

Kim, Chang Hyun; Lee, Kyung Yul; Kwon, Young Sun

**Conference Paper**

## Does the Video Assistant Referee (VAR) technology mitigate referee bias in professional football leagues?

31st European Conference of the International Telecommunications Society (ITS): "Reining in Digital Platforms? Challenging monopolies, promoting competition and developing regulatory regimes", Gothenburg, Sweden, 20th - 21st June 2022

**Provided in Cooperation with:**

International Telecommunications Society (ITS)

*Suggested Citation:* Kim, Chang Hyun; Lee, Kyung Yul; Kwon, Young Sun (2022) : Does the Video Assistant Referee (VAR) technology mitigate referee bias in professional football leagues?, 31st European Conference of the International Telecommunications Society (ITS): "Reining in Digital Platforms? Challenging monopolies, promoting competition and developing regulatory regimes", Gothenburg, Sweden, 20th - 21st June 2022, International Telecommunications Society (ITS), Calgary

This Version is available at:

<https://hdl.handle.net/10419/265643>

**Standard-Nutzungsbedingungen:**

Die Dokumente auf EconStor dürfen zu eigenen wissenschaftlichen Zwecken und zum Privatgebrauch gespeichert und kopiert werden.

Sie dürfen die Dokumente nicht für öffentliche oder kommerzielle Zwecke vervielfältigen, öffentlich ausstellen, öffentlich zugänglich machen, vertreiben oder anderweitig nutzen.

Sofern die Verfasser die Dokumente unter Open-Content-Lizenzen (insbesondere CC-Lizenzen) zur Verfügung gestellt haben sollten, gelten abweichend von diesen Nutzungsbedingungen die in der dort genannten Lizenz gewährten Nutzungsrechte.

**Terms of use:**

*Documents in EconStor may be saved and copied for your personal and scholarly purposes.*

*You are not to copy documents for public or commercial purposes, to exhibit the documents publicly, to make them publicly available on the internet, or to distribute or otherwise use the documents in public.*

*If the documents have been made available under an Open Content Licence (especially Creative Commons Licences), you may exercise further usage rights as specified in the indicated licence.*

# **Does the Video Assistant Referee (VAR) technology mitigate referee bias in professional football leagues?**

**Chang Hyun Kim, Kyung Yul Lee, Young Sun Kwon**

## **Abstract**

Evidence for home advantage is clear in sports including professional football. Among the factors that lead to home advantage is referee bias where referees make biased decisions in favor of the home sides. In order to minimize any bias or unrighteousness caused by referee bias, the Video Assistant Referee (VAR) was introduced to the world of professional football and is now widely adopted in domestic leagues across the world. However, it was not until 2018 when professional football leagues started to implement the VAR with the Australian A-League being one of the first football leagues to adopt the technology. This study compares the effects of the VAR technology on home advantage using difference-in-difference model and synthetic control method with eight professional football leagues constructing the treatment group and other 45 leagues constructing the control group. With home advantage measured with the number of goal counts, it is found that the adoption of the VAR technology significantly increases the average number of away team goals while the average number of home team goals remains unchanged. These findings may help better understand the effects of the VAR on home advantage, and the fact that econometrics models were applied to understand its effects carries importance as well.

## **INTRODUCTION**

There has been much controversy over the accuracy and righteousness of judgments made by referees in professional sports matches. In most team sports such as football, baseball, American football, rugby, basketball and ice hockey, the presence of home advantage is easily observed (Courneya & Carron, 1992; Nevill & Holder, 1999). Referee bias, which is known to contribute to home advantage (Boyko, Boyko & Boyko, 2007), is therefore subject to investigation as it has an intimate relationship with home advantage. With home teams being favored in football matches, referees are often blamed for the alleged benefits that the home team receives. These benefits may include referees penalizing the away side more harshly by issuing more disciplinary cards or calling more fouls. Such subjective and biased officiating may come from various external and internal factors. For example, in a study on match data from the 2009/10 and 2010/11 seasons of the Union of European Football

Associations (UEFA) Champions League and Europa League, crowd density was found to be a critical factor influencing referees' decision-making process (Goumas, 2014). Referee bias and explicit home advantage have negative influences not only on in-match factors but also on external factors such as crowd attendance, as such referee bias is known to contribute to low fan attendance (Bashiru & Opoku, 2017).

At the same time, referees frequently encounter situations that include a number of players moving rapidly with limited visibility, which makes it difficult to make accurate judgments (Lex et al., 2015). Not only restricted visibility, which makes it challenging to make fair decisions for referees, but also other factors such as the flash-lag effect and the difficulty of perceiving an object's position when there is something else happening simultaneously can interrupt referees' judgment (Helsen et al., 2007). Players' vocalization may also have unfavorable effects on referees' decision-making process (Lex et al., 2015). With all these factors interfering with referees' officiating, there has always been an urgent need for some way of assisting their decision-making process to resolve referee bias. This is where the Video Assistant Referee (VAR) has emerged as a solution to the long-held dispute over referees' subjective officiating.

The VAR was in fact not the first technology to be implemented in professional football matches. Goal-line technology, which detects whether the ball has completely crossed the goal line or not, was one of the successful cases of technology use in football. With the role of technology in professional football becoming more significant, Australia's A-League has become the first league to implement the VAR system in their domestic league. The VAR made its official international debut in the 2018 FIFA World Cup, and the Fédération Internationale de Football Association (FIFA) officially approved the use of the VAR in all matches. It has since been introduced in multiple professional football leagues,

including the English Premier League (EPL), the German Bundesliga, Spanish La Liga, Italian Serie A, French Ligue 1 etc. The technology is now being used in many top division football leagues around the world. With the VAR fulfilling its main objectives of assisting referees with decision-making, the predictive odds of making correct decisions were found to be significantly higher with the use of VAR compared to without VAR, with accuracy increasing from 92.1% to 98.3% (Spitz et al., 2020). Nevertheless, according to Kolbinger and Knopp's (2020) evaluative study on English Premier League fans' tweets in reaction to VAR, the overall sentiment on the technology does not appear to be positive. One of the most frequently criticized aspects of the VAR system is that it interrupts the flow of the game, negatively affecting the smoothness of the game to some extent. Furthermore, in the 2018 FIFA World Cup, it was claimed that the VAR was employed in favor of European countries, being biased against other countries.

With such various opinions and controversies regarding the VAR system as well as the consequences it has brought about in the world of football, there have been quite a few studies on its effects on referee bias in domestic leagues worldwide. In addition, as more and more top as well as lower divisions of football leagues are introducing VAR technology to their matches, there is an increasing need for accurate and reliable research on its influences on football matches. As more football leagues are expected to use the system, the importance of understanding the effects of VAR on professional football matches are becoming more significant.

This study therefore investigates the effects of the VAR technology on home advantage. The following variables are included in the analysis to represent home advantage and referee bias: *average number of goals scored by the away side* and *average number of goals scored by the home side*. We apply econometrics quasi-experimental approaches, the

difference-in-differences method and synthetic control method, to analyze the effects of VAR. We demonstrate that, with the implementation of VAR system, the average number of goals scored by the away side increase at a significant level while there is no the average number of goals scored by the home side remains unchanged even after the implementation of the VAR.

