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Productivity effects of air pollution: Evidence from professional soccer

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ABSTRACT

We estimate the causal effect of ambient air pollution on individual productivity using panel data on the universe of professional soccer players in Germany over the period from 1999 to 2011 matched to hourly information on the concentration of particulate matter near each stadium at the time of kick-off. We exploit exogenous variation in players' exposure to air pollution due to match scheduling rules that are beyond the control of teams and players. The results of our analysis reveal statistically significant negative effects of air pollution on players' productivity, measured by the total number of passes per match. Allowing for a non-linear dose-response relationship further reveals that our findings are not driven by extreme levels of air pollution. Rather, negative effects already emerge at moderate levels.

1. Introduction

Air pollution is considered an important environmental risk factor for human health. The European Environment Agency estimates that exposure to air pollution causes more than 550,000 premature deaths per year in Europe alone (EEA, 2016). Against this backdrop, a vast number of epidemiological studies has been devoted to quantitatively assessing the health impacts of exposure to various air pollutants (see, for example, Pope III (2000) and Pope III and Dockery (2006) for overviews). More recent contributions by the economics literature have further added to the understanding of this relationship by highlighting the importance of individuals' optimization and avoidance behavior in response to air pollution, and widening the focus beyond traditional health outcomes (see Graff Zivin and Neidell, 2013, for an overview).[1]

In addition to causing damage to individuals' health,[2] recent empirical evidence further suggests that exposure to ambient air pollution may induce additional costs for societies by reducing individuals' labor supply and productivity, and consequently hindering economic growth. Hanna and Oliva (2015) demonstrate that poor air quality can reduce labor supply at both the extensive and intensive margin, while Graff Zivin and Neidell (2012), He et al. (2016) and Chang et al. (2016) show that air pollution significantly impairs the productivity of low-skilled agricultural and factory workers.

Our paper contributes to this strand of the literature by analyzing the effect of ambient air pollution on the productivity of young adults who are positively selected with respect to their general physiological condition, namely professional athletes. For this purpose, we make use of panel data on the universe of players and teams in Germany's top professional soccer league (the *Bundesliga*) over the period from 1999 to 2011. The richness of these data along with particular institutional features of professional soccer in Germany provide a useful setting to study the causal

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[1] As discussed in more detail below, levels of air pollution may cause sorting of high-income individuals into areas with better air quality (Chay and Greenstone, 2005). Moreover, individuals may try to avoid exposure to pollution (e.g. by reducing the time spent outside), such that exposure to pollution is endogenous (Neidell, 2009).

[2] For economic studies on infant mortality, see Chay and Greenstone (2003), Luechinger (2014) or Tanaka (2015). Effects of air pollution on infants' and children's health are studied by Currie and Neidell (2005), Currie et al. (2009), Lleras-Muney (2010) and Janke (2014), among others. Deschênes et al. (2012) show that high concentrations of air pollution increase premature death among the elderly. Schlenker and Walker (2016) demonstrate that hospitalization rates among the working-age population increase with the level of air pollution.

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relationship between air pollution and individual productivity.[3] First, due to the *Bundesliga*'s match scheduling rules that are beyond the control of teams and players, individual exposure to ambient air pollution can be considered exogenous. Hence, our approach overcomes endogeneity concerns arising from residential sorting and behavioral responses to avoid exposure to pollution. Second, we are able to exploit rich data on individual productivity, which is measured in a consistent and comparable way in 2956 matches at 32 different stadiums throughout the country on a weekly basis over a twelve-year period. Such a comprehensive coverage is generally not available for most other occupations. For each match, we combine information on individual productivity with hourly data on the concentration of particulate matter (PM10) and ozone (O_3) in spatial proximity to the stadium at the time of kick-off.

As our main measure of a player's productivity we use the total number of passes per match. As discussed in detail below, passing constitutes a decisive element of the game and has been shown to be correlated with team success (see, for example, Collet, 2013). In addition, the number of passes is related to a player's physical ability but also reflects his effort choices during a particular game. Air pollution may thus impair the overall productivity of a player by limiting his physical capacity but also by inducing him to reduce his effort level in order to avoid additional physical strain.

