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The Impact of Sporting Events on Air Pollution: An Empirical Examination of National Football League Games

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Abstract: (1) Background: Prior research has found that large-scale sporting events may potentially impose negative consequences on the environment, thus impeding the sustainability goals of the sport industry. Along these lines, the current study extends the literature by examining the impact that National Football League (NFL) games have on local-area air pollution. (2) Methods: Air Quality Index (AQI) data measuring six major forms of air pollution were gathered from air monitors positioned close to NFL stadiums and matched with the number of attendees at games. From this, multiple regression analysis was utilized to estimate whether the number of fans was related to changes in air pollution. (3) Results: The regression models found that Ozone and Nitrogen Dioxide levels increased as more individuals attended NFL games. Additional robustness checks and falsification tests suggest that the average NFL event results in an approximately two-percent increase in Ozone levels. (4) Conclusions: The findings from this study contribute to the literature by providing evidence that highly attended sporting events increase pollution levels in the areas near stadiums. Thus, governments and sport organizations should consider low-emission methods to get fans to travel to games in order to reduce their environmental impact.

Keywords: air pollution; sustainability; sport; attendance; air quality index; National Football League

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1. Introduction

Over the last decade, sport scholars have begun to place emphasis on environmental sustainability in sport [1]. That is, beyond just understanding how sport organizations can be sustainable in terms of their business practices and operations, there has also been the recognition of the importance that underlies the relationship between sport and the environment [2]. There is the acknowledgment that not only are natural resources such as water and snow critical to the existence of sports such as golf, hockey, and skiing [3], but that sporting events and consumption of sport products can potentially impact the environment [4]. For example, numerous studies have found that fan travel is responsible for the largest part of the carbon footprint generated by sport mega-events [4,5].

At the same time, the literature focused on sport and the environment has primarily been concerned with examining the attitudes and perceptions of individuals towards sustainability practices [6]. Notably, most existing studies have focused on surveying consumers concerning whether pro-environmental behaviors of sport teams would influence their consumption patterns. What is missing from the extant literature are measures of the environmental conditions surrounding sporting events [7]. Even in examinations of the carbon footprint of sport-related activities, scholars have obtained their results by extrapolating data from surveying small segments of consumers [5,8], and thus they have not provided precise measurements of environmental conditions.

Against this backdrop, sport scholars have recently incorporated actual environmental measures within their research. The focus of these studies has predominantly been on

understanding how environmental conditions, such as air pollution, impact the behaviors and decision making of sport consumers and participants [9]. For instance, researchers found that Major League Baseball (MLB) umpires made more errors in their judgments when there were higher levels of air pollution in the local area where the game was played [10]. From the reverse perspective, there are two notable studies that have analyzed the impact of the sport industry on the environment [11,12]. Both works focused on the impact that the hosting of professional sporting events had on the local area Air Quality Index (AQI), a universal scientific measure of air quality used by most governments around the world. It was found that the hosting of either the Super Bowl [12] or the number of attendees at MLB games [11] caused increases in some of the gases and compounds that are measured by the AQI, indicating that these events led to an increase in air pollution.

Understanding the impact that sporting events have on air quality is critical, as the United Nations Framework Convention on Climate Change has established air pollution as one component of a triple planetary crisis along with climate change and loss of biodiversity [13]. Air pollution is the largest cause of disease and premature mortality worldwide, with studies indicating that around 90% of the Earth's population is exposed to levels of AQI pollutants that are higher than the established guidelines [13]. Previous research has found that even short-term exposure to increased levels of air pollution is linked with increased emergency room visits and mortality rates [14]. Additionally, repeated short-term exposure to air pollution can also manifest into long-term health issues, such as respiratory or cardiovascular disease [15]. As such, it is important to understand the role that sporting events play in impacting local-area air pollution, as even short durations of exposure to pollutants can manifest into severe health consequences for local populations.

Although prior research has established an initial understanding of the potential environmental consequences of hosting sporting events [11,12], there is a need to expand these examinations to develop a more nuanced picture of the impact of sporting events on local air quality. In considering the previous research focused on the impact of sporting events on air pollution, the study focused on the Super Bowl focused only on a single event [12], and thus it does not provide an accurate accounting of the scope of pollution that may be produced from sport competitions. Moreover, as Locke [11] found only small effects from the hosting of MLB games, especially bearing in mind that the consumer profile for MLB games is different from other highly attended sporting events in the country, it is necessary to study the impact other sport competitions have on the environment.

