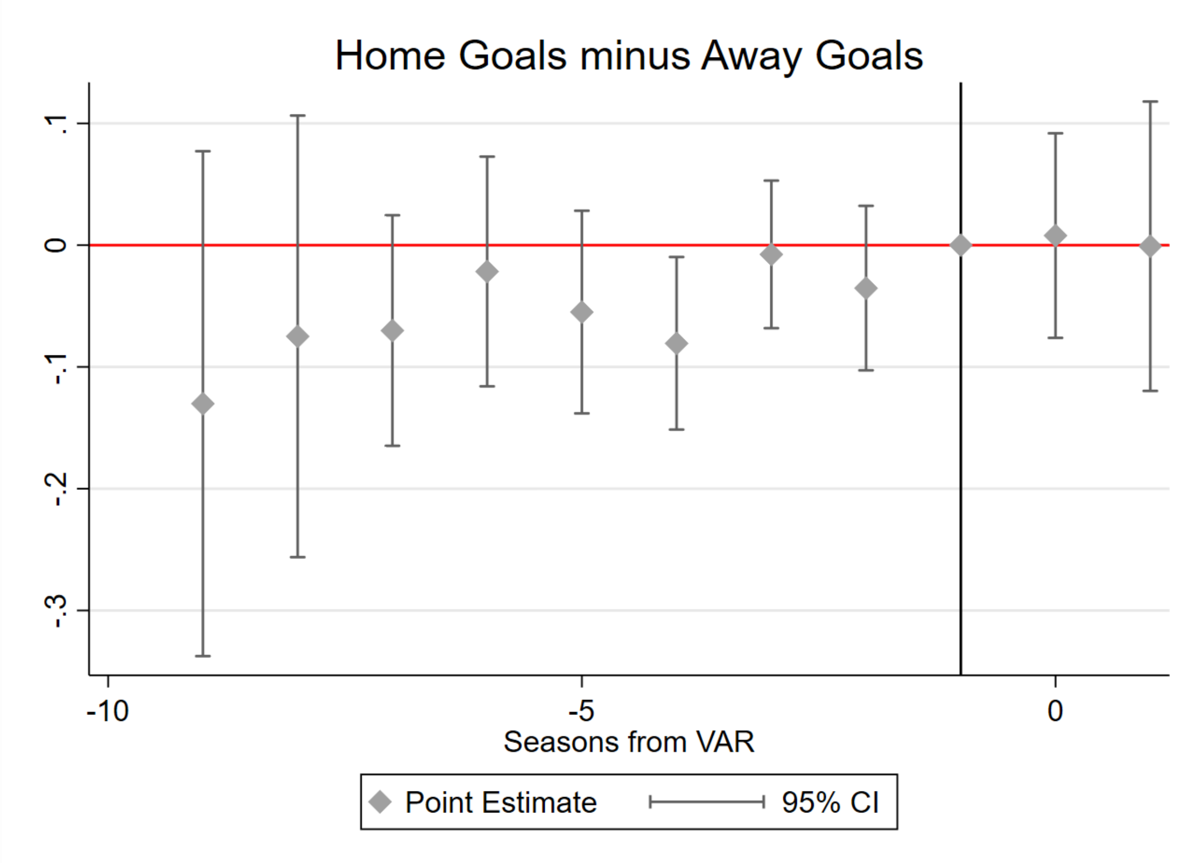
Notes: This figures shows the distribution of goal differences (home goals minus away goals) with and without Video Assistant Referees. The Kolmogorov-Smirnov test statistic is equal to 0.0063. The resulting p-value is 0.999, and we therefore fail to reject the null hypothesis that the distributions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

