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Expanding upon the weather: cloud cover and barometric pressure as determinants of attendance for NFL games

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Abstract

Purpose – Purpose of the study is to further expand insights into how weather impacts attendance at sporting events. With the NFL having only eight home games a year per team, it is more of an event than other North American sports. We explore this in terms of how sensitive fans are to weather, by not only looking at traditional factors, but also other weather variables available through Accuweather. In addition, the authors explore team success, outcome uncertainty and other factors as determinants of demand.

Design/methodology/approach – The method includes Tobit model of attendance in terms of percent of capacity in the National Football League. Model includes factors such as outcome uncertainty, team success, etc. but mainly focuses on weather. Weather factors studied include traditional variables such as temperature and precipitation, and also includes cloud cover, barometric pressure, wind speed and humidity. Different model specifications are included to explore results. Key findings allow for differences between games played outdoors versus indoors.

Findings – In terms of control variables, team success, new stadiums and stadium age play a significant role in attendance in terms of percentage of capacity. Outcome uncertainty does not appear to be important, and fans desire the opposite when the home team is an underdog. The main results concern the weather. When only traditional weather variables are included, precipitation plays a key role. With further expansion of the weather variables, it appears that cloud cover offers some additional information beyond precipitation. In addition, barometric pressure plays a minor, but statistically significant role as it relates to attendance in terms of capacity.

Research limitations/implications – Including deeper and richer weather data helps to further explain attendance at sporting events. With the NFL, this may be limited by it being such as event due to the scarcity of games in a season. In addition, the weather variables are not truly independent, although they are not as correlated as may be anticipated on the surface. Use of different types of weather variables in models of attendance may help to deepen our understanding of factors influencing consumer decisions. These factors may play larger roles in sports with wider variance in attendance during the season.

Practical implications – The practical implications are that other weather-related variables besides temperature and precipitation may offer insight into consumer decisions related to attendance at sporting events. Cloud cover gives insights into anticipated poor weather in addition to it directly leading to less of a sunny day to be outdoors at an event. Barometric pressure has been shown to influence headaches and joint pain and may also influence consumer decisions to venture out to sporting events.

Social implications – As data becomes more widely available in general, it's possible to add additional insights into factors influencing various forms of decision-making. In this study, we show that more information on weather can shed insights into consumer decisions as it relates to attending events such as sports. These decisions likely differ based upon whether the event is held outdoors or indoors. With more entertainment choices as substitutes, it is important to identify key factors which influence consumer decisions to help better structure events in the future.

Originality/value – Weather variables beyond temperature and precipitation are included in a Tobit model for NFL attendance using percentage of capacity as the dependent variable. These weather variables are cloud cover, wind speed, humidity, and barometric pressure. Cloud cover and barometric pressure were found to have some significant effects on percentage of capacity. When included, precipitation itself is no longer found to be significant, but precipitation interacted with games played in domes retains statistical significance as there are key differences between games held outdoors versus indoors.

Keywords Economics, Consumer behavior
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The National Football League is the most popular sport in the United States. It follows a definitive schedule, where each team plays one game a week over seventeen weeks with one built-in bye week for each team (sixteen games total per team). Compared to other major North American sports such as baseball (MLB: 162-game season), basketball (NBA: 82-game season), hockey (NHL: 82-game season), NFL games are scarce with only eight home games in one season. This heightens consumer interest for individual NFL games, as fewer opportunities exist to see the sport in person at the highest level.

This study examines the determinants of NFL attendance for the 2013–2019 seasons with a specific focus on the weather. Although the regression models investigated examine key factors such as team success, uncertainty of outcome, expected scoring, age of stadium, etc., we focus on how weather-related variables affect attendance in terms of percentage capacity. Specifically, we examine traditional weather-related variables, temperature and precipitation, on the day of the game. Beyond these traditional figures, we also add four suggested weather-related variables, cloud cover, wind speed, humidity, and barometric pressure. Cloud cover gives a feel for what type of day it is to attend an NFL game. Days with more cloud cover may feel dreary and lead to less excitement to be outside for an extended period of time. High winds may make attending a game less enjoyable for fans as it may feel colder and the wind itself can be distracting and annoying to fans watching a game. High humidity could also make being outside for games be less pleasant and could keep fans from attending games. Humidity is likely to be highly correlated with precipitation, however, so it may not be as directly informative as other variables. Barometric pressure is also included in the model as it may play a role in consumer activity. Research has shown that barometric pressure can influence headaches or migraines (Kimoto *et al.*, 2011) and also lead to joint pain (McAlindon *et al.*, 2007), both of which could influence the decision to attend games by fans.