## **LITERATURE REVIEW**

### **Referee bias and home advantage in football**

Home advantage is a term often found in sports where home teams are arguably more favored than away teams, thereby having higher chances of winning. With home advantage being one of the most controversial topics in the world of sports, there have been many precedent studies on home advantage. In a study carried out by M.B.Jones (2017), presence of home advantage was analyzed in various sports including football (English Premier League), basketball(National Basketball Association), American football(National Football League) and hockey(National Hockey League) mostly using data from North American leagues. In football, using penalty kicks , injury time (additional time) and goals as measurements of home advantage with the German Bundesliga data, it was observed home teams benefitted more than away teams (Dohmen, 2008). Dawson and Dobson (2010) used disciplinary cards – yellow and red cards – to confirm the existence of home advantage in European Cup matches over five seasons. Almeida and Volossovitch (2017) revealed that some extent of home advantage is present in the Portuguese football leagues, but its significance decreases from amateur to semi-professional level leagues. In addition to these leagues, effects of home advantage have been found to be evident across competitions including the Gaelic League and the Greek league (Rooney & Kennedy, 2018; Armatas et al., 2013).

Since home advantage is mostly coming from differences in goal counts, disciplinary

card counts and so on, referee bias is considered to be one of the factors leading to home advantage (Boyko, 2007). Various attempts have been made in order to understand what really cause referees to make biased decisions in football matches including psychological factors such as hormone differences of players in home and away games (Neave and Wolfson, 2003). One of the most common factors that influences referees' decision-making process is social pressure, which is often measured using crowd factors such as crowd size, crowd noise and crowd density. In one lab experiment where 40 qualified referees participated, significantly fewer fouls (15.5%) were called with the presence of crowd noise in the background, proving that influence of crowd noise on referee bias in favor of the home side is valid (Nevill et al., 2002). However, crowd size effects, in a study on the FA cup matches from 1996-2002 seasons, were found to be negligible (Downward & Jones, 2007), while crowd density was found to be a critical factor that influences referees' decision-making process in favor of the home side (Goumas, 2012).

Due to the recent outbreak of COVID-19, professional football matches worldwide were played behind closed doors, meaning the matches were played without spectators in the stadium to watch. Most of the major football leagues such as the English Premier League, the German Bundesliga had their matches played behind closed doors, being subject to further studies on crowd effects on referee bias. In one study on German football divisions, home advantage and referee bias effects were observed to be significantly reduced in the first division but not in lower divisions behind closed doors (Fischer and Haucap, 2020). Diminished degree of home advantage was also found across 15 leagues in 11 countries with fewer points and fewer goals for the home side (McCarrick et al., 2020). Focusing on matches with weak support for the away team, Endrich and Gesche (2020) also found that, using Germany's top two football divisions, the home teams were less favorably treated with

no crowd compared to when the crowds were allowed in the stadium.

### **Video Assistant Referee (VAR)**

As the VAR was introduced to the world of football only relatively recently, its effects and validity have not been thoroughly studied. Some previous studies examine its effects and how the technology has modified professional football matches in some aspects. Hence, several papers regarding the influences of VAR on professional football matches parameters will be reviewed in depth.

One of the first studies on the influence of VAR on in-game variables was conducted on the Italian Serie A and the German Bundesliga, which were two of the earliest leagues to implement the VAR system. The VAR was found to modify the matches by significantly decreasing the number of fouls, offsides, and yellow cards, and by significantly increasing the playing time in the first half and the total playing time with no significant change in the second half (Lago-Penas, 2019). A study on the Spanish La Liga, where the VAR has been in use since the 2018/19 season, analyzed 760 matches (380 without VAR and 380 with VAR) during the 2017/18 and 2018/19 seasons. In other words, matches immediately before and after the implementation of VAR were compared. The variables included fouls, goals, offsides, penalties, playing time, red cards and yellow cards in the first and the second half of the match, as well as in the full match. It was revealed that the number of offsides in the second half and in the full match was reduced significantly with the VAR, and the time duration in the first half, second half and the full match demonstrated significant increases in the 2018/19 season after the implementation of the VAR (Lago-Penas, Gomez & Pollard, 2020).

Another study on the Spanish La Liga implemented a different approach to understanding the effects of the VAR on playing time, technical-tactical and physical

performance in the professional football league. The study used 375 of 380 matches played during the 2018/19 season, which were divided into three categories depending on the number of times the VAR intervened during the match: none (VAR0,  $n = 273$ ), one (VAR1,  $n = 86$ ), and two or three (VAR2,  $n = 16$ ) (Errekagorri et al., 2020). For each of these categories, the influence of the VAR on i) playing time variables (total and effective playing time), ii) technical-tactical performance variables (passes, dribbles, crosses, shots, goals, corners, fouls, width, defense), and iii) physical performance variables (total distance covered and total distance covered above 21km/h) were examined. The results revealed that the total playing time slightly increased with increasing number of the VAR interventions. The effective playing was longer when the VAR was not involved. The VAR's influence on technical-tactical variables was found to be non-existent except for the goals where the trend was found to be as following at a significant level:  $VAR0 < VAR1 = VAR2$ . For the physical performance variable, total distance covered decreased with more the VAR interventions. However, the total distance covered above 21km/h showed no significant change (Errekagorri et al., 2020).

Han et al. (2020) examined the influence of the VAR on the Chinese Super League (CSL) using data from 480 matches (240 with the VAR and 240 without the VAR) in 2017 and 2018, as the VAR was introduced in the CSL in 2018. It was revealed that there was a significant decrease in the number of fouls and offsides in the 2018 season after the implementation of the VAR, while the number of minutes added to the playing time in the first and the second half as well as in the full time showed a significant increase in the CSL. Fewer number of offsides was also observed, while the total playing time, playing time in the first and the second half significantly increased with the VAR. In the same study, home teams showed a significantly higher number of goals and penalties and a lower frequency of

disciplinary cards and fouls before the adoption of the VAR in the Chinese Super League. However, after the implementation of VAR in 2018, the number of red and yellow cards increased for the home side, while they decreased for the away side, reducing the extent of home advantage to some degree. At the same time, the number of goals and penalties increased after the introduction of VAR in the CSL, while that of offside decreased (Han et al., 2020).

The FIFA 2018 World Cup is one of the major international tournaments that implemented the VAR in its early days. In one study comparing the FIFA 2014 World Cup (before VAR) and FIFA 2018 World Cup, it was discovered that the number of penalties as well as total playing time increased at a significant level, while there was a significant increase in the number of offsides (Kubayi et al, 2020).

These aforementioned studies have successfully shown how the introduction of new video technology has modified professional football in terms of in-match statistics such as goals, fouls, disciplinary cards, offsides etc.

## **THEORY AND HYPOTHESIS**

Home advantage was found to be present in various team sports, and professional football is one of them (Courneya & Carron, 1992; Nevill & Holder, 1999). Its presence has been verified across multiple professional football leagues and tournaments such as the UEFA Champions League and Europa League (Goumas, 2012), World Cup qualifications (Pollard & Armatas, 2017), English Premier League (Allen & Jones, 2012), English Premiership (Boyko & Boyko, 2007), Turkish Super League (Seckin & Pollard, 2008), Australian A-League (Goumas, 2013), France Ligue 1, German Bundesliga, Italian Serie A, Eredivisie and so on (Leita, 2017).