The current study examines the impact that attendance at National Football League (NFL) games has on local-area air pollution. The NFL is selected as the setting for this study for several reasons. While Locke [11] found a link between fan attendance at MLB games and air pollution, there are critical differences between MLB and the NFL that must be considered. Because the NFL has the highest average attendance of any professional sport league in North America, averaging over 60,000 fans a game, it plays in venues that are much larger than those utilized for MLB contests. This also means that NFL stadiums are in different locations than their MLB counterparts. The NFL also plays a different schedule than MLB. The NFL plays games between September and January, while MLB holds games between March and October. Additionally, NFL contests are held predominantly on the weekend, while MLB plays games throughout the week. Because research has demonstrated that both location and timing can play a critical role in pollution levels [16], there is a need to move beyond just the existing examination of professional baseball's impact on air pollution. As higher levels of short-term air pollution can lead to increases in emergency room visits and mortality rates [13,15], there is a need to consider how sport contests of different sizes and timings may impact local air quality. As such, to advance the understanding of how sporting events effect air quality, the current study focused on the impact that attendance at NFL games has on AQI levels. The NFL is also a suitable setting because game attendance over the sample period ranges from 21,054 to 93,579 attendees, thus providing significant variation that allows for better consideration of the impact that the number of attendees has on pollution.

The analysis for this study was conducted by collecting attendance data for all home games played by NFL teams in the U.S. over a five-year period (2014–2018). These data were then matched with the U.S. government's Environmental Protection Agency (EPA) data, which specifically provided the AQI levels from the monitoring station that was closest to the stadium where each game was played. Additional control variables were included for other factors that could impact pollution. From this, results were estimated using panel regression analysis to determine whether the number of attendees at a game had a significant relationship with any forms of air pollution that are measured in the AQI.

Along these lines, the current study makes several contributions. First, in addition to answering the aforementioned need for further examinations of the impact of sport on the environment, it also helps to build a better theoretical and empirical understanding of sport's ecological impact. Notably, this work also extends Locke's model [11] by considering additional factors that could impact pollution levels, including the distance between the monitor and stadium at which games are played, as well as the type of stadium games are played in. As such, the current study aims to extend the inquiries of environmental economics further into the realm of sport. Additionally, as this study provides information regarding the level of impact that large-scale sporting events and fan travel may have on air quality, it can also help to inform policies and decision-makers about ways in which sporting events could be made more sustainable by reducing their impact on the environment.

2. Literature Review

To date, a handful of studies have examined the complex relationship that exists between sport and the environment [17]. Early research in sport considering climate change noted the potential impact on the ski industry, with warming temperatures being related to less snowfall and shorter ski seasons, thus reducing the ability for individuals to participate in winter sport, as well as having a negative financial impact on businesses reliant on these resources [18–20]. The management of resources such as water also present challenges for the sustainability of sport activities as the climate continues to change [21]. Researchers have also examined the carbon footprint of various sport activities, including the amount of carbon produced by community ice hockey teams [22], as well as those from sport tourists and participants [5,23]. Despite this recent surge in research utilizing environmental measures to examine the impact of sport on the environment, few studies have used secondary data to measure actual effects [24]. Rather, scholars have mostly relied on surveys of human activities to estimate how much carbon is produced.

Against this backdrop, a new lineage emerging within sport ecology [1] has utilized public databases of air pollution to provide a more precise accounting of the relationship between sport and the environment. Watanabe et al. [9] considered whether pollution levels in major Chinese cities had an impact on consumer interest in attending professional soccer matches. Despite being one of the most heavily polluted regions in the world, this study found no evidence of pollution reducing sport consumption. Such findings are especially concerning considering the Chinese government's approach to dealing with pollution [25] and the potential health consequences of exposure to such high levels of air pollutants [26]. Scholars have also considered the potential for air pollution to cause highly skilled workers to commit errors [10]. Specifically, it has been found that when pollution was higher during Major League Baseball (MLB) games, umpires were more likely to make errors in their calls.

At the same time, there is still a need to consider the reverse relationship of how human behaviors in sport affect the environment [6]. To date, the main study to accomplish this is Locke's [11] examination of whether attendance at MLB games impacts air pollution levels in the same market. Notably, through using data from the Environmental Protection Agency (EPA), Locke developed a model estimating various types of air pollution as a function of attendance, weather, and other game-related factors. The results of this study found that as the number of individuals attending MLB games increased, the pollution

levels also increased. Although the effect size was relatively small, with a typical game raising pollution by less than a percent, considering that 81 home games are played within a season, the total volume of air pollutants that could potentially be attributed to activities around professional sport may be rather significant.

Considering the above literature, including recent calls for increased economic examination of the ecological and environmental effects of sport [1,6], this study extends the work of Locke [11] by analyzing the impact of NFL games on air pollution. Specifically, a model is estimated to examine whether certain prevalent forms of air pollution increase as the number of attendees at games rises. Along these lines, we develop the following research question:

RQ: Is there a relationship between the attendance at NFL games and local-area air pollution?