Figure 2: Home Field Advantage Comparison



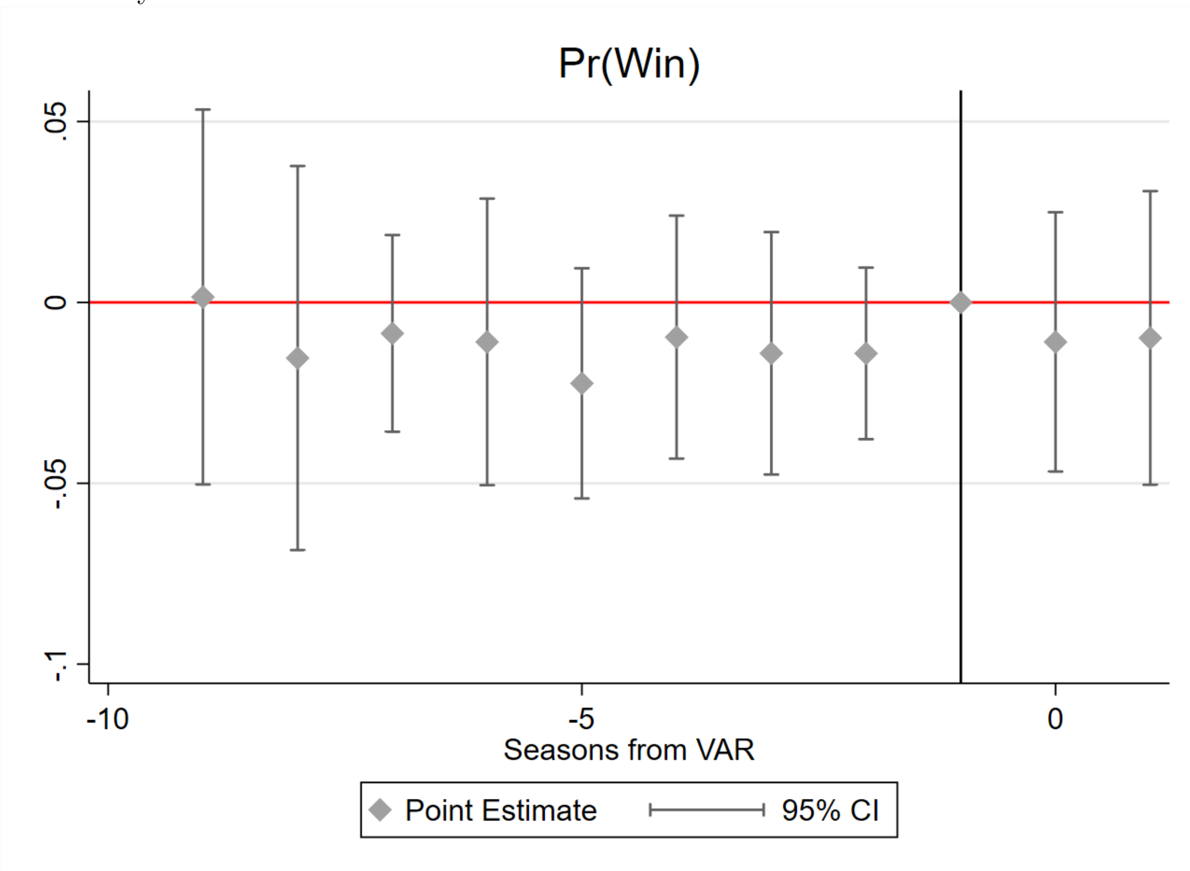
Notes: This figure compares the estimated effect of Video Assistant Referee implementation and no-fans policies adopted in 2020 to mitigate the spread of COVID-19 (Cross & Uhrig, 2023). The left coefficient and confidence interval is derived from the full-sample estimates in this paper. The middle coefficient 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 & Uhrig (2023). 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 & Uhrig (2023) and the precise null estimates in this paper highlight the lack of any effect of Video Assistant Referee implementation on home field advantage.