Overall, we find significant negative effects of ambient air pollution on players' productivity. Using within-player variation and controlling for weather conditions on the matchday as well as a variety of player, team and match variables we find that a one standard deviation increase in the concentration of particulate matter (around 16 $\mu g/m^3$) reduces the number of total passes played by 0.4 – or 2.4% of a standard deviation – on average. When allowing for a non-linear dose-response relationship, our results further reveal that negative effects of PM10 concentration already emerge at moderate levels of air pollution. By contrast, we do not find a statistically significant effect of ozone concentration on players' productivity once controlling for weather conditions and the time of kick-off. We show that this is most likely due to limited variation in ozone concentration in our estimation sample, given that *Bundesliga* matches are generally not held during summer when ozone concentrations peak due to intense solar radiation and high temperatures.

While our estimates do not allow us to disentangle the relative importance of the pure physiological effect of air pollution from players' behavioral responses to the additional physiological strain, we provide suggestive evidence that both factors drive the observed reduced-form effect. More precisely, we show that air pollution affects players' pass accuracy as well as their style of play, measured by the ratio of long over short passes. While we argue that the former measure rather reflects a player's physiological ability, the latter relates more to his behavioral choice regarding the style of play as he may be able to alleviate physical strain by kicking the ball far away.

Our analysis further reveals considerable heterogeneous effects of air pollution across individuals. We find that negative effects of particulate matter on passing increase with age and are largest for players aged above 30. Lastly, we show that aggregate team- and match-level regressions yield similar results, suggesting that interaction effects between pollution, individual productivity and the player's team-mates' or opponents' productivity are either small or cancel out.

The remainder of this paper is organized as follows. Section 2 describes the institutional background and data. Section 3 introduces the empirical strategy. The results are presented in Section 4, before Section 5 concludes.

2. Background and data

2.1. Professional soccer in Germany

In our analysis, we exploit rich data on athletes' performance in matches of the *Bundesliga*, Germany's top professional league of men's soccer. Every season, eighteen teams face each other at home and away (see Fig. 1 for the geographic spread of teams across Germany). Thus, a season comprises 34 matchdays and 306 matches, which are typically held on weekends between late August and May.[4] At the beginning of every season, the German Soccer League determines the match schedule for the entire season and specifies the weekend on which a specific matchday takes place as well as which teams face each other at which stadium. The exact day and time of each match is determined several weeks in advance and subject to a set of factors, such as international soccer competitions, television agreements or security considerations.[5] Importantly, match schedules are beyond any control of teams and players.

2.2. Productivity of soccer players

Information on players' productivity is provided by *deltatre*, a commercial enterprise collecting data on professional sports and serving as an external service provider to the media and sports clubs. The dataset comprises information on all *Bundesliga* matches for every season from 1999/2000 to 2010/2011 and contains detailed information for each match (location, date and kick-off time, home and away teams) and each player who was on the pitch at any point during the match.[6] For every player, we observe the number of minutes played (up to the full duration of 90 min), the team played for, the position played (defender, midfielder or striker) as well as various measures of productivity. We exclude goalkeepers from our analysis as they constitute a very different style of play.

We use players' total number of ball passes during a match as our main measure of individual productivity. Passes generally serve as one key statistic for the assessment of players' performance in soccer matches. Although teams might be successful by pursuing a rather defensive style of play and thus passing the ball less often than their opponent, research shows that the number of passes represents an essential element of team success. For example, Redwood-Brown (2008) shows that a team's number of completed passes significantly increases in the five minutes before scoring. Moreover, focusing on the major European soccer leagues (including the *Bundesliga*), Collet (2013) documents a strong positive relationship between the number of passes and various measures of team success, such as the total number of goals scored, the likelihood of winning and the points earned in one season.[7]

We consider a player's total number of passes as a suitable

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[3] Professional sports data have been frequently used to analyze economic questions (see Kahn, 2000, for an overview). For example, Parsons et al. (2011) study behavioral implications of discrimination using umpire decisions in professional baseball. Brown (2011) shows how workers' effort in competitions depends on the relative ability among competitors by exploiting the presence of a superstar in professional golf tournaments. Kleven et al. (2013) exploit cross-country differences in labor market regulation and income taxation to analyze the effect of top-income tax rates on international migration decisions of soccer players in Europe. Using data on professional golf players, Rosenqvist and Skans (2015) investigate how past success can boost future performance.