3. Materials and Methods

In order to examine whether attendance at NFL games has an impact on air quality, pollution data were collected from the EPA's data warehouse from 2014 through 2018. A five-year period was chosen because NFL teams only play ten home games a season (eight regular season and two pre-season contests). As such, the longer time frame allows us to capture a larger number of observed games across various markets. Moreover, this time frame also has a number of teams that change the venue at which they play games, allowing for some variation within markets in terms of location, size, and access to the stadium.

For this study, six dependent variables were used to measure the six different gases/compounds that are used to measure AQI [26]. Notably, the six gases/compounds that make up AQI are: ozone (O_3), sulfur dioxide (SO_2), nitrogen dioxide (NO_2), carbon monoxide (CO), as well as two sizes of particulate matter (PM 2.5 and PM 10). These six gases/compounds were selected by scientists when creating the AQI as they all measure the primary forms of air pollution created by human activities. Notably, AQI values are presented to help the public understand the level of pollution in the air using the pollutant with the highest value over the previous hour. While this presents a metric that is easier to understand, it is possible that there are high levels of more than one pollutant in the air. As such, we separated the six gases and compounds used to measure AQI into their own dependent variables and models to consider the potential links between sporting events and various forms of air pollution.

The six gases/compounds used in the AQI measure were all chosen because of their relation to human activities and the impacts they have on health and the environment. Ozone is created by the emissions from internal combustion engines or power plants and is the primary component which makes up smog. Likewise, nitrogen dioxide is a byproduct of high-temperature combustion and is what gives the brown color to smog clouds. Sulfur dioxide is a colorless gas that is created by burning fossil fuels containing sulfur, such as diesel gas. Carbon monoxide is caused by the incomplete burning of organic matter such as fossil fuels or wood. Finally, PM 2.5 and PM 10 measure the fine particulate matter in the air (either 2.5 or 10 microns in diameter or smaller), which can be created by power plants, vehicle emissions, as well as agricultural burning or forest fires [26].

Within his examination of air pollution at MLB games, Locke [11] only found significant changes in ozone in relation to attendance. Such findings are logical in the understanding of the nature of air pollution in the U.S., as ozone is created by combustion engines, and thus the findings indicate a larger number of people traveling to games by car when there is higher attendance. Following Locke's modeling, we similarly utilize all six gases/compounds in their own individual models to examine whether attendance at NFL games impacts the level of air pollution. In terms of the actual measurement of AQI, we utilized daily averages reported by air quality monitors that have been deployed by the EPA across the country. Because the EPA provides the latitude and longitude coordinates of each air quality monitor, we were able to determine the closest air quality monitor to every stadium in the NFL, as well as the exact distance in miles between the two locations

by using the Haversine formula for calculating circle distance between two points on the Earth:

$$\begin{aligned} Distance = \quad & ACos(Cos(Radians(90 - Lat1)) \times Cos(Radians(90 - Lat2)) \\ & + Sin(Radians(90 - Lat1)) \times Sin(Radians(90 - Lat2)) \\ & \times Cos(Radians(Lon1 - Lon2))) \times 3958.756. \end{aligned} \quad (1)$$

The dependent variables in this study are the six different gases/compounds used to measure AQI from the monitor that is closest to each stadium. Because not all air quality monitors measure every type of pollution, it needs to be noted that multiple monitors were utilized in some markets to measure each form of pollution. Furthermore, as some markets did not have complete air quality data for every day of the five-year period examined in this study, there are differences in the number of observations for the dependent variable. The summary statistics presented in Table 1 display that while most measures had a relatively higher number of observations, typically between 45,000 and 58,432, PM 10 only had 22,609 observed values within this dataset. As the five-year dataset encompasses a total of 1826 days, the maximum number of observations across 32 teams should be 58,432. As such, less than 39% of days had observations of PM 10. Finally, after examining histograms of the pollution measures, we transformed all of them according to their natural log to normally distribute the data.

Table 1. Summary Statistics.