Figure 3: Home Field Advantage by Season Relative to VAR Implementation - Goal Difference



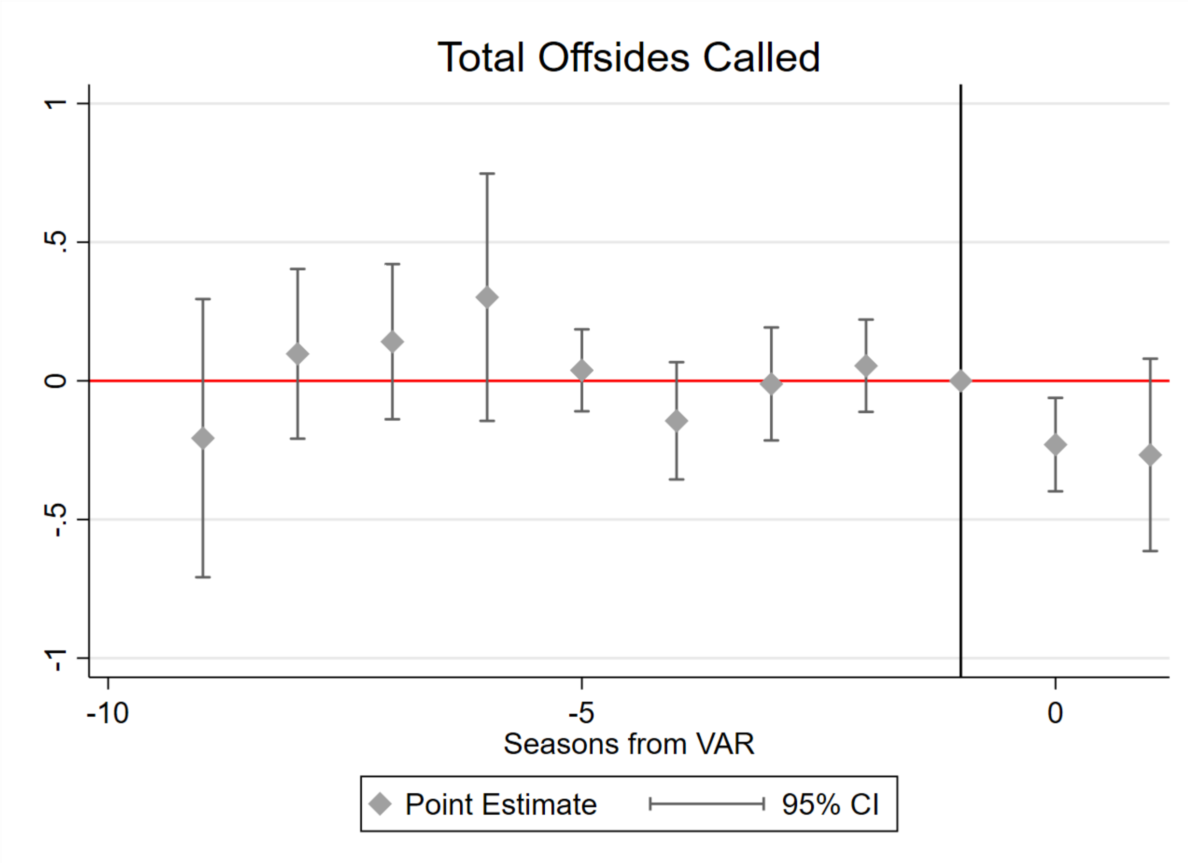
Notes: This figure shows the results of the event study specification described in Equation (2), where the outcome of interest is the home field advantage as measured by goal difference. These results suggest that home field advantage did not significantly change in response to Video Assistant Referee,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

Figure 4: Home Field Advantage by Season Relative to VAR Implementation - Home Win Probability