The paper is structured as follows. Section 1 contains a literature review related to studies of NFL attendance and weather-related attendance studies. Section 2 describes the regression models with the various weather-related variables included and presents the results. Section 3 concludes the paper and discusses the findings.

1. Literature review

The list of potential variables impacting attendance demand, and the empirical literature addressing it, is extensive (Mueller, 2020). Some examples include ticket pricing (Humphreys and Soebbing, 2012; Sweeting, 2012), day and time of a game (Tainsky and Winfree, 2010), promotions (Kappe *et al.*, 2014), weather (Ge *et al.*, 2020), and team success (Bradbury, 2019), among others. Several papers have examined these demand factors specifically for the National Football League (e.g. Coates and Humphreys, 2010; Diehl *et al.*, 2016; Gropper and Anderson, 2018). There is also extensive literature on the uncertainty of outcome hypothesis (Rottenberg, 1956) and its impact on attendance. According to the uncertainty of outcome hypothesis (UOH), consumers prefer games with uncertain outcomes. The theoretical implications of the UOH was examined in Coates *et al.* (2014) and is often tested empirically using betting market data.

Borland and MacDonald (2003) categorize five main subcategories of determinants of demand for attendance at live sporting events: form of consumer preferences, economic price, quality of viewing experience, characteristics of the viewing contest, and supply capacity. Weather directly impacts the quality of the viewing experience, as poor weather likely reduces the quality of the gameday experience. Indirectly, weather can impact the economic price of attending a sporting event because of bad weather on increased traveling costs. For domed stadiums, bad weather can also decrease competition for consumer dollars by removing otherwise available outdoor substitutes.

Popp *et al.* (2019) and Schreyer *et al.* (2019) examine the impact of various demand factors on no show attendance behaviors, including weather. Popp *et al.* (2019) find that rainy weather led to more no shows for NCAA football attendance, but temperature had no effect. Schreyer *et al.* (2019) find that temperature has a statistically significant U-shaped quadratic relationship in the German Bundesliga, but no statistically significant effect of precipitation. Many studies have identified a negative relationship between game day attendance and current rainfall. Kalist (2010) and Agha and Rhoads (2018) identify that current rainfall reduces current Major League Baseball and minor league baseball attendance, respectively.

Ge *et al.* (2020) utilize adverse weather shocks to study habit formation and persistence in attending live sporting events for Major League Baseball. Adverse weather reflects a source of variation in attendance demand uncorrelated with past attendance and unobserved fan characteristics. They identify that lagged rainfall has a positive impact on current attendance. They also examine different specifications for current day precipitation and conclude that forecasted accumulated rainfall has a greater impact on attendance demand than actual accumulated rainfall two hours prior to the game and four hours prior to the game, suggesting that fans rely heavily on weather forecasts when making their purchasing decisions. When examining the effects of domed stadiums, they find that attendance increases on rainy days, suggesting that indoor baseball games serve as strong substitutes for other indoor entertainment options.

2. Regression model and results of NFL attendance and weather-related variables

The dependent variable in our model, across its various specifications, is the attendance in terms of percentage of capacity of the stadium for each NFL game for the 2013 through 2019 regular seasons. There are 32 teams in the NFL for each of the years in the sample and each team plays eight regular season home games a year for a sample of 1,792 games. The median stadium capacity in the sample is over 69,000, although some teams play in smaller stadiums (the now-former Oakland Raiders and the in-sample temporary home of the Los Angeles Chargers until they move into their new stadium) while the Dallas Cowboys could hold more than 100,000 fans for a game.