Even though precise causes of home advantage and how they influence home advantage are not clearly established, various factors have been suggested as possible causes of home advantage in football. One of the most widely understood factors is crowd effects. Football fans themselves believe they make important contributions to home advantage by showing their support the home team and distracting the away team (Wolfson et al., 2007). However, the relationship between crowd size and home advantage was not found to be significant (Boyko & Boyko & Boyko, 2007), while crowd noise significantly and dramatically influences referees' decision-making (Nevill et al., 2002) as well as crowd density (Inan, 2020). Along with crowd effects, a travel effect is one of the possible factors affecting home advantage, but there was little evidence of a significant relationship between distance traveled and home advantage (Goumas, 2014). In addition, geographical variations of extent of home advantage reveal that territoriality is one of the contributing factors to home advantage (Neave and Wolfson, 2003). One very obvious cause of home advantage is referee bias, and there have been many studies to confirm their association. Home advantage is usually measured with home team win rates, home team goal counts, home team points earned etc., and these are eventually influenced by referees' decisions. One of the factors found to have influences on referee bias is crowd support (Nevill et al., 2002), where referees' tendency to make decisions in favor of the home side increased with crowd noise. Referee bias in football, whereby referees make decisions in favor of the home team in sports, may vary depending on crowd support, referees themselves and referees' experience (O'Brien & Mangan, 2021).

However, there are limitations as to controlling referees' decision-making process since contributing factors to referee bias are not very clear and obvious. There could always be unexpected and unseen factors that may lead to referee bias in football, and unconscious

referee bias could essentially be considered as human errors. This is where the Video Assistant Referee comes in to exert influences on referees' decision-making process by aiding them with technology, which is rather considered fair and reliable when employed well. The main purpose of using this video technology is to reduce referees making random or deliberate errors, and such an improvement in referees' officiating will contribute to lessen effects of home advantage. In other words, home advantage in total will decrease while away team's disadvantage will decrease. Such mitigation of home advantage or away disadvantage could result in various outcomes such as changes in the number of goals, fouls, disciplinary cards and so on. Since it is the number of goals that determine the result of a match in the end, and under the assumption that other in-game factors eventually influence the number of goals scored, this study focuses on the goal count to understand the VAR effect.

Therefore, it is predicted that the introduction of VAR in professional football matches will reduce home advantage, leading to an increase in the number of goals for the away side, while there will not be a significant change in the number of goals for the home side. The reasoning behind this hypothesis is, even though the VAR technology may contribute to decreasing the degree of away disadvantage by eliminating random errors in referees' decisions, it cannot fully exclude other uncontrollable factors such as crowd effects, territoriality and home team familiarity, meaning the home team goal will not decrease at a significant level in the end.

**Hypothesis:** Adoption of the VAR technology in professional football will lead to a decrease in the extent of home advantage in terms of the number of goals

## RESEARCH SETTING

### About VAR technology

#### *Match Officials*

Law 5 and Law 6 of the LOTG 2021/22 provide information and laws regarding the referee and the other match officials, respectively. There are several referees involved in a professional football including one main referee, two assistant referees, fourth official, additional assistant referees and video match officials.

The main referee is the one who runs alongside the football players on the pitch and has full authority to enforce the Laws of the Games in connection with the match (IFAB, 2021). The referee has full discretion to make decisions under the principles of the LOTG. Some of authorities of the main referee include keeping a record of the match, timekeeping, supervising the restart of the play, taking disciplinary actions against the players to be penalized and so on (IFAB, 2021). Disciplinary actions can be practiced by showing a yellow card as a caution or a red card as a direct send-off of a player. The referee is also responsible for halting or restarting the play in cases of player injuries.

In addition to the main referee, other match officials are appointed to matches including two assistant referees, fourth official, two additional assistant referees, reserve assistant referee, video assistant referee (VAR) and at least one assistant VAR (AVAR) (IFAB, 2021). Assistant referees, or often called linesmen, are mainly responsible for judging when the ball is out of play. They are located along the touch line holding a flag that is used for communicating signals. Corner kicks, throw-ins and goal kicks are some of the actions that could potentially take place when the ball has left the line. In addition to these, the assistant referees may be in charge of supervising substitutions during matches. There is one fourth official in professional football matches whose duties consist of monitoring substitutions and

checking players' equipment. The fourth official indicates who is subbed in and out as well as the additional time at the end of each half. The video assistant referee (VAR) and assistant video assistant referee (AVAR) are officials who are in charge of communicating with the main referee on the pitch and going through the replay footage of incidents in matches. They are both at work in the video operation room where they assist the main referee's decision-making by reviewing videos of certain incidents during matches. It is the VAR who is responsible for communicating with the main referee throughout the match while the AVAR's main role is to assist the VAR. The VAR and AVAR have relatively recently appeared in professional football since the rules regarding the VAR technology was first introduced in the official LOTG in 2016. The importance and principles of their roles will be further introduced in the next section.

### ***Video Assistant Referee (VAR) protocols***

To minimize the limitations of referees' decision-making processes that could be hindered by multiple factors, several technological aids have been introduced in sports (Kolbinger & Lames, 2017). Such technological devices can be categorized into three major groups: (1) those that assist referees' decision-making process, (2) those that replace decisions made by referees, and (3) those that assist referees to enforce certain rules of the sport. The VAR, with the aim of helping referees with their decision-making, falls under the first category. With an increasing presence in various domestic leagues and cup competitions, VAR technology aims to minimize errors coming from referees' subjective officiating. To fulfill its role as an assistant for referees, the VAR has its own rules and regulations set by FIFA. These are clearly stated in the Laws of the Game (LOTG), the official codified rules of football that all professional football matches must obey and follow (International Football Association Board, IFAB, 2018).

Implementation of the VAR system is authorized only if the match or competition organizer has fulfilled all the protocols of the VAR, and if FIFA or IFAB has given written permission. In football matches where the VAR is permitted and introduced, there must be a video operation room (VOR), which is usually located in the stadium, and a referee review area (RRA), which is located outside the field. In the video operation room, VAR, assistant VAR and replay operators are located to review videos of incidents and communicate with the main referee on the pitch. A referee review area, RRA, is where the main referee on the pitch can review (on-field review) the video of the event whenever needed, and it must be in a visible location outside the pitch (IFAB, 2018). On-field reviews are practiced when the main referee on the pitch needs to check the video review himself or herself.

The principles of VAR are consistently updated and new protocols have been added since its first appearance in the LOTG. The most recent VAR principles can be found in the LOTG 2021/22 which include a set of principles, practicalities and procedures of VAR which are collectively referred to as protocols. The first of all principles of VAR states that the VAR can only be used during matches only in the event of ‘clear and obvious error’ or ‘serious missed incident’ that are related to (i) goal / no goal, (ii) penalty / no penalty, (iii) direct red card (not second yellow card), and (iv) mistaken identity when referees penalize the wrong player (IFAB, 2022). Each of these events can be broken down into more specific cases. For (i), there is a VAR review if there is any foul, handball or offside that directly or indirectly leads to a goal. For (ii), whether a foul location was within the penalty line, whether the ball was out of play before the incident, and offence by defenders or goalkeeper within the penalty zone may be reviewed with the VAR for potential penalty kicks. The VAR helps with (iii) by allowing the referee to see if the foul denied an obvious goal-scoring opportunity or if it included violent and insulting gestures. For (iv), the main referee can review the situation

to see if the wrong player was penalized, but the actual offence itself cannot be reviewed or overturned unless it is related to goal, penalty, or red card events. Regarding the aforementioned four events, the main referee must always make a decision before the incident is reviewed with the VAR so that the flow of match is not interrupted.

One example of VAR use could be when a player allegedly committed a handball foul before scoring a goal. In this case, the referee may declare a goal in the first place and then review the situation with VAR. The referee is prohibited from giving ‘no decision’ and then use VAR to make the decision (IFAB, 2021). It is the main referee on the field who can initiate a VAR review. The VAR and other match officials in the video operation room can only recommend a review to the main referee (IFAB, 2021). Likewise, the final decision from the VAR review is made by the main referee, and he/she can choose to conduct an ‘on-field review’(OFR) at the referee review area that is located on the pitch. While going through an on-field review, the referee must remain ‘visible’ during the review process to ensure transparency, and players and team officials cannot surround the referee during the review as such behavior can interfere with fair VAR review process.