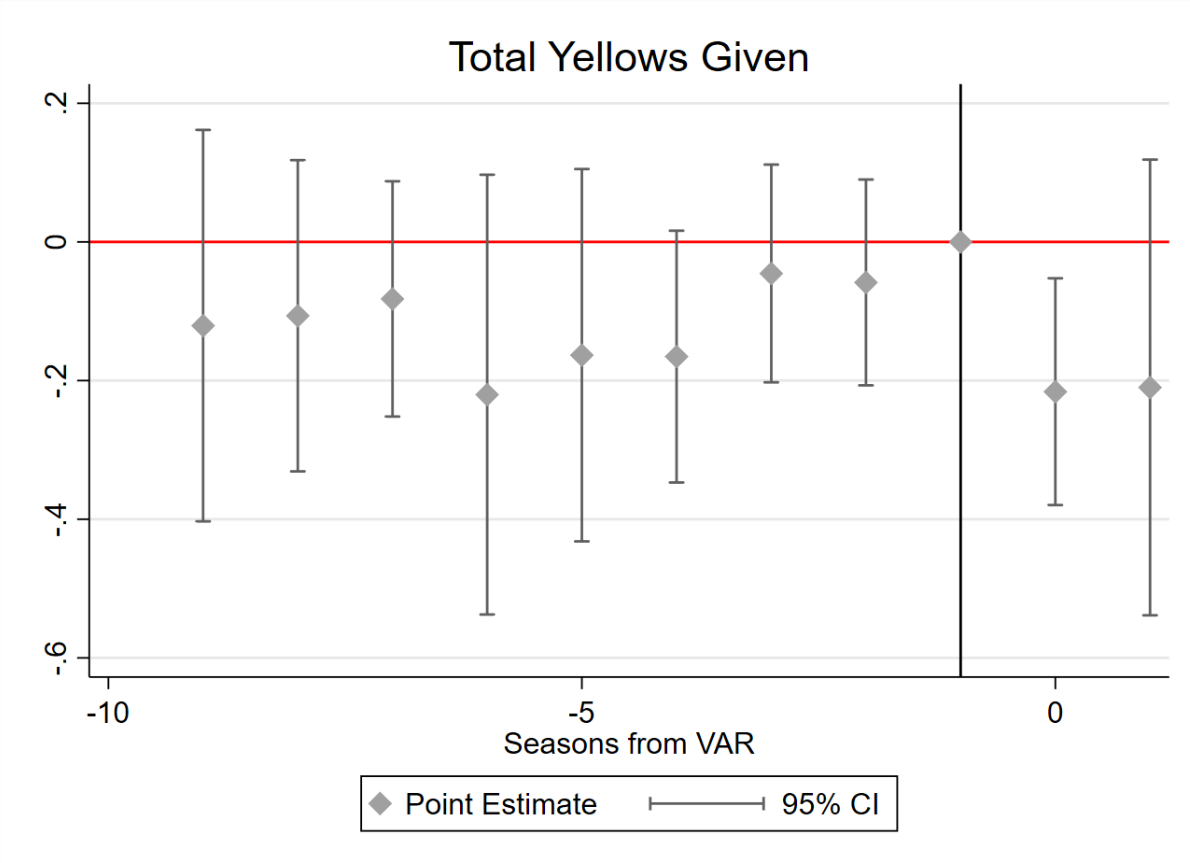
Notes: This figure shows the results of the event study specification described in Equation (2), where the outcome of interest is the home field advantage as measured by win probability for the home team. These results suggest that home field advantage did not significantly change in response to Video Assistant Referee, reaffirming the results presented in Table 4.

Figure 5: Total Offsides by Season Relative to VAR Implementation



Notes: This figure shows the results of the event study specification described in Equation (2), where the outcome of interest is the total number of offsides called by the referees. These results suggest that the total number of offsides decreased in response to Video Assistant Referee.

Figure 6: Total Yellow Cards by Season Relative to VAR Implementation



Notes: This figure shows the results of the event study specification described in Equation 2, where the outcome of interest is the total number of yellow cards. These results suggest that the total number of yellow cards given decreased in response to Video Assistant Referee.

Online Appendix for "Video Assistant Referee and home field advantage: implications for referee bias"

A Season-level Analysis

As Table 1 shows, the identifying variation we leverage occurs at the country-by-season level. Our primary results, however, utilize an approach where the unit of observation is the match level, thereby aligning with later analysis that exploits match-level variation in referees. One would expect, however, that our primary findings remain unchanged when the outcomes are averages for a given season and country.

To explore this, we estimate a specification nearly identical to Equation (1):

$$y_{ct} = \alpha + \beta Post_{ct} + \lambda_c + \delta_t + \epsilon_{ct} \tag{3}$$

where the dependent variable y_{ct} is the average of an outcome (e.g., home minus away goal difference) for a given country c and season t. In this section, we show the results for all of the outcomes evident in Tables 3, 4, and 5. $Post_{ct}$ is an indicator variable equal to 1 if country c utilizes VAR during season t and 0 otherwise, so β is the coefficient of interest representing the effect of VAR on the outcome of interest. To account for average differences by country and season, we include λ_c and δ_t, which are country and season fixed effects, respectively. The error term ϵ_{ct} is clustered at the country level to account for correlation in the treatment variable (Bertrand et al., 2004).