As many NFL games are near sell-outs or are sell-outs, a Tobit model was used. A Tobit model is a regression model where the observed range of the dependent variable is censored. In our sample, the censoring of the dependent variable occurs at the top end of the distribution due to capacity constraints on individual stadiums. For any game that listed attendance beyond stated capacity, the result was simply recorded as a sell-out (observation equal to one). The data is panel in nature with eight home games per season for each NFL team (32). Fixed effects for the home and road team in each game are used in the model. The Tobit regression model is as follows:

$$A_{it} = \alpha_i + \beta X_{it} + \lambda Z_{it} + \varepsilon_{it} \tag{1}$$

The terms in the empirical model are: A_{it} is the attendance in terms of stadium capacity for each NFL team, X_{it} is a vector of control variables related to team performance, game expectations, and other factors described below, Z_{it} is a vector of weather-related variables including temperature, precipitation, and other measures described below, ε_{it} is the random error term, α_i is a vector of parameters capturing unobservable fixed-effects with each team stadium, β is a vector of parameters related to the control variables, and λ is a vector of parameters related to gameday weather variables. More specific details on the individual control and weather variables are described below.

The control variables consist of categories related to day and time of the game, whether the game was played in a dome, stadium attributes, team performance, game expectations, and weather-related factors. The game data was obtained from www.nfl.com [1], the betting market data was obtained from www.covers.com [2], the stadium data was created from information obtained from Wikipedia [3], and the weather data was obtained directly from Accuweather [4].

NFL games are primarily played on Sunday afternoons, but there are prime-time games that occur Sunday, Monday and Thursday nights. In addition, following the conclusion of the college football regular season, some NFL games are also played on Saturday. The reference category is Sunday, with dummy variables created for Monday, Thursday, Saturday and Sunday Night. If any of these special/primetime games are more desirable for fans to attend, these dummies should have positive and significant coefficients.

Team performance has been shown to have a positive influence on game attendance in studies across various sports around the world. The home team win percentage entering the game (lag of win percentage) is included as an independent variable in the model to consider team performance. For the first game of the season, each team is treated equally, with all win percentages entering these games set to 0.5. Various other specifications were tried (setting lagged win percentage to 0.5 for the first 2 weeks, using the previous season win percentage for opening week, etc.) and none of these specifications meaningfully changed the results. If NFL fans prefer teams that win more often during the season, this variable should have a positive and significant effect on attendance.

Dome stadiums are advantageous for teams that play in extreme climates (hot or cold), but often times do not give fans the same experience as an outdoor stadium. Games played in a dome are included in the model as a dummy variable taking the value of one if the game was played in a dome. If fans do not like games in a dome as much as being outside, then this variable should have a negative and significant impact on attendance.

As mentioned earlier in terms of domed stadiums, the venue itself may have a significant effect on the desire by fans to see a team play at home. New stadiums often offer a temporary increase in attendance, due to the "honeymoon effect" and fans wanting to experience the new environment with the updated amenities. A dummy variable for the first year in a new stadium is included in the model. In addition, the age of the stadium may also play a role in fan decisions to attend games. Older stadiums are likely to not have as many features or amenities as newer stadiums. However, long-lived stadiums offer some appeal on their own; offering a connection to the team's past and have historic value in a city.

Game expectations could also play a considerable role in NFL gameday attendance. The NFL has a much shorter season than other North American leagues; only sixteen games total with eight being at home for each team, so individual game matchups may play a lesser role for the NFL than for a sport like Major League Baseball that plays 81 home games a year (in a 162-game schedule). That said, fans may still respond to outcome uncertainty and to expected excitement, proxied by scoring. The betting market for the NFL provides insights into these game attributes through the point spread and the total on the game. Both the point spread and the total have been shown in the literature to be generally efficient, with the possible exceptions in certain subsets of data (biggest favorites, home favorites, highest totals, etc.) (Levitt, 2004; Paul and Weinbach, 2009; 2008).

Although model specifications using the point spread, the point spread in the form of a quadratic, and the absolute value of the point spread were tried, none of the models captured the intricacies of fan expectations, as results were different based upon whether the home team was favored or not. To alleviate this issue, we converted point spreads into win probabilities using a conversion chart from the website Sportsinput [5]. Although this is an approximation, it serves as a proxy to allow for the point spread to be converted into odds and then into win probabilities. The home team win probability and the square of the home team win probability are included in the model to test the role of outcome uncertainty.