[4] The season pauses for a winter break, generally lasting from late December until late January. After each season, the worst three teams are relegated, while three teams are promoted from the second division (*2. Bundesliga*).

[5] For example, teams from the same city or neighboring areas do not play matches at home on the same day.

[6] Even if matches end in a draw after 90 min, there is no overtime or penalty shootout in the *Bundesliga*.

[7] Players' running distance might serve as another interesting measure of productivity. Unfortunately, information on running distance was not collected prior to the season of 2010/2011, which precludes us from analyzing this measure. However, using publicly available data for the seasons of 2013/2014 to 2015/2016, we show that the relationship between players' running distance and the number of passes per match appears to be strongly positive (see Appendix Fig. A.1). The underlying data were obtained from the German soccer magazine *Kicker*, see www.kicker.de.

Fig. 1. Geographic distribution of stadiums across Germany.
Note: Location of Bundesliga stadiums across Germany. The number of stadiums in each city is indicated in brackets. Locations in the densely populated Rhine-Ruhr Area are not labeled individually due to lack of space and comprise (from West to East) the stadiums in Mönchengladbach (2), Düsseldorf, Duisburg, Gelsenkirchen, Bochum and Dortmund.

measure of productivity as it reflects both individuals' physical ability as well as effort choices during a particular match; factors that determine workers' productivity in any other occupational task as well. Thus, the reduced-form effect of air pollution may be due to impaired physical capacity but may also be driven by behavioral responses in light of the additional physical strain. In order to assess the relative importance of these elements, two additional measures of players' performance are considered: pass accuracy and the ratio of long over short passes. We argue that the former measure mainly reflects players' physical ability while the latter rather represents a behavioral response in the players' style of play.[8]

2.3. *Air pollution and weather*

We combine the data on soccer players' productivity with detailed information from the air pollution monitoring system of the German Federal Environment Agency (*Umweltbundesamt*). For each match, we extract all available hourly monitor readings for the concentration of particulates with a diameter smaller than ten micrometers (PM10) and ozone (O_3) in ambient air within a radius of ten kilometers (about 6.2 miles) around the stadium at the hour of kick-off and compute inverse-distance weighted means for both pollutants. Matches without pollution readings within this radius are dropped from the sample (716 out of 3672).[9]

We expect that both pollutants – particulate matter and ozone – negatively affect the productivity of soccer players. A high concentration of particulate matter in ambient air is particularly harmful to humans' health as it enters deep into the lungs and affects the pulmonary and cardiovascular functioning.[10] While particulate pollution may have natural sources (e.g. wildfires, sandstorms or volcano eruptions), there are various man-made emission sources such as automobile exhaust, electricity generation or any other industrial activity involving combustion processes. By contrast, ozone is not directly emitted to ambient air but emerges from complex chemical interactions between specific precursors (nitrogen oxides or volatile organic chemicals) under conditions of substantial solar radiation and high temperatures. Ozone has been shown to impede the respiratory system of the human body by irritating lung airways.[11]

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[8] Reductions in pass accuracy, lowering a team's possession of the ball, cannot be considered as a deliberate behavioral choice in order to reduce physical strain. By contrast, adjustments in the style of play, i.e. kicking the ball far away, may indeed (temporarily) reduce the overall physical burden.

[9] The results of our analysis are robust to relying on monitor readings from the closest station within a ten kilometer radius only.

[10] The sports medicine literature provides evidence of a negative relationship between ambient air pollution and athlete performance through particulate matter inhalation (see Rundell, 2012, for an overview).

[11] Alternatively, one could also study the effect of other air pollutants such as sulfur dioxide (SO_2) or nitrogen dioxide (NO_2). However, particulate matter acts as a suitable proxy for air pollution in general given that it is positively correlated with all other main air pollutants except for ozone (Ziebarth et al., 2013). Rather than

Table 1
Summary statistics on player- and match-level variables.