For all outcomes, our conclusions remain unchanged when analyzing season-level data compared to our preferred specifications, where the unit of observation is the match-level. Specifically, comparing the season-level results shown in Table A.1 to the match-level findings shown in Tables 3 and 4, we see a similar lack of evidence that implementing VAR had any effect on any of the four average measures of match results: home minus away goals per game, fraction of games won by the home team,[27] fraction of matches ending in a draw, and home

[27] At the match-level the outcome is an indicator equal to 1 if the home team won the game, but when aggregated to the season-by-country level the outcome is now the fraction of games won by the home team.

team points per game. Moreover, when we analyze the impact of VAR on referee statistics, our findings remain similarly unchanged when the unit of analysis is the country-by-season level. Table A.2 highlights that the only outcomes for which we see evidence of an effect of VAR are average yellow cards and offsides per game. These findings mirror those shown in Table 5, but with slightly less precision.

Table A.1: Home Field Advantage - Goal Difference

	(1) G_{H-A}	(2) Win	(3) Draw	(4) Points
Constant	0.360***	0.456***	0.249***	1.618***
	[0.005]	[0.002]	[0.002]	[0.004]
VAR	0.029	0.000	0.002	0.003
	[0.047]	[0.014]	[0.016]	[0.034]
Season FE	Yes	Yes	Yes	Yes
Country FE	Yes	Yes	Yes	Yes
Observations	116	116	116	116
Clusters	16	16	16	16

Notes: This table shows the change in match outcomes after the implementation of Video Assistant Referee systems. The first row shows the baseline home field advantage prior to implementation and the second row shows the change in response to VAR. Each column shows the results from our preferred specification that includes season and country fixed effects, but with different outcomes. The outcome in the first column is the average home minus away goal difference. The outcome in the second column is the fraction of games won by the home team. The outcome in the third column is the fraction of games that end in a draw. The outcome in the last column is the average number of points that the home team earns in a match. Standard errors in brackets are clustered at the country level. Significance: *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$.

Table A.2: Other Outcomes

Panel 1: Home-Away Diff	(1) Fouls	(2) Yellow Cards	(3) Red Cards	(4) Offsides	(5) Penalty Kicks
Constant	-0.460***	-0.291***	-0.033***	0.218***	0.062***
	[0.019]	[0.008]	[0.002]	[0.009]	[0.003]
VAR	-0.040	-0.068	-0.016	-0.086	0.024
	[0.134]	[0.054]	[0.014]	[0.060]	[0.020]
Panel 2: Match Total	**Fouls**	**Yellow Cards**	**Red Cards**	**Offsides**	**Penalty Kicks**
Constant	14.147***	2.041***	0.123***	2.249***	0.143***
	[0.045]	[0.011]	[0.002]	[0.016]	[0.001]
VAR	-0.405	-0.175*	0.016	-0.240*	0.013
	[0.317]	[0.078]	[0.012]	[0.115]	[0.009]
Season FE	Yes	Yes	Yes	Yes	Yes
Country FE	Yes	Yes	Yes	Yes	Yes
Observations	70	70	70	70	70
Clusters	9	9	9	9	9

Notes: This table shows the change in various match statistics after the implementation of Video Assistant Referee systems. The first panel shows the results when the outcomes are average differences between the home and away team, while the second panel shows results where the outcomes are average match totals. The first row of each panel shows the baseline value prior to 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 country fixed effects. These data are at the country-by-season level. Standard errors in brackets are clustered at the country level.
Significance: *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$.