Outcome uncertainty was first hypothesized in Rottenberg (1956), where it was suggested that fans will prefer to attend games where there is greater outcome uncertainty. Games with a point spread close to zero are highly uncertain, while games with greater point spreads have more certainty. An alternative model of reference-dependent preferences (Coates *et al.*, 2014) tested and showed in some cases fans prefer attending games where the home team is expected to easily win or where the home team has an opportunity for a considerable upset. These preferences are the opposite of the original uncertainty of outcome hypothesis, as close games would be least desirable. If fans prefer outcome uncertainty, the signs on the home team win probability should be positive and the home team win probability squared should be negative. If fans have reference-dependent preferences, the result will be the opposite.

The betting market also offers insights into the amount of scoring expected in a game through the betting market total (over/under). Fans may prefer the excitement of higher-scoring games to lower-scoring contests. Fantasy leagues disproportionately award scoring in their structure, so fans who play fantasy games (year-long leagues or daily fantasy) likely prefer seeing more scoring to less. Past research (Paul and Weinbach, 2007) has shown that higher totals impact television rating for NFL games and higher-scoring games tend to keep viewers into the second half of prime-time games. If fans attending a game in person prefer more scoring to less, then the total should have a positive and significant effect on attendance.

The depth and scope of the weather variables available from Accuweather allowed for a deeper dive into fan preferences for attending NFL games. Although previous studies of sports attendance have used temperature and precipitation (or categorized weather conditions) in the model, Accuweather offers many more potential variables of interest. Many of the weather variables are inter-related, leading to substantial multicollinearity issues when grouped together. However, we believe we have identified a few key variables, beyond temperature and precipitation, which are likely to play a role in fan decisions. One potential variable of interest is cloud cover. Sunny days are likely much better days to enjoy being outdoors, particularly in the fall and winter months when NFL games are played. Cloud cover may yield "dreary" days where people may prefer to stay inside. Accuweather provides cloud cover as a percentage of the sky for each city in their sample. We would expect that cloud cover would have a negative effect on attending NFL games.

Another factor which may make attending a game less enjoyable would be high winds. Wind speed can be disruptive to the fan experience and could lead to fewer fans attending games in high-wind conditions. Wind speed is included directly in the model and is expected to have a negative effect on attendance. Humidity is another factor which could influence attendance. High humidity days are generally unpleasant to be outside, so this could influence outdoor attendance negatively, while influencing indoor attendance in a positive manner. Barometric pressure is also included in the model. Barometric pressure has been linked in medical studies to both migraine headaches (Kimoto *et al.*, 2011) and to joint pain (McAlindon *et al.*, 2007). These factors could influence consumer behavior when making the decision to attend games.

As expected, there is some correlation between the weather-related variables. The correlation coefficient table is presented in Appendix. The highest correlation coefficient is between humidity and cloud cover, where it exceeds 0.5. Cloud cover and precipitation (0.3185) and humidity and precipitation (0.3086) are the next highest, while no other off-diagonal relationships are shown to be above 0.3. These relationships are addressed by using different model specifications and ultimately not using the highest-related weather independent variables together in the final specification (humidity and cloud cover).

Given the available Accuweather data, we used a variety of information to specify different regression models. Overall, we present three different model specifications, which differ based upon the number of weather-related variables included. The first model specification only includes the traditional weather variables, temperature and precipitation.

They are included on their own and also interacted with the dome games dummy variable to separate the influence of these weather-related variables on games inside versus outside. Model II adds the other weather variables considered for this study, cloud cover, wind, humidity, and barometric pressure. As with temperature and precipitation, these variables are included individually and also interacted with the dome game dummy variable. Model specification III takes the results of model II and eliminates any of the insignificant new weather variables (both individually and interacted with the dome dummy) to include only those that showed statistical significance in model II either by itself or through the interaction term.

Table 1 shows the summary statistics of the key variables in the model. Table 2 presents the results of each of the regression models. The coefficient of each independent variable and its associated t-statistic is shown for each of the nine models. Results are shown using Huber/White robust standard errors. Statistical significance is noted with *-notation. Significance is indicated at the 10% (*), 5% (**), and 1% (***) levels in the table.