Variable	Mean	Std. deviation	Median	Minimum	Maximum	Obs.
Panel (a): Player-level data						
Player productivity						
Total passes	26.3	16.48	25	0	138	75,163
Total passes (full-time players)	34.2	14.47	32	1	138	43,346
Log of total passes	2.92	1.11	3.22	−2.3	4.93	75,163
Short passes	23.95	15.06	23	0	123	75,163
Pass accuracy (completed over total)	0.77	0.15	0.79	0	1	73,832
Pass ratio (long over short)	0.1	0.15	0.06	0	6	73,718
Player characteristics						
Age (years)	26.81	3.93	26.71	16.92	39.55	75,163
Tenure (matches for team)	51.22	52.08	34	1	390	75,163
Played full-time (0/1)	0.58	0.49	1	0	1	75,163
Minutes played	70.6	28.97	90	1	90	75,163
Home match (0/1)	0.5	0.5	1	0	1	75,163
Panel (b): Match-level data						
Pollution variables						
PM10 (μg/m^3)	23.76	16.22	20.05	0.53	158.28	2956
Ozone (μg/m^3)	55.06	34.27	53.21	0.13	248	2956
Ln(PM10)	2.96	0.68	3	−0.64	5.06	2956
Ln(Ozone)	3.69	1.01	3.97	−2	5.51	2956
Weather variables						
Maximum temperature (°C)	12.59	7.6	12.35	−12.15	36.06	2956
Precipitation (mm/m^2)	1.97	3.81	0.2	0	34.03	2956
Dewpoint (°C)	4.47	5.69	4.56	−17.06	18.79	2956
Air pressure (hpa)	992.99	22.74	998.73	924.84	1044.7	2956
Wind speed (m/ss)	3.61	1.84	3.2	0.8	16.6	2956
Match characteristics						
Stadium attendance (in 1000 s)	38.34	17.18	36.09	6	83	2956
Matchday: Tuesday (0/1)	0.02	0.15	0	0	1	2956
Matchday: Wednesday (0/1)	0.03	0.17	0	0	1	2956
Matchday: Thursday (0/1)	0.01	0.04	0	0	1	2956
Matchday: Friday (0/1)	0.05	0.23	0	0	1	2956
Matchday: Saturday (0/1)	0.69	0.46	1	0	1	2956
Matchday: Sunday (0/1)	0.2	0.4	0	0	1	2956
Kick-off: 3 p.m. (0/1)	0.69	0.46	1	0	1	2956
Kick-off: 5 p.m. (0/1)	0.18	0.38	0	0	1	2956
Kick-off: 6 p.m. (0/1)	0.02	0.15	0	0	1	2956
Kick-off: 7 p.m. (0/1)	0	0.03	0	0	1	2956
Kick-off: 8 p.m. (0/1)	0.11	0.31	0	0	1	2956

Note: This table provides descriptive statistics on our estimation sample. Information on players' productivity and match characteristics was provided by deltratre. Data on pollution levels and weather conditions was obtained from the German Federal Environment Agency (*Umweltbundesamt*) and the German Meteorological Service (*Deutscher Wetterdienst*), respectively.

Since weather conditions are important environmental confounding variables in the context of air pollution, we further supplement our dataset with a rich set of weather controls. The data are provided by the German Meteorological Service (*Deutscher Wetterdienst*) and contain daily information on temperature, precipitation, humidity, air pressure and wind speed. As before, we derive inverse-distance weighted means from monitor readings in proximity to each stadium (40 km or 24.9 miles) on each matchday.

2.4. Descriptive statistics

Our final dataset covers twelve seasons (1999/2000–2010/2011) and comprises 1771 professional athletes playing for 29 different teams in 2956 matches in 32 stadiums across Germany, totaling to 75,163 player-match observations. On average, we observe 42 matches per player. Table 1 provides descriptive statistics at the player and match level. Panel (a) summarizes players' characteristics and measures of productivity. On average, a player passes the ball about 26 times per match (34 times conditional on playing for the full match) at an average accuracy of 77%, with more than 90% of these passes being short ones, i.e., over a distance of less than 30 m. Consequently, the mean ratio of long over short passes is about 0.1. On average, professional athletes in the *Bundesliga* are aged 27, play 71 min per match and cover the full duration (90 min) in 58% of games played.