B Additional Tables and Figures

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

	(1) G_{H-A}	(2) G_{H-A}	(3) G_{H-A}	(4) G_{H-A}
Constant	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
Country 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 to 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 country fixed effects. The third column includes various controls for team quality. The last column includes both season and country 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 B.2: Home Field Advantage - Alternative Specifications

	(1) G_{H-A}	(2) G_{H-A}	(3) G_{H-A}	(4) G_{H-A}	(5) G_{H-A}
Constant	0.371***	0.360***	0.359***	0.362***	0.357***
	[0.005]	[0.007]	[0.008]	[0.008]	[0.009]
VAR	0.031	0.011	0.018	0.013	0.017
	[0.041]	[0.048]	[0.055]	[0.046]	[0.053]
Season FE	Yes	Yes	Yes	Yes	Yes
League FE	Yes	Yes	Yes	Yes	Yes
Referee FE	No	Yes	Yes	Yes	Yes
Home Team FE	No	No	Yes	Yes	No
Home*Away Team FE	No	No	No	No	Yes
Team Quality Controls	No	No	No	Yes	Yes
Observations	35,183	27,359	27,359	24,667	22,255
Clusters	16	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 to implementation and the second row shows the change in response to VAR. Each column shows a separate specification. The first column has season and country fixed effects, replicating Column 2 of Table 3. The second column includes season, country, and referee fixed effects. The third column includes season, country, referee, and home team fixed effects. The fourth column includes all of the fixed effects from Column 3 as well as various controls for team quality. Specifically, we control for team form through a vector of controls that include the point difference in the most recent four games, point difference in the full season to date, and the previous season point difference. Lastly, Column 5 is identical to Column 4 except with home-by-away team fixed effects instead of home team fixed effects. Standard errors in brackets are clustered at the country level. Significance: *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$.

Table B.3: Game Outcomes - Alternative Specifications

	(1) Win	(2) Win	(3) Win	(4) Win	(5) Win
Constant	0.459***	0.456***	0.456***	0.457***	0.457***
	[0.002]	[0.002]	[0.003]	[0.003]	[0.003]
VAR	-0.002	-0.009	-0.008	-0.010	-0.012
	[0.014]	[0.015]	[0.019]	[0.017]	[0.020]
Season FE	Yes	Yes	Yes	Yes	Yes
League FE	Yes	Yes	Yes	Yes	Yes
Referee FE	No	Yes	Yes	Yes	Yes
Home Team FE	No	No	Yes	Yes	No
Home*Away Team FE	No	No	No	No	Yes
Team Quality Controls	No	No	No	Yes	Yes
Observations	35,183	27,359	27,359	24,667	22,255
Clusters	16	16	16	16	16

Notes: This table shows the change in the probability that the home team wins the match after the implementation of Video Assistant Referee systems. The first row shows the home field advantage prior to implementation and the second row shows the change in response to VAR. Each column shows a separate specification. The first column has season and country fixed effects, replicating Column 2 of Table 4. The second column includes season, country, and referee fixed effects. The third column includes season, country, referee, and home team fixed effects. The fourth column includes all of the fixed effects from Column 3 as well as various controls for team quality. Specifically, we control for team form through a vector of controls that include the point difference in the most recent four games, point difference in the full season to date, and the previous season point difference. Lastly, Column 5 is identical to Column 4, except with home-by-away team fixed effects instead of home team fixed effects. Standard errors in brackets are clustered at the country level. Significance: *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$.

Table B.4: Home Field Advantage - Referee Experience

	(1) G_{H-A}	(2) G_{H-A}	(3) G_{H-A}
Constant	0.371***	0.318***	0.375***
	[0.005]	[0.038]	[0.005]
VAR	0.031	0.138	0.028
	[0.041]	[0.170]	[0.046]
Season FE	Yes	Yes	Yes
League FE	Yes	Yes	Yes
Observations	35,183	3,923	31,260
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 country fixed effects as well as various controls for team quality. Standard errors in brackets are clustered at the country level. Significance: *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$.