We will first discuss the findings as it relates to the weather-related variables and then to the control variables. First, there were some statistically significant results as it relates to the weather, with possible additional information added by the new variables introduced to the models. In model I, where the traditional weather variables of temperature and precipitation were included as independent variables, both the temperature and the temperature interacted with a dome game were found to be statistically insignificant. Precipitation, on the other hand, was found to be statistically significant for both the variable alone and interacted with dome games. Precipitation was found to have a negative effect on attendance leading to less percentage capacity for NFL games. Precipitation interacted with dome games was found to have a positive effect on percentage capacity. For every 0.1 increase in participation, it leads to approximately 70-person decrease in attendance for non-dome stadiums and about 140-person increase in domed stadiums (assuming 70,000-seat stadium). Each variable was found to be statistically significant at the 10% level. Precipitation affects percent of capacity negatively, as fans attend fewer games when there is rain or snow. On the other hand, precipitation makes indoor activities more attractive and more fans attend games, increasing the percent of stadium capacity, when there is gameday precipitation in cities where the NFL team plays in a dome.

In model II, cloud cover, wind speed, humidity, and barometric pressure were added to the model. Wind speed (alone or interacted with dome games) was not found to be statistically significant. Cloud cover was found to be statistically significant at the 10% level and had a negative effect on percent capacity. The marginal effect was very small, as a 1% increase in

Table 1.
Summary statistics

Variable	Mean	Median	Standard Deviation
Attendance	67,525.81	68,499.00	10,146.72
Abs(Line)	5.0230	4.00	3.36
Total	45.58	45.00	4.98
Years in stadium	19.81	16.00	15.41
Day of game temperature	55.93	57.00	16.69
Day of game wind speed	7.51	7.00	3.94
Day of game cloud cover	51.67	51.00	33.64
Day of game precipitation	0.09	0	0.27
Hour of game temperature	60.94	62	18.38
Hour of game precipitation	0.003	0.00	0.02
Previous day temperature	55.84	57.00	16.59
Previous day precipitation	0.10	0.00	0.33

Table 2. Regression model results: NFL attendance (dependent variable: Attendance as percentage of capacity)

Variable	I	II	III
Intercept	0.9890*** (33.9731)	0.4679 (1.6229)	0.5165* (1.8929)
Monday	0.0066 (1.1486)	0.0066 (1.1595)	0.0065 (1.1506)
Thursday	0.0015 (0.3195)	−0.0002 (−0.0356)	−0.0002 (−0.0321)
Saturday	−0.0026 (−0.2086)	−0.0041 (−0.3201)	−0.0042 (0.7434)
Sunday night	0.0055 (0.3408)	0.0055 (0.9704)	0.0055 (0.9697)
Win $\%_{t-1}$	0.0374*** (5.2176)	0.0370*** (5.1626)	0.0372*** (5.2244)
Dome	0.0006 (0.0253)	−0.7074 (−0.6771)	−0.7871 (−0.8722)
New stadium	0.0368*** (3.3299)	0.0359*** (3.2518)	0.0359*** (3.2474)
Years in stadium	0.0011** (2.4404)	0.0011** (2.3891)	0.0011** (2.4076)
Win probability	−0.1229** (−2.3407)	−0.1183** (−2.2655)	−0.1193** (−2.2906)
Win probability^2	0.1037** (2.1554)	0.1000** (2.0848)	0.1007** (2.1055)
Total	0.0004 (1.1917)	0.0004 (1.0887)	0.0004 (1.0630)
Temperature	−0.0001 (−0.5480)	0.0001 (0.2042)	3.79e-05 (0.1949)
Interaction: temperature and dome	−0.0003 (−0.8383)	−0.0002 (−0.5157)	−0.0002 (−0.5742)
Precipitation	−0.0121* (−1.9251)	−0.0071 (−1.0194)	−0.0065 (−0.9383)
Interaction: precipitation and dome	0.0211* (1.8977)	0.0278** (1.9429)	0.0277* (1.8945)
Cloud cover		−0.0001* (−1.7785)	−0.0001* (−1.7344)
Interaction: cloud cover and dome		−0.0001 (−0.4990)	−0.0001 (−0.7861)
Wind speed		0.0002 (0.4387)	
Interaction: wind speed and dome		0.0002 (0.4387)	
Humidity		6.93e-05 (0.5168)	
Interaction: humidity and dome		−3.96e-05 (−0.1031)	
Barometric pressure		0.0167* (1.8134)	0.0153* (1.7412)
Interaction: barometric pressure and dome		0.0238 (0.7030)	0.0262 (0.8848)
Weekly dummies	Yes	Yes	Yes
Home team dummies	Yes	Yes	Yes
Road team dummies	Yes	Yes	Yes