Procedures of VAR can be divided into four: original decision, check, review and final decision (IFAB, 2021). The main referee on the field must always make an initial decision before reviewing the situation with VAR, and making no decision regarding the situation is never permitted. The VAR and other match officials in the VOR are constantly monitoring and ‘checking’ the incidents throughout the match. If the VAR review indicates a ‘clear and obvious error’ or ‘serious missed incident’, the VAR communicates with the main referee on the pitch to inform him/her with the accurate situation. It is the main referee who eventually decides whether to continue the match or to review the incident. The referee can choose to review for a potential ‘clear and obvious error’ or ‘serious missed incident’ if the

referee missed something about the incident or if the VAR recommends a review. The referee must show a ‘TV signal’ (miming a square) to undertake an on-field review (OFR) at the referee review area where he/she can have a direct look at the screen to understand the situation better. OFRs can help referees understand the situation more accurately and closely, and they can request slow-motion or different camera angles as necessary for making the final decision. Once the review process is over, the referee comes back to the pitch and shows the ‘TV signal’ and convey the final decision (IFAB, 2021).

## **DATA & METHODOLOGY**

### **Data**

To estimate the effect of VAR adoption on referee bias in football leagues, we use data from Data Sports Group (DSG).<sup>1</sup> DSG is a sports data content and service provider for media firms, digital publishers, and sports entertainment firms. DSG provides information of 53 football leagues worldwide from 2013 to 2021, making it 415 seasonal data in total. The data includes the first, second, and third divisions of the football league as well as the women’s football league. Information about the leagues is shown in Table 1.

(Insert Table 1 about here)

---

<sup>1</sup> Sources: <https://datasportsgroup.com/>

## **Methodology**

### ***Overview***

Difference-in-differences method (DiD) and synthetic control method (SCM) are quasi-experimental research methods that are used for estimating effects of policy intervention. In causal analysis, it is important to understand what would have happened to the treated group in the absence of policy intervention which is usually referred to as ‘counterfactual’.

However, despite wide applications of these methodologies in various areas such as health care and epidemiology, their applications have been very limited in sports. Therefore, using DiD along with SCM will allow us to have more comprehensive and differentiated insights into the effects of implementation of VAR in professional football. The following subsections give a brief introduction to each methodology and how these methodologies will be applied in our study.

### ***Difference-in-differences***

The very first application of DiD estimation traces back to the 19<sup>th</sup> century when John Snow used this method to understand whether cholera was caused by bad air or bad water (Snow, 1855). From this study, he discovered that people who received contaminated water had significantly higher death rates due to cholera. Since then, DiD model has been applied not only to epidemiology area but also to other areas such as addressing policy effects. For example, effects of the Americans with Disabilities Act (ADA), law enacted in order to prohibit discrimination against the disabled, were investigated by Acemoglu and Angrist (2001) using the DiD model. Besstremyannaya (2013) investigated effects of the Japanese hospital financing reform on technological and cost efficiency of local public hospitals, and Wan et al. (2019) studied whether China’s ship emission controlling policy was effective in

reducing sulfur dioxide concentrations using the difference-in-differences method.

Difference-in-differences technique estimates the treatment effect by comparing the average change of the dependent variable for the treatment group against that for the control group over a certain period of time that includes the treatment period. The treatment group refers to a unit or a group of units that has been affected by the treatment or intervention, while the control group is not subject to such treatment or intervention at the period of interest. While all the OLS model assumptions are applied to DiD as well, parallel trends assumption must hold as well in order to evaluate causal effects using DiD. Parallel trends assumption states that there should be no time-varying differences between the treatment and control groups. In other words, the treatment and control groups must share parallel/similar trends before the treatment period so that any difference in trends after the treatment are attributable to the treatment effect. The parallel trend assumption must be inspected carefully since violation of this assumption could lead to biased estimation of treatment effect.

The simplest form of the difference-in-differences design would be a case when only two groups (A: control, B: treatment) are analyzed over two time periods (Period 1: before treatment, Period 2: after treatment). In this case,  $Y_{gt}$  represents an outcome of dependent variable for group  $g$  in time period  $t$ . For example,  $Y_{A,1}$  represents the outcome for the control group in time period 1 when treatment has not taken place yet, and  $Y_{B,2}$  represents the outcome for the treatment group in time period 2, after the treatment has taken place. The average treatment effect,  $\delta_{DD}$ , then can be written as

$$\delta_{DD} = (\bar{Y}_{B,2} - \bar{Y}_{A,2}) - (\bar{Y}_{B,1} - \bar{Y}_{A,1}) \quad (1)$$

where the first term  $(\bar{Y}_{B,2} - \bar{Y}_{A,2})$  is the difference across control and treatment group after treatment and the second term  $(\bar{Y}_{B,1} - \bar{Y}_{A,1})$  represents the difference between the groups

before the treatment. In other words, the average treatment effect  $\delta_{DD}$  is simply the difference between the outcome for the control and treatment groups over the time periods. In addition, equation (1) can be rewritten as following:

$$\delta_{DD} = (\bar{Y}_{B,2} - \bar{Y}_{B,1}) - (\bar{Y}_{A,2} - \bar{Y}_{A,1}) \quad (2)$$

Equation (2) is essentially equivalent to equation (1) except that interpretation could be done differently. According to equation (2),  $\delta_{DD}$  could be understood as the difference between the treatment effect on the treatment group and the treatment effect on the control group. The average treatment effect can be calculated by incorporating the DiD design in an OLS model. Here we add two dummy variables,  $D_{TREAT_i}$  and  $D_{POST_i}$ , which take  $i = 1$  if observation  $i$  is in the treatment group and if is in the post-treatment period, respectively. Then in a simple DiD design, the treatment variable is the product of these two dummy variables,  $D_{TREAT_i} \times D_{POST_i}$ . In a regression equation form, we can write the observed outcome equation in terms of the group and time period variables in order to obtain which is as following:

$$Y_i = \beta_0 + \beta_1(D_{TREAT_i}) + \beta_2(D_{POST_i}) + \delta_{DD}(D_{TREAT_i} \times D_{POST_i}) + \epsilon_i \quad (3)$$

To study whether the adoption of VAR contributes to decreasing referee bias in football leagues, we use a difference-in-differences methodology with the treatment year of 2018, the first year VAR was introduced throughout the season (treatments). Specifically, we compare the difference in referee bias by *the average number of goals scored by the away side and the average number of goals scored by the home side* before and after the treatment for leagues that adopt the VAR (treatment group) with the corresponding differences for leagues that are not adopting the VAR but are otherwise similar (control group).

#### *Treatment group*

The treatment group includes all leagues that belong to one of the first, second, and third

divisions and that implemented the VAR in 2018 and has been using onwards. Since the VAR system was adopted in the middle of the season for some leagues, we only classified a league as a treatment group when the VAR was adopted for the entire season. From 2018 to 2021, there were total of eight leagues that adopted the VAR for the entire season, including A-league (Australia), Bundesliga (Germany), Chinese Super League (China), K League 1 (South Korea), K League 2 (South Korea), Liga NOS (Portugal), MLS (USA), and Serie A (Italy). Those eight leagues are included in the treatment group as they satisfy the criteria.

### *Control group*

To construct a sample group of leagues that are similar to the treated leagues in the pre-treatment period, we compare the treated league to the control league based on league-level characteristics. There are some criteria that must be satisfied in order to be included in the control group.