Table B.5: Home Field Advantage - Schedule Differences

	(1) G_{H-A}	(2) G_{H-A}	(3) G_{H-A}	(4) G_{H-A}
Constant	0.371***	0.372***	0.372***	0.374***
	[0.005]	[0.005]	[0.004]	[0.005]
VAR	0.031	0.022	0.024	0.040
	[0.041]	[0.042]	[0.039]	[0.045]
Season FE	Yes	Yes	Yes	Yes
League FE	Yes	Yes	Yes	Yes
Observations	35,183	35,183	35,183	31,067
Clusters	16	16	16	14

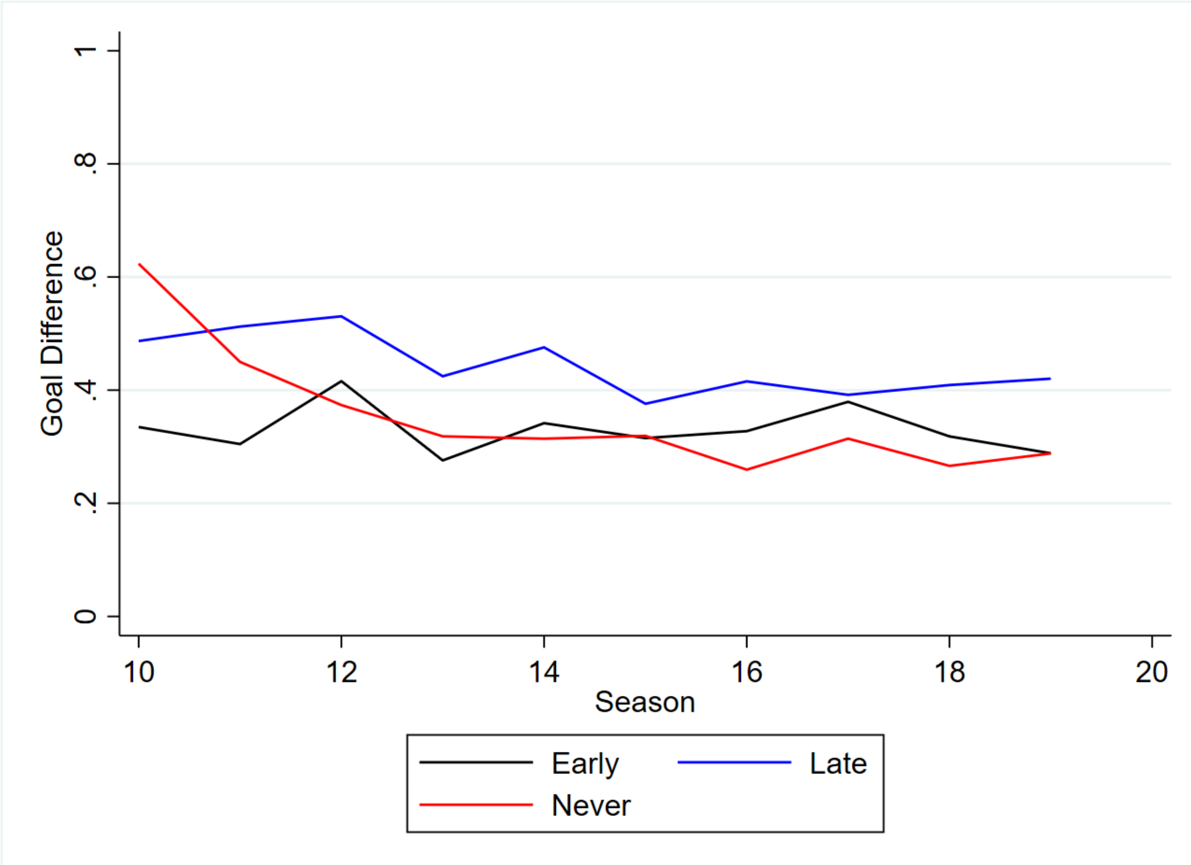
Notes: This table shows the results from various specifications checking the robustness given differences in schedule type across countries. Column 1 shows the results of the primary specification. Column 2 shows the results from the specification in which inverted seasons are included with the previous 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 countries that use an inverted schedule. Results are similar to those in Table 3. Significance: *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$.