Ozone	**Obs**	**Mean**	**Std. Dev.**	**Min**	**Max**	**NO_2**	**Obs**	**Mean**	**Std. Dev.**	**Min**	**Max**
AQI	51,531	36.10	16.34	0	187	AQI	48,572	23.42	12.24	0	104
lnAQI	51,531	3.52	0.4356	0	5.24	lnAQI	48,572	3.05	0.5792	0	4.65
Attendance	51,531	1703	10,645	0	93,579	Attendance	48,572	1797	10,971	0	93,579
Distance	51,531	5.05	3.24	0.6231	15.18	Distance	48,572	3.81	2.84	0.5712	11.30
Dome	51,531	0.2278	0.4194	0	1	Dome	48,572	0.2709	0.4444	0	1
WindSp	51,531	8.23	3.57	0	38.03	WindSp	48,572	8.29	3.61	0	38.03
Precip	51,531	0.1050	0.3302	0	9.92	Precip	48,572	0.1063	0.3380	0	9.92
Temp	51,531	60.75	17.67	−17	105	Temp	48,572	60.14	18.27	−17	105
SO_2	**Obs**	**Mean**	**Std. Dev.**	**Min**	**Max**	**PM 2.5**	**Obs**	**Mean**	**Std. Dev.**	**Min**	**Max**
AQI	52,246	3.42	9.33	0	150	AQI	60,185	36.07	16.88	0	222
lnAQI	52,246	0.8720	0.9303	0	5.02	lnAQI	60,185	3.49	0.5347	0	5.41
Attendance	52,246	1827	11,080	0	93,579	Attendance	60,185	1806	10,994	0	93,579
Distance	52,246	5.20	3.86	0.9136	18.86	Distance	60,185	4.12	3.19	0.5712	51.17
Dome	52,246	0.2558	0.4363	0	1	Dome	60,185	0.2574	0.4372	0	1
WindSp	52,246	8.34	3.64	0	38.03	WindSp	60,185	8.29	3.62	0	38.03
Precip	52,246	0.1074	0.3378	0	9.92	Precip	60,185	0.1084	0.3431	0	16.07
Temp	52,246	59.17	18.76	−17	105	Temp	60,185	59.17	18.65	−17	105
CO	**Obs**	**Mean**	**Std. Dev.**	**Min**	**Max**	**PM 10**	**Obs**	**Mean**	**Std. Dev.**	**Min**	**Max**
AQI	45,505	6.09	4.31	0	55	AQI	22,609	19.57	11.24	0	141
lnAQI	45,505	1.80	0.5651	0	4.03	lnAQI	22,609	2.89	0.5288	0	4.96
Distance	45,505	4.18	4.59	0.4964	18.86	Attendance	22,609	1817	10,858	0	92,076
Attendance	45,505	1798	10,857	0	91,046	Distance	22,609	4.77	3.72	0.5522	18.86
Dome	45,505	0.1918	0.3937	0	1	Dome	22,609	0.2981	0.4574	0	1
WindSp	45,505	8.48	3.68	0	38.03	WindSp	22,609	8.29	3.50	0	29.97
Precip	45,505	0.1063	0.3261	0	8.67	Precip	22,609	0.1140	0.3524	0	9.92
Temp	45,505	58.08	18.36	−17	98	Temp	22,609	60.41	19.65	−9	105

Turning to the independent variables to be included in our model, we first utilized data from the pollution monitors to create control variables. To begin with, following Locke's [11] model, we include measures of average temperature (F), average wind speed (MPH), and the volume of precipitation (inches). All measures of weather conditions were collected in Imperial units as the U.S. EPA data site only provides information in this format. We also include the attendance at each game, as reported in the official box scores for each

contest. For this study, we include all games played during the five-year period, including pre-season, regular season, playoff games, and the Super Bowl.

Two additions are made to the model to control for factors that are not included within Locke's model. First, we include a dummy variable for games played in domed stadiums (*Dome*), as previous studies have noted for the potential for domes to impact air pollution levels [9]. Because domes may use additional systems, such as air conditioning, it is possible that they could produce higher levels of certain types of emissions. There is also the possibility that because a dome may trap other types of gases that are normally associated with games, such as the smoke from fireworks, lower levels of pollution could potentially be observed. Second, we use the Haversine calculations to measure the distance in miles between the stadium and air quality monitors (*Distance*). Because of the potential for air pollution to be concentrated in areas with high volumes of traffic, as well as dissipate the further one moves from these regions, *Distance* is included to account for any effects distance may have on measured pollution levels. From this, the estimated model within this study takes the form of:

$$AQI_{ijks} = \alpha_0 + \beta_1 Attendance_{ijks} + \beta_2 Distance_{ijks} + \beta_3 Dome_{ijks} + \beta_4 Wind\ Speed_{ijks} + \beta_5 Precipitation_{ijks} + \beta_6 Temperature_{ijks} + \mu_{ijks}. \quad (2)$$

Due to the panel nature of the data, there is need to consider whether to estimate the regression results with either fixed or random effects. Prior research in sports economics focused on attendance demand have noted the preference for using fixed effects as they allow scholars to control for differences in time and location. Locke [11] utilized fixed effects to account for differences in stadiums and the timing of games in his analysis of the impact of MLB game attendance on pollution. Scholars have utilized random effects in their panel regressions when there are important time-invariant variables within the model, as the use of fixed effects would drop any time-invariant measures from the estimated results [27].