cloud cover led to about seven more fans on average (assuming a 70,000-seat stadium). Cloud cover interacted with domed games was not found to be statistically significant. Humidity and humidity interacted with the dome game dummy were not found to have statistically significant effects. Barometric pressure was found to have a positive and significant effect on percent capacity at the 10% level (for every 0.1 increase in barometric pressure, it led to an increase in attendance of about 1,050 fans assuming a 70,000-seat stadium), but not when interacted with dome. For the traditional weather variables in this specification, temperature and temperature interacted with dome were not found to be statistically significant, while precipitation interacted with dome games was again found to have a positive and significant effect at the 5% level (precipitation on its own was not found to be statistically significant). Although the variables are related, it appears that actual precipitation leads some residents to substitute into going to NFL games if their city's team has a domed stadium, but cloud cover does not. In terms of the rest of the games, cloud cover appears to possibly have more of a statistically significant impact than precipitation, as the threat of precipitation may be more informative than actual precipitation. Barometric pressure appears to play a role as well, as days with higher barometric pressure lead to more fans, which is consistent with low barometric pressure being associated with negative health issues.

The third regression model specification removes the insignificant new weather variables from specification II (wind speed and humidity) and only includes temperature, precipitation, cloud cover, and barometric pressure as weather-related variables in the model (in addition to their interacted effects with dome). The results are similar to specification II as precipitation interacted with dome was found to have a positive and significant effect, cloud cover was found to have a negative and significant effect, and barometric pressure was found to be positive and significant.

In relation to the non-weather variables in the regression model, dummy variables for the different days of the week where NFL games were played were not found to have a statistically significant effect on percentage capacity of NFL stadiums. It does not appear that Thursday night, Sunday night, or Monday night significantly change attendance compared to Sunday afternoon. In addition, games played in Domes were not found to have significant effects on percentage capacity.

Team performance measured by the lag of win percentage (the win percentage entering the game) was found to have a positive and significant effect on percentage capacity of attendance across all model specifications. More successful teams attract more fans and move attendance closer to capacity. In general, an increase in win percentage of 0.1 will translate into an increase in percentage of capacity by 0.003–0.004 (approximately 200–300 fans for a 70,000-seat stadium).

Significant stadium effects were also found. The first year in a new stadium led to a positive and significant increase in percentage capacity of attendance at the 1% level. An increase in 0.036 in terms of percentage of capacity translates into around 2,520 more fans for a 70,000-seat stadium. The number of years in the stadium for a team also had a positive and significant effect (5% level), implying that older stadiums were also popular for fans as it likely held some nostalgia advantages for the local population.

Game expectations, in terms of home team win probability derived from the betting market, were found to have statistically significant and non-linear effects on attendance. The home team win probability was found to have a negative effect and the home team win probability squared was found to have a positive effect. Both were statistically significant at the 5% level. It appears NFL fans have reference-dependent preferences as they prefer either the home team to be a large favorite or a considerable underdog. This result is the opposite of the original uncertainty of outcome hypothesis, as in this sample, NFL fans do not appear to prefer games that are expected to be close. Fans appear to prefer to attend games where the home team is expected to win easily or to witness a great visiting team (with the chance of seeing an upset victory for the home team).

3. Discussion and conclusions

This study examined NFL attendance for the 2013–2019 regular seasons. The NFL is the most popular sport in the United States and has a distinct schedule structure with each team playing one game a week, with eight home games in a season. This structure, coupled with intense fan interest in the sport, tends to make NFL games more of a major event than its other professional peers in North America.

With this in mind, this study attempts to isolate the effects of various weather conditions on game attendance. Using detailed data from Accuweather, with many possible weather variables to choose from, we explored how the levels of various weather-related variables impacted NFL attendance. Given the scarcity of games in the home city and the once-a-week nature of games, the weather may play a much smaller role for NFL attendance than it does for other sports. We directly tested this hypothesis, while exploring which of the reported weather variables may best relate to consumer decisions, through various specifications of regression models using the natural log of attendance as the dependent variable.