Firstly, leagues that did not introduce the VAR from 2018 to 2021 were considered as a control group. For example, the English Premier League (England) adopted VAR in 2019/2020 for the first time, but it is excluded from our sample of control group as well as treatment group. This is because the VAR was not introduced in the English Premier League in 2018 (treatment group criteria), and because it introduced the system in 2019/2020 which violates the criteria to be included in the control group. However, the J1 League (Japan) is included in our control group, as the league adopted VAR in the 2020 Emperor's Cup final, but never really adopted the VAR in the league from 2018 to 2021.

Secondly, most of the domestic leagues have several divisions, just as there are K League 1, K League 2, and K3 League in South Korea. The leagues within each country show similar properties. For example, environmental characteristics including temperature

and humidity, laws of the game, and football style are similar (REFERENCES). In order to find leagues that are similar to the treatment group, lower divisions of the leagues that are included in the construction of treatment group were also considered as the control group. The K3 league (South Korea), USL Championship (USA), and Serie C (Italy) fall under this category.

Thirdly, we choose the closest leagues among the remaining options based on five league-level variables: *total matches*, *average goals in 76 to 90 min*, *average corners per match*, *average cards per match by the home team*, and *age*. The five variables were selected to describe and consider the characteristics of each league, and their meanings are as follows. Total matches correspond to the total number of matches that have been publicly scheduled for the season. *Average goals in 76 to 90 min* means the average number of goals scored between 76th and 90th minute of the game. *Average corners per match* means the average number of corner kicks in each league for every match. *Average cards per match by the home team* corresponds to the average number of yellow and red cards received by the home team per match. Based on these five variables, we construct the counterfactual using the control group leagues to figure out to what would have happened if the VAR had not been adopted in the treated leagues.

Table 2 provides descriptive statistics for the five variables to describe the similarities between treated and control leagues before VAR adoption (pre-treatment period). The table provides the means, 25th, 50th, and 75th percentiles for each variable for both the 38 treated league observations and the 171 control league observations. The p-value of the difference-in-means test is shown in the last column of the table (t-test). As demonstrated, treated and control leagues are similar across all of these variables in the pre-treatment period, which is before 2018. In particular, the null of equal means cannot be rejected for all

variables (with  $p$ -values ranging from 0.119 to 0.997). In summary, the statistics presented in Table 2 demonstrate that control leagues are highly similar to treated leagues thus these statistics are highly likely to offer a reliable counterfactual of how treated leagues would perform in the absence of the VAR adoption.

(Insert Table 2 about here)

We measure the effect of VAR adoption on referee bias by estimating the following regression:

$$Referee\ bias_{ls} = \alpha_s + \beta \times VAR\ adoption_{ls} + \gamma X_{ls} + \varepsilon_{lt}$$

where  $l$  indexes the league and  $s$  indexes the season, *VAR adoption* is a dummy variable (treatment dummy) that takes 1 for treated leagues and 0 for control leagues,  $X$  corresponds to the vector of control variables, which consists of the five variables used to build the control group (total matches (log-transformed), average goals in 76 to 90 min, average corners per match, average cards per match by the home team, and age (log-transformed)), and  $\varepsilon$  corresponds to the error term. We clustered standard errors at the league level. The coefficient of  $\beta$  assesses the difference between treated and control leagues in referee bias which is the main variable of interest.

### ***Synthetic Control Method***

As a complementary methodology to the difference-in-difference, we also conducted a synthetic control method. The synthetic control method is a statistical measure to evaluate the treatment effect in comparative case studies. The synthetic control method evaluates the effect of a treatment or policy by comparing the change in an outcome variable for a group affected by the treatment to the change in the same outcome variable for a 'synthetic control group'. The synthetic control group is constructed by searching for a weighted combination of control groups chosen to approximate the group influenced by the treatment with respect to predictor variables. The change in an outcome variable for the synthetic control group is a counterfactual estimate of what would have been observed for the influenced (treatment) group in the absence of treatment.

We construct synthetic VAR-adopted-leagues as a weighted average of potential control leagues, with weights chosen so that the resulting synthetic VAR-adopted-leagues appropriately reproduces the values of a set of predictors of referee bias in VAR adopted leagues before the VAR adoption. Since the synthetic VAR-adopted-leagues are intended to reproduce the referee bias that would have been observed for the VAR adopted leagues in the absence of VAR, leagues that adopted VAR between 2018 and 2021 are excluded from the donor pool. This left us with 45 leagues as a donor pool which equivalent to the control group used in the difference-in-differences methodology.

The outcome variable of interest is referee bias at a league level, measured in our dataset as *the average number of goals scored by the away side* and *the average number of goals scored by the home side*. We include five controls (total matches, average goals in 76 to 90 min, average corners per match, average cards per match by home team, and age) that were used in our main analysis with difference-in-difference model as predictors of referee

bias. These variables are averaged over 2013-2017, the pre-treatment period, and augmented by adding two years of referee bias variables.

### ***Descriptive statistics***

The descriptive statistics and correlations of the variables are presented in Table 3. Since a few of the variables in Table 3 show relatively high correlations, we examine variance-inflation factors (VIFs). The results showed that none of the VIFs are greater than 3, reducing concerns about multicollinearity.

(Insert Table 3 about here)

## **RESULTS**

### **Difference-in-Difference**

The main results are presented in Table 4-5. The dependent variable for Model 1~3 in Table 4 is the average number of goals scored by the away side and the dependent variable for Model 4-6 in Table 5 is the average number of goals scored by the home side. In Model 1 and 4, we only include VAR adoption dummy as an explanatory variable in the regression. In Model 2 and 5, we include year fixed effects along with the VAR adoption dummy variable, and for Model 3 and 6 we further include control variables.

In Model 1-3 of Table 4, coefficient for VAR Adoption is positive and significant ( $p < 0.05$ ). This indicates that the leagues that adopted VAR had more average number of goals scored by the away side compared to the leagues that did not adopt VAR. However, we found that the coefficient of VAR adoption in Model 4-6 of Table 5 is insignificant. This means that there is no significant difference in average number of goals scored by the home side between

leagues that adopted VAR and those that did not. In summary, it was found that the league that adopted VAR led to an increase in the number of goals scored by the away side than the league that did not adopt VAR, whereas no significant change in average home goals was not observed. Together, the results support our hypothesis.

### **Synthetic control method**

The comparison between the pre-treatment characteristics of the leagues that introduced the VAR in 2018 with those of the synthetic VAR adopted leagues, and the population-weighted average of the 45 leagues in the donor pool are presented in Table 7a-b. It is clearly seen that, for the pre-treatment period, the synthetic VAR-adopted-leagues accurately reproduces the values of predictor variables of the leagues that actually adopted the VAR

(Insert Table 7a about here)

(Insert Table 7b about here)

The estimate of the effect of the VAR adoption on referee bias is the difference between *the average number of goals scored by the away side* and *the average number of goals scored by the home side* in the VAR adopted leagues and their synthetic version in the post-treatment period. As can be seen in Figure 1, the two lines begin to diverge noticeably for *the average number of goals scored by the away side*. However, noticeable diverge is not observed on *the average number of goals scored by the home side* between the VAR adopted leagues and synthetic VAR-adopted leagues in Figure 2. The clear discrepancy between the two lines in Figure 1 suggests a noticeable effect of the VAR adoption on referee bias in terms of the average number of goals scored by the away side.