Rather than assume that fixed effects were the suitable method of estimation, we followed the guidance of prior econometric works by conducting a Hausman test. Models were first estimated using fixed and then random effects to test whether the difference in the coefficients were systematic. The Hausman test was significant at the five-percent level for all six dependent variables, indicating that fixed-effects are best suited for estimating results. As such, to analyze whether there is a relationship between air pollution and game attendance at NFL games, we utilized a panel regression with fixed effects to control for differences in stadiums, days of the week, week of the year, and years, similar to the model used by Locke's analysis of AQI and Major League Baseball attendance [11]. In Equation (2), *i* indexes stadium, *j* indexes day of the week, *k* indexes week of the year, and *s* indexes year.

4. Results

4.1. Summary Statistics

To answer the research question of whether there is a relationship between attendance at NFL games and local-area air pollution, we first estimate results for six regression models. Because AQI is made up of six different gases/compounds, we estimate a separate model for each form of air pollution to analyze whether sporting events have an impact on any specific pollutants. Additionally, because not all forms of air pollution were gathered at continuous intervals from the local monitoring stations located near stadiums, there are differences in the number of observations for the various pollutants. Examining Table 1, which contains the summary statistics for the data used within this research, one can see that there are different numbers of observations for each AQI gas/compound. While most of the pollutants have around 50,000 to 60,000 observations over the five-year period of this study, we were only able to obtain 22,609 observations of pm10 close to NFL stadiums.

In further considering the summary statistics, one can see the variation in the key independent variables of interest. *Attendance* varies from 0 to over 90,000. The values of 0 would indicate days when games were not played, and thus there were no fans attending

games at these facilities. The actual average attendance for NFL games over the course of this five-year dataset was 60,000. One other variable to note is the *Distance* measure, which indicates how far on average the air pollution readings were taken from the stadium as measured in miles. This value ranges between half a mile and 18.86 miles, with the average distance between a stadium and an AQI monitor being around 4 to 5 miles.

4.2. Regression Results

The estimated results for the six panel regressions with fixed effects are presented in Table 2. Considering that our main research question focused on whether there is a relationship between hosting NFL games and air pollution, the results indicate that the ozone and nitrogen dioxide were both positive and significant in relation to home attendance. The AQI measurements of all other forms of air pollution (sulfur dioxide, carbon monoxide, PM 2.5, and PM 10) were insignificant. At a base level, the findings for ozone match those from Locke [11], in that the higher the attendance at a game, the greater the level of ozone within the atmosphere. Locke found no evidence of any other gas/compound having a significant relationship with attendance, yet we find some evidence of an increase in nitrogen dioxide levels as more people attend NFL games, though this result is only significant at the ten-percent level.

Table 2. Regression Results.

	Ozone	**SO_2**	**CO**	**NO_2**	**PM 2.5**	**PM 10**
Variables	**Coef.**	**Coef.**	**Coef.**	**Coef.**	**Coef.**	**Coef.**
Attendance (×10,000)	0.0031 **	0.0002	0.0003	0.0030 *	0.0006	−0.0025
	(0.0015)	(0.0032)	(0.0019)	(0.0016)	(0.0018)	(0.0029)
Distance	0.0835 *	−0.5130 ***	−0.1062	−0.0477	−0.0128 ***	−0.1399
	(0.0493) **	(0.1437)	(0.1004)	(0.0922)	(0.0010)	(0.1982)
Dome	−0.1436 ***	0.3760 **	0.2017 ***	−0.1376 **	−0.7025 ***	−0.0334
	(0.0563)	(0.1538)	(0.0762)	(0.0700)	(0.0690)	(0.2176)
WindSp	0.0023 ***	−0.0401 ***	−0.0483 ***	−0.0712 ***	−0.0464 ***	−0.0312 ***
	(0.0005)	(0.0010)	(0.0006)	(0.0005)	(0.0006)	(0.0010)
Precip	−0.1732 ***	−0.1334 ***	0.0009	−0.0277 ***	−0.1345 ***	−0.2399 ***
	(0.0047)	(0.0100)	(0.0060)	(0.0051)	(0.0056)	(0.0085)
Temp	0.0061 ***	−0.0006 *	0.0057 ***	0.0014 ***	0.0033 ***	0.0082 ***
	(0.0002)	(0.0003)	(0.0002)	(0.0002)	(0.0002)	(0.0003)
constant	2.5322 ***	3.6366 ***	2.5175 ***	3.6652 ***	4.0879 ***	3.1948 ***
	(0.2550)	(0.7738)	(0.4286)	(0.3636)	(0.0251)	(0.9917)
R-Squared	0.1638	0.0444	0.0886	0.3047	0.0325	0.0375
Observations	51,531	52,246	45,505	48,572	58,432	22,609

*—significant at the 10% level, **—significant at the 5% level, ***—significant at the 1% level.