In terms of the weather variables, some informative results were gathered. In the model using only traditional measures of weather variables, temperature and precipitation, significant effects on percentage capacity were found only for precipitation as temperature was not significant. Precipitation and precipitation interacted with dome were both found to have significant effects on percentage capacity, with precipitation being negative and precipitation interacted with dome being positive. Fans prefer to attend fewer outdoor games when there is precipitation but attend more games when the home team plays in a dome and there is precipitation.

The second model specification added cloud cover, wind speed, humidity, and barometric pressure to the model. When included, precipitation was no longer statistically significant, but precipitation interacted with dome still was (positive at the 10% level). For these new weather variables in the second specification, cloud cover and barometric pressure were each found to have statistically significant results, with cloud cover being negative and barometric pressure being positive. The other weather variables and their interactions with the dome dummy variable were not statistically significant. The third regression model specification restricted the independent weather variables to temperature, precipitation, cloud cover, and barometric pressure and found similar results to the second model as precipitation interacted with dome (positive), cloud cover (negative), and barometric pressure (positive) had statistically significant results.

It appears that cloud cover and barometric pressure may add some information to attendance models for the NFL. In the sample studied, temperature was not found to be a significant determinant of attendance in terms of percentage capacity of the stadium. Precipitation was found to be significant when the only weather-related variables included in the model were temperature and precipitation. In the model specifications with cloud cover, precipitation was not statistically significant, but cloud cover was found to be statistically significant at the 10% level. Fans respond to less-sunny days, which could include actual precipitation and also possible expected precipitation, rather than just precipitation itself. In addition, barometric pressure, which can play a role in common conditions such as headaches and joint pain, was found to have a positive and significant effect on percentage capacity. This is consistent with low barometric pressure being associated with negative health issues. Wind speed and humidity were not found to be statistically significant determinants of attendance in terms of percentage capacity.

In relation to variables other than weather, NFL fans were shown to react positively to winning teams. The lagged win percentage (win percentage entering game) was shown to have a positive and significant effect on attendance across specifications. The number of years a team was in their stadium was shown to have a positive and significant effect on attendance. Fans were shown to not desire outcome uncertainty but had reference-dependent preferences as they prefer to either see the home team win or to possibly witness a big upset of a dominant road team visiting the stadium.

The implication of the findings of this paper is that other weather-related factors besides temperature and precipitation could be important in estimating fan demand to attend sporting events such as NFL games. Specifically, cloud cover and barometric pressure were found to play a role in fan decisions. Although these variables were found to be statistically significant, the magnitude in the change in the number of fans attending is not overly large. This could be due to the NFL being more of an event than other sports, with so few home games during the season. These variables, including those not found to be statistically significant here, could be further tested in attendance models for other sports to further investigate which weather-related variables play a significant role and to what extent in terms of attendance.

Notes

1. Retrieved from each game in the sample from www.nfl.com/scores/2019/REG1 and all other weeks and relevant years
2. Retrieved from each team page on the www.covers.com website – for example the 2019–2020 Buffalo Bills were retrieved from https://www.covers.com/sport/football/nfl/teams/main/buffalo-bills/2019-2020
3. https://en.wikipedia.org/wiki/List_of_current_National_Football_League_stadiums

4. Archived data were purchased directly from Accuweather (https://www.accuweather.com/)
5. Retrieved from https://sportsinput.com/nfl-win-probability-point-spread-converted-to-percentage/

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Appendix

	Temp	Precip	Cloud cover	Wind speed	Humidity	Baro pres
Temp	1.0000	0.0440	−0.2285	−0.1292	−0.0535	−0.2945
Precip	0.0440	1.0000	0.3185	0.1801	0.3086	−0.2621
Cloud cover	−0.2285	0.3185	1.0000	0.2951	0.5038	−0.1210
Wind speed	−0.1292	0.1801	0.2951	1.0000	−0.0006	−0.2003
Humidity	−0.0535	0.3086	0.5038	−0.0006	1.0000	−0.1309
Baro pres	−0.2945	−0.2621	−0.1210	−0.2003	−0.1309	1.0000

Table A1. Correlation matrix of weather-related variables

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