## CONCLUSION & LIMITATIONS

The objective of this study is to understand how the implementation of the Video Assistant Referee in professional football leagues has contributed to mitigating the extent of referee bias. Unlike conventional approaches to understand the effect of the VAR in football, quasi-experimental econometrics methodologies were employed to achieve the same purpose. Using the difference-in-differences model and synthetic control method, it was discovered that the number of away goals has increased at a significant level after the adoption of the VAR, whereas the number of home goals remained unchanged. In terms of goal counts, therefore, it can be concluded the introduction of the VAR technology has mitigated referee bias to some extent.

However, there are several limitations of this study and room for further work. Firstly, goal count variable was used to represent referee bias. However, there are many other variables that have been chosen to represent referee bias such as disciplinary cards, penalty kicks and injury time added. If similar results are observed with these variables as well with the adoption of the VAR, further evidence for positive effects of the VAR in mitigating referee bias can be confirmed. Secondly, five variables – total matches, average goals in 76 to 90 min, average corners per match, average cards per match by the home team and age – were chosen in this study to represent league characteristics. However, it is hard to say that only these five variables can represent league characteristics, so more variables could be carefully chosen to be considered. Lastly, the pre-treatment period was not long enough to have parallel trends before 2018. The dataset of football leagues was from 2013 to 2021, and the treatment period (adoption of the VAR) took place in 2018, giving us five years of pre-treatment period and four years of post-treatment period. In other words, the pre-treatment period was not sufficiently long to create a synthetic control group to match the pre-treatment

trend of the treatment group. Therefore, extending the span of the dataset could help more clearly observe the treatment effect using synthetic control method.

Nonetheless, the results of this study can help better understand the effects of the adoption of the VAR in professional football leagues across divisions. In addition, this study carries importance in that difference-in-differences model and synthetic control method were used to analyze the VAR's influences on referee bias for the first time.

## References

- Courneya, K. S., & Carron, A. V. (1992). The home advantage in sport competitions: a literature review. *Journal of Sport & Exercise Psychology*, 14(1).
- Nevill, A. M., & Holder, R. L. (1999). Home advantage in sport. *Sports Medicine*, 28(4), 221-236.
- Boyko, R. H., Boyko, A. R., & Boyko, M. G. (2007). Referee bias contributes to home advantage in English Premiership football. *Journal of sports sciences*, 25(11), 1185-1194.
- Goumas, C. (2014). Home advantage and referee bias in European football. *European journal of sport science*, 14(sup1), S243-S249.
- Bashiru, S., & Opoku, E. (2017). Referee bias and its impact on low fans attendance at stadiums: standpoints from Ghana. *International Journal of Physical Education, Sports and Health*, 4(5), 139-47.
- Lex, H., Pizzera, A., Kurtes, M., & Schack, T. (2015). Influence of players' vocalisations on soccer referees' decisions. *European journal of sport science*, 15(5), 424-428
- Gabbard, S. R., & Watamaniuk, S. N. (2011). The flash-lag effect (FLE) as a biasing factor for offside determination in soccer. *Journal of Vision*, 11(11), 759-759.
- Spitz, J., Wagemans, J., Memmert, D., Williams, A. M., & Helsen, W. F. (2021). Video assistant referees (VAR): The impact of technology on decision making in association football referees. *Journal of Sports Sciences*, 39(2), 147-153.
- Kolbinger, O., & Knopp, M. (2020). Video kills the sentiment—Exploring fans' reception of the video assistant referee in the English premier league using Twitter data. *PloS one*, 15(12), e0242728.
- Jones, M. B. (2018). Differences in home advantage between sports. *Psychology of Sport and Exercise*, 34, 61-69.
- Dohmen, T. J. (2008). The influence of social forces: Evidence from the behavior of football referees. *Economic inquiry*, 46(3), 411-424.
- Dawson, P., & Dobson, S. (2010). The influence of social pressure and nationality on individual decisions: Evidence from the behaviour of referees. *Journal of Economic Psychology*, 31(2), 181-191.
- Almeida, C. H., & Volossovitch, A. (2017). Home advantage in Portuguese football: Effects of level of competition and mid-term trends. *International Journal of Performance Analysis in Sport*, 17(3), 244-255.
- Rooney, L., & Kennedy, R. (2018). Home advantage in Gaelic football: the effect of divisional status, season and team ability. *International Journal of Performance Analysis in Sport*, 18(6), 917-925
- Armatas, V., Yiannakos, A., Seaton, M., & Rigas, G. (2013). Home advantage: comparison between professional and amateur Greek football leagues. *Journal of Sport and Health Research*, 5(1), 95-106.
- Neave, N., & Wolfson, S. (2003). Testosterone, territoriality, and the 'home advantage'. *Physiology & behavior*, 78(2), 269-275
- Nevill, A. M., Balmer, N. J., & Williams, A. M. (2002). The influence of crowd noise and experience upon

refereeing decisions in football. *Psychology of sport and exercise*, 3(4), 261-272.

- Downward, P., & Jones, M. (2007). Effects of crowd size on referee decisions: Analysis of the FA Cup. *Journal of sports sciences*, 25(14), 1541-1545.
- Goumas, C. (2014). Home advantage and referee bias in European football. *European journal of sport science*, 14(sup1), S243-S249.
- Fischer, K., & Haucap, J. (2021). Does crowd support drive the home advantage in professional football? Evidence from German ghost games during the COVID-19 pandemic. *Journal of Sports Economics*, 22(8), 982-1008
- McCarrick, D., Bilalic, M., Neave, N., & Wolfson, S. (2020). Home Advantage during the COVID-19 Pandemic in European football.
- Endrich, M., & Gesche, T. (2020). Home-bias in referee decisions: Evidence from “Ghost Matches” during the Covid19-Pandemic. *Economics Letters*, 197, 109621.
- Carlos, L. P., Ezequiel, R., & Anton, K. (2019). How does Video Assistant Referee (VAR) modify the game in elite soccer?. *International Journal of Performance Analysis in Sport*, 19(4), 646-653.
- Lago-Peñas, C., Gómez, M. A., & Pollard, R. (2021). The effect of the Video Assistant Referee on referee's decisions in the Spanish LaLiga. *International Journal of Sports Science & Coaching*, 16(3), 824-829.
- Errekagorri, I., Castellano, J., Echeazarra, I., & Lago-Peñas, C. (2020). The effects of the Video Assistant Referee system (VAR) on the playing time, technical-tactical and physical performance in elite soccer. *International Journal of Performance Analysis in Sport*, 20(5), 808-817.
- Han, B., Chen, Q., Lago-Peñas, C., Wang, C., & Liu, T. (2020). The influence of the video assistant referee on the Chinese Super League. *International Journal of Sports Science & Coaching*, 15(5-6), 662-668
- Kubayi, A., Larkin, P., & Toriola, A. (2021). The impact of video assistant referee (VAR) on match performance variables at men's FIFA World Cup tournaments. *Proceedings of the Institution of Mechanical Engineers, Part P: Journal of Sports Engineering and Technology*, 1754337121997581.
- Snow, J. (1855). *On the mode of communication of cholera*. John Churchill
- Acemoglu, D., & Angrist, J. D. (2001). Consequences of employment protection? The case of the Americans with Disabilities Act. *Journal of Political Economy*, 109(5), 915-957
- Besstremyannaya, G. (2013). The impact of Japanese hospital financing reform on hospital efficiency: A difference-in-difference approach. *The Japanese Economic Review*, 64(3), 337-362.
- Wan, Z., Zhou, X., Zhang, Q., & Chen, J. (2019). Do ship emission control areas in China reduce sulfur dioxide concentrations in local air? A study on causal effect using the difference-in-difference model. *Marine Pollution Bulletin*, 149, 110506
- Kolbinger, O., & Lames, M. (2017). Scientific approaches to technological officiating aids in game sports. *Current Issues in Sport Science (CISS)*
- Pollard, R., & Armatas, V. (2017). Factors affecting home advantage in football World Cup

qualification. *International Journal of Performance Analysis in Sport*, 17(1-2), 121-135.