Panel (b) of Table 1 shows summary statistics for our two pollution variables of interest as well as the set of weather and match controls. The mean concentration of particulate matter at the time of kick-off is 23.8 micrograms per cubic meter (μg/m^3) but substantially varies from 0.5 to 158 μg/m^3. The mean concentration of ozone is 55 μg/m^3 in our sample, ranging from 0.1 to 248 μg/m^3 at the hour of kick-off. The table further reveals that matches usually take place at moderate weather conditions on a weekend afternoon.

In order to better understand the observed variation in pollution levels, we present additional information on differences in the emergence of these two pollutants by season, calendar month and location. In Fig. 2, panel (a) reveals that there is no remarkable time trend in PM10 concentration across seasons: at most, there is a slight reduction in average PM10 levels after 2005 when an EU-

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(*footnote continued*)
studying the effect of PM10, one could also analyze effects of fine particulate matter (PM2.5), given that smaller particulates can penetrate deeper into the human body and thus are even more harmful than PM10. Unfortunately, the concentration of PM2.5 has only been monitored since 2008 in Germany, which substantially limits both the sample size (by around 83%) and variation in air pollution. Nevertheless, we find a negative – albeit insignificant – effect of PM2.5 on player productivity.

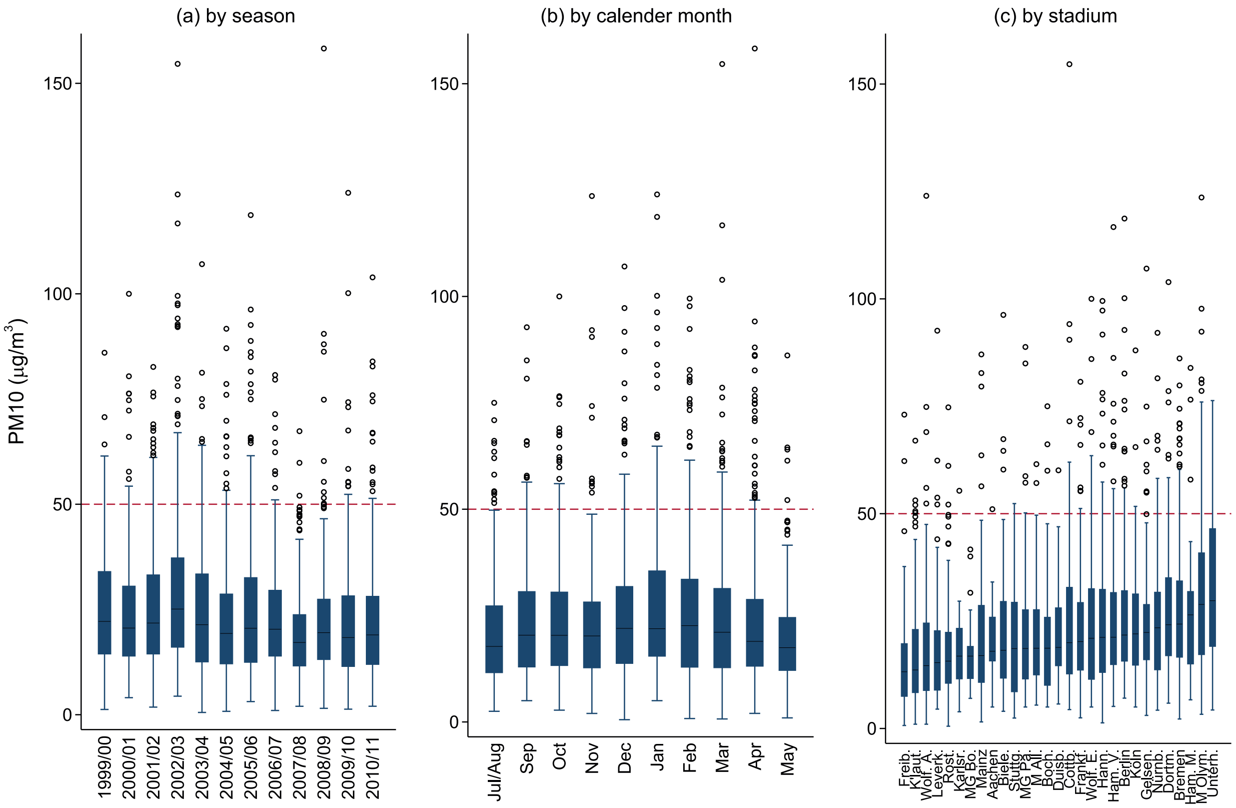

Fig. 2. Variation of particulate matter across matches.
Note: Boxplots of the concentration of particulate matter (PM10) at the hour of match kick-off by seasons (panel (a)), calendar months (panel (b)) and across different stadiums (panel (c)). Monitor readings from July (N=4) are merged with August. There are no matches scheduled in June. Stadiums with less than ten match observations are excluded from this graph. The horizontal line indicates the EU regulatory threshold of 50 µg/m^3 for daily mean concentration. Dots indicate matches where very high levels of PM10 concentration have been observed.

wide regulation became binding.[12] Panel (b) further shows a weak seasonal pattern in PM10, with pollution levels being slightly higher during winter months. Finally, panel (c) ranks stadiums with respect to the median level of PM10 concentration, reflecting patterns of population size and density as well as the degree of industrialization in proximity to the stadiums to some extent. The dashed horizontal line in every panel of Fig. 2 indicates the daily mean threshold of 50 µg/m^3.[13] While our measure of air pollution comprises hourly concentration levels and is thus not perfectly comparable to this threshold, we observe that this critical value is exceeded in around 7% of the observed matches; and at least once in every season, calendar month and stadium.