In further considering these results, the coefficients for both the ozone and NO_2 models indicate that for every 10,000 people who attended a game, there was a 0.3% increase in the AQI. As the average attendance for games in our sample was 60,000, this means that on average a game increased the level of ozone and NO_2 in the air by about 1.8%. Because ozone and nitrogen dioxide are typically the two primary components of smog, these results seem to indicate that the estimated increases in air pollution are likely related to vehicle emissions. This is consistent with prior studies that note that the greatest ecological impact of sporting events is from fan travel [4]. In other words, it is not the operations of a sporting event that are likely the main cause of air pollution, but instead fans traveling to games in their own personal vehicles that generate significant increases in ozone.

Comparing the coefficients from the ozone model in this research with the results with those from Locke [11], we find approximately four times more ozone created per attendee at NFL games than at MLB games. There are several potential explanations for this result, including that NFL fans may be more inclined to drive to games, tailgate in parking lots

before games, or even drive vehicles that have higher emission levels than those who attend MLB games. Although we find each attendee at NFL games produces about four times more ozone than those at MLB games, it should be noted that the 32 NFL teams typically play 10 home games a year, while the 30 MLB teams will play a minimum of 81 home games in a season. As such, even though the NFL boasts higher average attendance per game, MLB games may introduce a greater total volume of pollution into the air over the course of a year due to the sheer number of events that take place. At the same time, because NFL games are found to cause greater short-term increases in air pollution, this may pose greater health risks for individuals with certain cardiovascular conditions such as asthma [14], or even increased hospitalization and mortality rates [9].

Continuing to the other independent variables within the models, *Distance* was negative and significant in the sulfur dioxide and PM 2.5 models, while PM 10, carbon monoxide, and nitrogen dioxide were insignificant. Curiously, ozone was positive and significant in relation to distance from the stadium, which could be attributed to the fact that AQI monitors positioned further from a stadium may be located near areas of high concentration of ozone pollution such as highways. Next, domed stadiums were found to be associated with a significant decrease in ozone, nitrogen dioxide, and PM 2.5, and a significant increase in sulfur dioxide and carbon monoxide. Notably, as sulfur dioxide and carbon monoxide are associated with the combustion of organic materials such as fossil fuels, these results indicate that the areas around domed stadiums have higher levels of fossil fuel use [26]. Future research should investigate whether this increase in fossil-fuel-based pollution is because of the operations of domed stadiums or other sources, especially considering that most domed stadiums have their electricity generated by power plants in distant locations.

Turning to weather-related control variables, wind speed (*WindSp*) had a positive relationship with ozone, and a negative relationship will all other gases/compounds. This would suggest that as conditions became windier, pollution tended to dissipate within a local area. Similar findings are found for precipitation, which was negative and significant for all measures except carbon monoxide, indicating that weather systems producing precipitation may be effective in reducing polluting gases and compounds within a city [28]. Finally, average temperature was found to have a positive relationship with ozone, carbon monoxide, nitrogen dioxide, PM 2.5, and PM 10, but a negative relationship with sulfur dioxide. These findings indicate that as the temperature increased within markets, the level of air pollution also increased, which is in line with prior research that has noted a potential positive correlation between temperature and air pollution [9].

4.3. Robustness Checks

To further probe the results of the initial models that found a statistical relationship between attendance at NFL games and levels of ozone and nitrogen dioxide, additional robustness checks were conducted on the data. To begin, the full data set used to estimate the results in Table 2 includes all days of the week, where NFL games are only played on Thursday, Saturday, Sunday, and Monday. As such, we removed the data from the days of the week from the dataset that the NFL does not play games on, as those days would have no variation in the attendance values and could potentially skew the results. Estimating the results for all six forms of AQI pollutants using this reduced form of the dataset produced similar results, and thus would suggest the robustness of our findings.

For the next stage of robustness checks, we introduced a square term for the temperature variable (*TempSq*), as there may be a U-shaped relationship between temperature and air pollution, as there should be greater combustion of fossil fuels when the temperature is both cold (heating) and hot (air conditioning). The results for this robustness check can be found in the first two models displayed in Table 3. Notably, the results for ozone and nitrogen dioxide were consistent with the findings from the full models (Table 2), including producing similar coefficients as well as the fact that there was only a weak relationship between nitrogen dioxide and attendance at NFL games.

Table 3. Robustness Test.