- Allen, M. S., & Jones, M. V. (2014). The home advantage over the first 20 seasons of the English Premier League: Effects of shirt colour, team ability and time trends. *International Journal of Sport and Exercise Psychology*, 12(1), 10-18.
- Seckin, A., & Pollard, R. (2008). Home advantage in Turkish professional soccer. *Perceptual and motor skills*, 107(1), 51-54.
- Goumas, C. (2014). Home advantage in Australian soccer. *Journal of Science and Medicine in Sport*, 17(1), 119-123.
- Leite, W. S. (2017). Home advantage: Comparison between the major European football leagues. *Athens Journal of Sports*, 4(1), 65-74.
- Wolfson, S., Wakelin, D., & Lewis, M. (2005). Football supporters' perceptions of their role in the home advantage. *Journal of sports sciences*, 23(4), 365-374.
- Inan, T. (2020). The effect of crowd support on home-field advantage: Evidence from European football. *Annals of Applied Sport Science*, 8(3), 0-0.
- Pollard, R. (2006). Worldwide regional variations in home advantage in association football. *Journal of sports sciences*, 24(3), 231-240.
- O'Brien, K. A., & Mangan, J. (2021). The Issue of Unconscious Bias in Referee Decisions in the National Rugby League. *Frontiers in Sports and Active Living*, 260.

Table 1. Information of worldwide football leagues

League	Country	Division	Founded	Gender	Number of teams	VAR Adoption (2018)
1 Lyga	Lithuania	2	1991	Men	14	
1. Deild	Iceland	2	1997	Men	12	
1. Liga	Poland	2	1948	Men	18	
A-League Men	Australia	1	2004	Men	12	Yes
Allsvenskan	Sweden	1	1924	Men	16	
Belarusian First League	Belarus	2	1992	Men	16	
Bundesliga	Germany	1	1963	Men	18	Yes
Burundi Ligue A	Burundi	1	1972	Men	16	
Categoría Primera B	Colombia	2	1991	Men	15	
Championship	England	2	1892	Men	24	
Championship	Scotland	2	2013	Men	10	
Chinese Super League	China	1	2004	Men	18	Yes
Division 1	Sweden	3	2006	Men	32	
Eerste Divisie	Netherlands	2	1956	Men	20	
EFL League One	England	3	2004	Men	24	
Ekstraklasa	Poland	1	1927	Men	18	
Eliteserien	Norway	1	1937	Men	16	
Esiliiga	Estonia	2	1992	Men	10	
Esiliiga B	Estonia	3	2013	Men	10	
FA Women's Super League	England	1	2010	Women	12	
Feminine Division 1	France	1	1974	Women	12	
First Division	Norway	2	1948	Men	16	
First Division	Republic of Ireland	2	1985	Men	9	
Girabola	Angola	1	1979	Men	16	
J1 League	Japan	1	1992	Men	18	
K League 1	South Korea	1	1983	Men	12	Yes
K League 2	South Korea	2	2013	Men	11	Yes
K3 League	South Korea	3	2007	Men	16	
League One	Scotland	3	2013	Men	10	

Liga de Fútbol Profesional Boliviano	Bolivia	1	1977	Men	12	
Liga NOS	Portugal	1	1934	Men	18	Yes
Ligue 2	France	2	1933	Men	20	
Meistriliiga	Estonia	1	1992	Men	10	
MLS	USA	1	1993	Men	28	Yes
Nadeshiko League 1	Japan	1	1989	Women	12	
Premier Division	Republic of Ireland	1	1985	Men	10	
Premiership	Scotland	1	1890	Men	12	
Primera Categoría Serie A	Ecuador	1	1957	Men	12	
Primera Categoría Serie B	Ecuador	2	1971	Men	10	
Primera División	Peru	1	1912	Men	19	
Primera Division Women	Spain	1	1988	Women	16	
S.League	Singapore	1	1996	Men	8	
Segunda División	Peru	2	1943	Men	13	
Segunda División	Spain	2	1929	Men	22	
Serie A	Italy	1	1898	Men	20	Yes
Serie C	Italy	3	1935	Men	60	
Toppserien	Norway	1	1984	Women	10	
Úrvalsdeild	Iceland	1	1912	Men	12	
USL Championship	USA	2	2010	Men	27	
V.League 1	Vietnam	1	1980	Men	14	
V.League 2	Vietnam	2	1990	Men	12	
Virsliga	Latvia	1	1927	Men	10	
Vysheyshaya Liga	Belarus	1	1992	Men	16	

Table 2. Summary statistics for treated and control leagues before the VAR adoption

		Obs.	Mean	25th percentile	50th percentile	75th percentile	p-value (t-test)
Average number of goals scored by the away side	Control	171	1.244	1.100	1.220	1.360	0.144
	Treated	38	1.192	1.100	1.180	1.290	
Average number of goals scored by the home side	Control	171	1.591	1.420	1.550	1.740	0.191
	Treated	38	1.540	1.440	1.565	1.653	
Total matches	Control	171	264.538	180.000	240.000	306.000	0.880
	Treated	38	268.684	228.000	253.000	338.000	
Average goals in 76 to 90 min	Control	171	0.630	0.564	0.621	0.712	0.569
	Treated	38	0.642	0.597	0.631	0.693	
Average corners per match	Control	171	9.974	9.500	10.080	10.600	0.309
	Treated	38	9.794	9.183	9.800	10.460	
Average cards per match by home team	Control	171	4.051	3.360	3.980	4.640	0.146
	Treated	38	4.478	3.955	4.115	5.113	
Age	Control	171	43.058	17.000	30.000	78.000	0.997
	Treated	38	43.079	11.750	30.500	79.250	

Table 3. Descriptive statistics

	1	2	3	4	5	6	7	8	9
1 Average number of goals scored by the away side	1								
2 Average number of goals scored by the home side	b	1							
3 VAR adoption	-0.059 (0.228)	-0.022 (0.651)	1						
4 Year 2018	-0.030 (0.540)	0.015 (0.756)	0.291 (0.000)	1					
5 Total matches <sup>a</sup>	-0.161 (0.001)	-0.294 (0.000)	0.052 (0.295)	-0.040 (0.415)	1				
6 Average goals in 76 to 90 min	0.460 (0.000)	0.509 (0.000)	0.078 (0.113)	-0.112 (0.022)	-0.081 (0.101)	1			
7 Average corners per match	0.333 (0.000)	0.335 (0.000)	-0.007 (0.885)	-0.094 (0.056)	0.079 (0.107)	0.315 (0.000)	1		
8 Average cards per match by home team	-0.026 (0.600)	-0.138 (0.005)	0.039 (0.429)	-0.056 (0.259)	0.252 (0.000)	0.047 (0.341)	0.210 (0.000)	1	
9 Age <sup>a</sup>	-0.059 (0.231)	-0.159 (0.001)	0.021 (0.673)	0.092 (0.060)	0.248 (0.000)	-0.033 (0.499)	0.084 (0.088)	0.257 (0.000)	1
Mean	1.575	2.839	0.077	0.496	262.841	0.617	9.856	1.911	43.511
Std. Dev.	0.232	0.401	0.267	0.501	164.322	0.131	0.909	0.535	33.010
Min	0.900	1.730	0.000	0.000	36.000	0.008	3.900	0.290	0.000
Max	2.360	4.310	1	1	1194	0.989	11.870	3.390	123.000
Obs	415	415	415	415	415	415	415	415	415