Table B.6: Home Field Advantage - By Treatment Cohort

	(1) G_{H-A}	(2) G_{H-A}	(3) G_{H-A}
Constant	0.371***	0.380***	0.394***
	[0.005]	[0.003]	[0.004]
VAR	0.031	0.054	0.034
	[0.041]	[0.064]	[0.064]
Team Quality Controls	No	No	No
Season FE	Yes	Yes	Yes
Country FE	Yes	Yes	Yes
Observations	35,183	27,148	20,907

Notes: This table shows the results estimated by treatment cohort. 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 countries, thus only comparing those countries that become treated in 2017-2018 to untreated countries. Column 3 shows the results of the primary specification for the full sample of years but excluding those countries that implement VAR in the 2017-2018 season (and countries that follow an inverted schedule). This restriction means that no countries are already treated in this specification; the 2018-2019 treatment cohort is only compared to countries 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 B.1: Home Field Advantage by Season - Adoption Timing



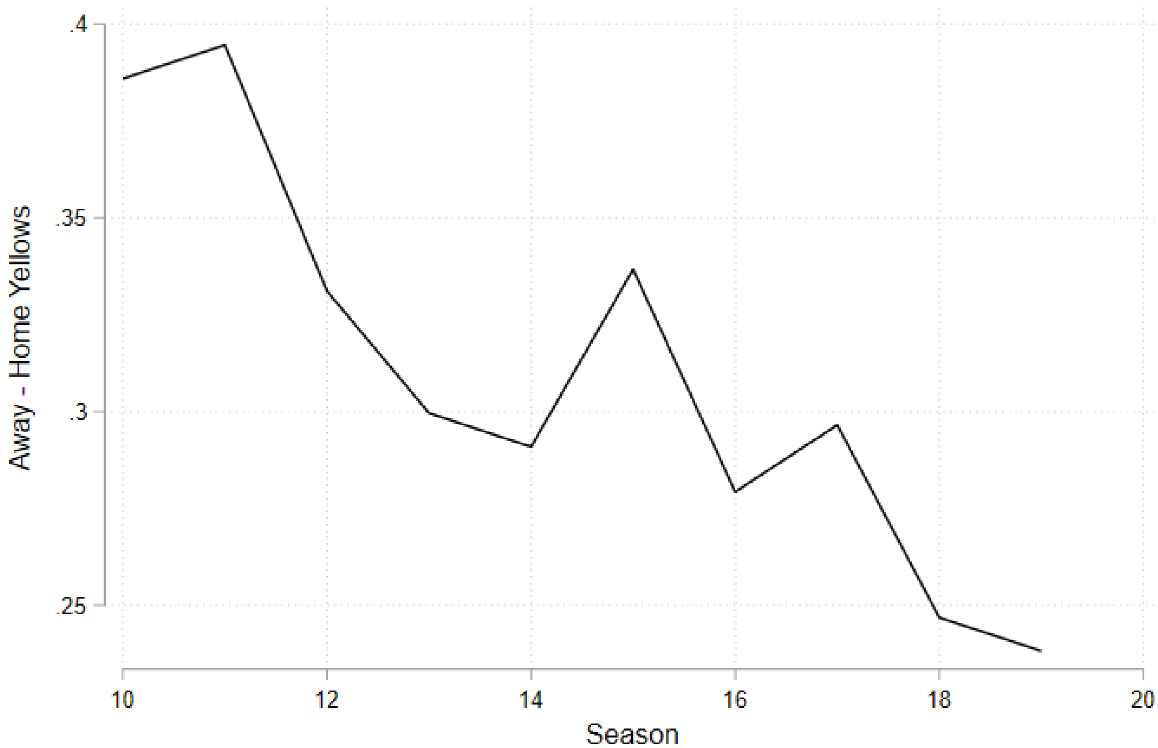
Notes: This figure shows the home field advantage, as measured by goal difference, over the sample time period by groups organized by adoption of Video Assistant Referee.

Early Adopters: Italy, Germany, Portugal, Australia

Late Adopters: France, Spain, Netherlands, Turkey

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

Figure B.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 parallel trends assumption that those differences would have remained unchanged in the absence of VAR.