	Ozone	NO_2	Ozone	NO_2
Variables	**Coeff.**	**Coeff.**	**Coeff.**	**Coeff.**
Attendance	0.0032 **	0.0031 *	—	—
	(0.0015)	(0.0016)	—	—
Game	—	—	0.0212 **	0.0179
	—	—	(0.0101)	(0.0111)
Distance	0.0768	−0.0513	0.0834 *	−0.0497
	(0.0488)	(0.0919)	(0.0493)	(0.0919)
Dome	−0.1295 **	−0.1347 *	−0.1434 **	−0.1385 **
	(0.0558)	(0.0698)	(0.0563)	(0.0698)
WindSp	0.0021 ***	−0.0712 ***	0.0024 ***	−0.0712 ***
	(0.0005)	(0.0005)	(0.0005)	(0.0005)
Precip	−0.1702 ***	−0.0275 ***	−0.1733 ***	−0.0279 ***
	(0.0046)	(0.0051)	(0.0047)	(0.0051)
Temp	−0.0059 ***	−0.0003	0.0061 ***	0.0014 ***
	(0.0004)	(0.0004)	(0.0002)	(0.0002)
TempSq	0.0001 ***	<0.0001 ***	—	—
	(<0.0001)	(<0.0001)	—	—
constant	2.720 ***	4.0187 ***	2.4756 ***	3.9839 ***
	(0.2527)	(0.3627)	(0.2550)	(0.3656)

*—significant at the 10% level, **—significant at the 5% level, ***—significant at the 1% level.

To further analyze the link between attendance and the two pollutants (ozone and nitrogen dioxide) that had statistically significant relationships with attendance, we introduce a robustness check similar to Locke (2019). That is, we removed the *Attendance* variable, and instead replaced it with a dummy variable that simply measured whether an NFL game was played on that day (*Game*). The results from this robustness check are displayed in the last two models in Table 3. Notably, the *Game* variable had a positive and significant relationship with ozone, with the coefficient indicating that an NFL game increased ozone levels by about 2.1%. Again, this is similar to the findings from the original models that utilized the full dataset (Table 2), as those results indicated that an NFL game with an average attendance of 60,000 would experience a 1.92% increase in ozone in the local area. Focusing on the model measuring nitrogen dioxide, the *Game* variable was insignificant, suggesting that there may not be a relationship between hosting NFL contests and the volume of nitrogen dioxide in the atmosphere.

Although all of our models indicate that there is a significant relationship between NFL games and ozone levels, it is possible that the statistical relationship may be related to other factors that are not accounted for in the dataset. As such, in order to examine the causal relationship, the last stage of our analysis is to conduct a falsification test. Specifically, we replace the *Game* variable that measured the presence of a home game, with *Away* which measures days when the home team was playing in a different location. The results for the falsification test can be found in Table 4. In this final model, *Away* was insignificant in relation to ozone, indicating that when the team was playing games against teams in other markets, there was no significant increase in attendance. Based on this, it provides strong evidence that hosting NFL games causes increases in local ozone levels, with the results from multiple models suggesting that the average NFL game increases the amount of ozone by around two percent.

Table 4. Falsification Test for Ozone.

Variable	Coeff.
Attendance	—
	—
Game	—
	—
Away	0.0079
	(0.0116)
Distance	0.0830
	(0.0493)
Dome	−0.1440
	(0.0563)
WindSp	0.0023
	(0.0005)
Precip	−0.1733
	(0.0047)
Temp	0.0062
	(0.0002)
TempSq	—
	—
Constant	2.5367 ***
	(0.2550)

***—significant at the 1% level.

5. Conclusions

The findings from this study extend the examination of the impact of sport on the environment, specifically highlighting the impact that large-scale sporting events can have on local air quality. Notably, the results from empirical models and robustness checks fall in line with the results from Locke [11], in that ozone, the primary component of smog, increases significantly as more people attend NFL games. Particularly, the results from this study show about four times more production of ozone per person than Locke's [11] study of MLB games. Although MLB games may introduce a greater volume of air pollution through the course of a season, the increased levels of air pollution related to NFL games is alarming. Research has noted that air pollution may be the greatest current health risk to humans, with millions dying each year from exposure to and the side effects of air pollutants [13]. As our calculations suggest that NFL games produce around four times more air pollution than MLB events, professional football games in America could pose significant health and ecological risks to local communities. At the same time, it should also be acknowledged that college football games are also some of the highest-attended sporting events in the U.S., sometimes boasting even higher attendance than NFL contests. Where professional sporting events almost entirely take place in urban areas, college football is often played in rural or suburban locations, and as such, these games could potentially lead to an increase in pollution in a variety of settings. Following from this consideration, future research should continue investigating the relationship sporting events have with air pollution, as well as other potential ecological impacts.