<sup>a</sup>Logged values used for regression and correlations, untransformed values for descriptive statistics. <sup>b</sup> Never used in the same model as *Average number of goals scored by the away side* and *Average number of goals scored by the home side*, which is obviously highly collinear. We run the difference-in-differences regression models alternatively with and without relatively highly correlated variables and the result is not different. *p*-value in parentheses

Table 4. Dependent variable: Average number of goals scored by the away side

VARIABLES	Model 1	Model 2	Model 3
VAR adoption	0.060** (0.025)	0.060** (0.025)	0.048** (0.021)
Year 2018	0.032 (0.020)	0.026 (0.035)	0.060** (0.026)
Total matches (ln)			-0.037 (0.035)
Average goals in 76 to 90 min			0.715*** (0.081)
Average corners per match			0.031** (0.012)
Average cards per match by the home team			-0.013 (0.027)
Age (ln)			-0.034* (0.020)
League effects	fixed	fixed	fixed
Year dummies	not included	included	included
Constant	1.235*** (0.008)	1.250*** (0.021)	0.838*** (0.236)
Observations	415	415	415
R-squared	0.040	0.063	0.359
Number of Leagues	53	53	53
<i>p-value</i>	< 0.01	< 0.01	< 0.01

Standard errors in parentheses. All tests are two-tailed. \*\*\* p<0.01, \*\* p<0.05, \* p<0.1

Table 5. Dependent variable: Average number of goals scored by the home side

VARIABLES	Model 4	Model 5	Model 6
VAR adoption	0.013 (0.024)	0.013 (0.024)	0.005 (0.019)
Year 2018	-0.014 (0.018)	-0.049 (0.034)	-0.021 (0.033)
Total matches (ln)			0.142*** (0.051)
Average goals in 76 to 90 min			0.513*** (0.075)
Average corners per match			0.041*** (0.012)
Average cards per match by the home team			-0.010 (0.031)
Age (ln)			-0.038*** (0.011)
League effects	fixed	fixed	fixed
Year dummies	not included	included	included
Constant	1.581*** (0.008)	1.572*** (0.022)	0.220 (0.275)
Observations	415	415	415
R-squared	0.003	0.037	0.261
Number of Leagues	53	53	53
<i>p-value</i>	< 0.01	< 0.01	< 0.01

Standard errors in parentheses. All tests are two-tailed. \*\*\* p<0.01, \*\* p<0.05, \* p<0.

Table 7a. Predictor means of average number of goals scored by the away side

Variables	VAR adopted leagues		Average of 45 control leagues
	Real	Synthetic	
Total matches	265.350	265.825	250.182
Average goals in 76 to 90 min	0.643	0.591	0.603
Average corners per match	9.804	9.815	9.861
Average cards per match by home team	2.046	2.048	1.882
Age	41	41.06	39.133
Average number of goals per match (2013)	1.183	1.184	1.284
Average number of goals per match (2015)	1.176	1.174	1.229

Table 7b. Predictor means of average number of goals scored by the home side

Variables	VAR adopted leagues		Average of 45 control leagues
	Real	Synthetic	
Total matches	265.350	265.005	250.182
Average goals in 76 to 90 min	0.643	0.643	0.603
Average corners per match	9.804	9.800	9.861
Average cards per match by home team	2.046	2.046	1.882
Age	41	41.007	39.133
Average number of goals per match (2013)	1.521	1.521	1.608
Average number of goals per match (2015)	1.508	1.508	1.577

Figure 1. Trends in the average number of goals scored by the away side: VAR adopted leagues vs. synthetic VAR-adopted-leagues

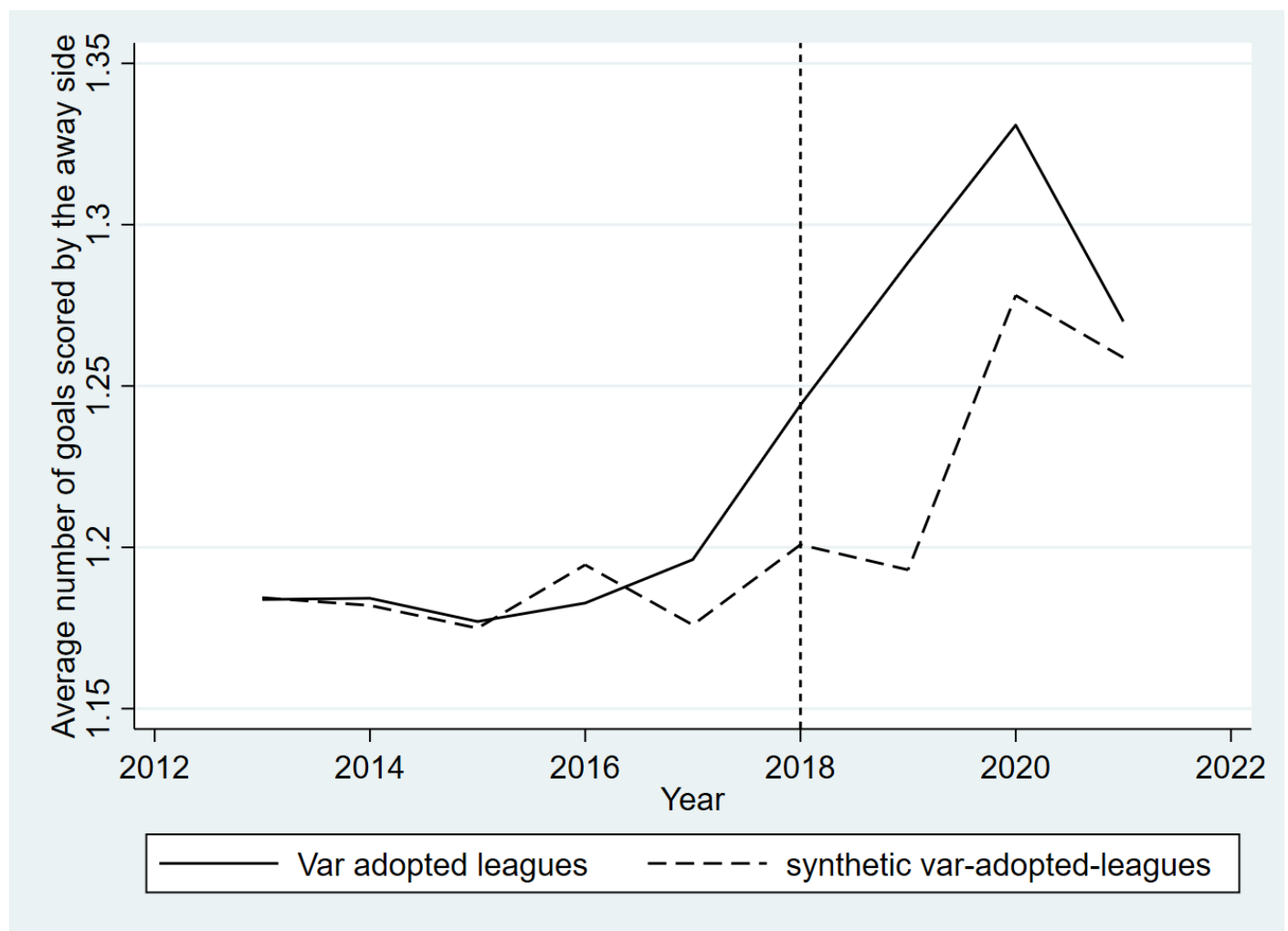


Figure 2. Trends in the average number of goals scored by the home side: VAR adopted leagues vs. synthetic VAR-adopted-leagues