Overall, this current research extends prior work examining the relationship between sport and the environment. From the perspective of enhancing the sustainability of the sport industry, the findings from this study highlight that hosting large-scale sporting events with many attendees will indeed have an ecological impact. In this manner, as research has consistently found that sporting events will lead to increased levels of air pollution, there is a need to consider the development of policies and practices that will reduce the negative impact of sporting events. Simply banning fan travel or canceling sporting events does not seem to be a proper approach to trying to alleviate the impact of these events, as owners of sport organizations will not readily give up one of their main revenue sources, as well as the fact that consumers will often substitute one form of entertainment with another. That is, even if individuals do not attend a sporting event,

they may choose to participate in other activities such as going to concerts, movie theaters, restaurants, or other such leisure activities that might also have effects on local air pollution.

As the results from this research find an increase in ozone, which is likely related to the use of motor vehicles to travel to games, the solution for decreasing pollution and enhancing the sustainability of sporting events is likely through providing environmentally friendly ways for fans to travel to stadiums. Although most stadiums in the NFL can be accessed through public transportation, it is the case that many fans are still accustomed to traveling to events by driving their own personal vehicles. Thus, no matter how much professional sport teams tout the environmental sustainability of their facilities, they are likely not addressing the behavior that is having the largest environmental impact: fans driving to games. Based on this fact, enhancing the sustainability of sport events will probably require a multi-pronged approach, with teams and cities cooperating to encourage fans to travel to sporting events using lower-emission travel options, including public transit, low-emission vehicles, and so forth. Indeed, in some cases, professional sport teams have started to encourage fans to travel using public transportation, but this has not necessarily reduced the number of fans choosing to travel via motor vehicles. It should also be noted that in some instances, the location of stadiums is also part of the problem, as some NFL teams have chosen to build their facilities in suburban areas that are right next to highways and limited public transit options. Additionally, because most NFL teams have large parking infrastructures built in the immediate proximity of a stadium, it creates a situation where fans will typically choose to commute to games using personal vehicles because of lower travel costs. In this manner, the burden of enhancing the sustainability of sporting events should not just be placed upon fans, but also needs to be considered by sport organizations and governments when new facilities are being planned and constructed. In many cases, teams and other stakeholders may be reluctant to participate in such activities, as this would mean the reduction or even potential elimination of parking revenue. Thus, for games to be more sustainable and reduce air pollution levels, there is need to disrupt the existing model of fan travel to sporting events in North America, which would require a shift in the operational practices of powerful sport organizations such as the NFL and its teams. There are a few limitations in this study that warrant discussion. To begin with, the data set for some gases/compounds is not complete (especially PM 10), and thus the results for some of the pollutants do not use the data from every day within the dataset. As weather and pollution are complex environmental systems, the use of econometric models may not be able to fully account for variations in observed air quality levels. For example, the direction of the wind may constantly change, and thus shift pollution so that it is not captured by the monitor, despite there being a large volume of smog in the area. Another similar issue arises in that the data set used within this study uses daily measures; recent work measuring AQI levels at a single college football stadium show there can be greater variation in the pollution levels at the minute-by-minute level [29]. Additionally, the study of college football air pollution also highlights that the positioning of monitors and their proximities to stadiums can play a critical role in obtaining proper measurements of air pollution. Another limitation of this study is that we are unable to control for other events that could lead to increased pollution near NFL games. Although most other large events such as professional sport games, conventions, or concerts avoid scheduling in areas near NFL games because of traffic congestion and other logistical concerns, there is still the possibility that a few events may have been hosted near NFL games. However, the size and number of such events would be rather small, and thus would likely have an insignificant impact on air quality levels throughout the dataset.

In conclusion, the results from this study indicate that NFL games are responsible for a small but significant change in daily air quality. Due to the large health and ecological consequences that come from air pollution, it is certainly the case that future research should further develop this lineage to understand the impact of sport events on air pollution, as well as to help create better policies. For example, future research could consider the differences in pollution between locations hosting games where fans primarily drive to

games versus those where individuals take public transportation. Such research would allow for better understanding of the factors that lead to increases of pollution and things that could be done to alleviate the negative ecological impacts. Notably, many countries such as Germany and Qatar have started to provide free transit to fans who purchase tickets to football (soccer) matches to encourage them to use transit and reduce emissions created from driving to games [30]. At the same time, it should be recognized that many professional sport leagues, including the NFL, have been accused of "green washing"—adopting small-scale lower impact environmental practices to enhance their image by amplifying and captivating consumers' eco-blindness in green firms and products [31,32]. That is, while environmental assessments continue to identify travel as having the largest ecological impact and carbon footprint of hosting professional or mega sport events [33], most sport leagues instead focus on developing recycling programs or other activities with little environmental impact. Thus, there is a need for continued research into the effect that sport events have on air pollution, as hosting events has the potential for negative consequences for both the environment and human health.

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