Analogously, we plot the variation in ozone levels in Fig. 3. As for PM10, panel (a) provides no evidence of a strong time trend across seasons. By contrast, panel (b) displays a very strong seasonal pattern. High levels of ozone are only observed for those matches scheduled in summer months, which reflects the fact that ozone emerges under heat and sunlight. The EU-wide target value for an 8-h mean ozone concentration of 120 µg/m^3 – as indicated by the bottom horizontal line – is exceeded in 4% of the matches covered, virtually all of them taking place between April and September. The EU information and alert thresholds of 180 and 240 µg/m^3 – indicated by the upper two horizontal lines – are only exceeded in a tiny number of matches.

3. Empirical Strategy

As the match scheduling rules of the *Bundesliga* expose players to varying levels of pollution for exogenous reasons, the underlying framework provides a useful setting to overcome empirical challenges when estimating the causal effect of air pollution on productivity.[14] Moreover, any behavioral response to avoid exposure to pollution is virtually impossible in this context, given that there is no option to reschedule matches and players cannot evade air pollution on the field even in case of awareness.

Our empirical strategy exploits this exogenous variation in players' exposure to pollution. The underlying empirical model reads as follows:

$$\begin{aligned}\text{Passes}_{imt} \;=\; & \beta_1 \text{PM10}_m + \beta_2 \text{Ozone}_m + X'_{imt}\gamma + W'_m\delta + M'_m\mu \\ & + C_{c(tm)} + T_{ts(m)} + \alpha_i + \varepsilon_{imt}, \qquad (1)\end{aligned}$$

where the number of passes of player i in match m for team t (Passes_{imt}) is regressed on the concentration of particulate matter and ozone at the hour of kick-off (PM10_m and Ozone_m). In our preferred specification, both the dependent variable as well as the two pollution variables enter our model in levels. However, we also present regression results where both the outcome and our variables of interest enter the model in logarithmic form, which allows us to interpret the coefficients of interest (β_1 and β_2) as elasticities.[15]

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[12] In EU member states, air pollution is regulated by the "*Directive 2008/50/EC of the European Parliament and of the Council of 21 May 2008 on ambient air quality and cleaner air for Europe*".

[13] According to the European regulation, the daily mean concentration of PM10 may not exceed the limit value of 50 µg/m^3 on more than 35 days per calendar year. The annual mean may not exceed 40 µg/m^3.

[14] Note that even in the very unlikely case of athletes self-selecting into teams in low-pollution locations, only half of a season's matches are held at the home stadium, while away matches take place at stadiums across Germany (see Fig. 1).

[15] In this case, we assign zero passes a log value of zero and account for the difference between one and zero passes by means of a corresponding dummy variable. When dropping all observations with zero passes from our sample (N = 1331; 1.8% of the sample), the results remain unaffected. In columns (1)–(4) of

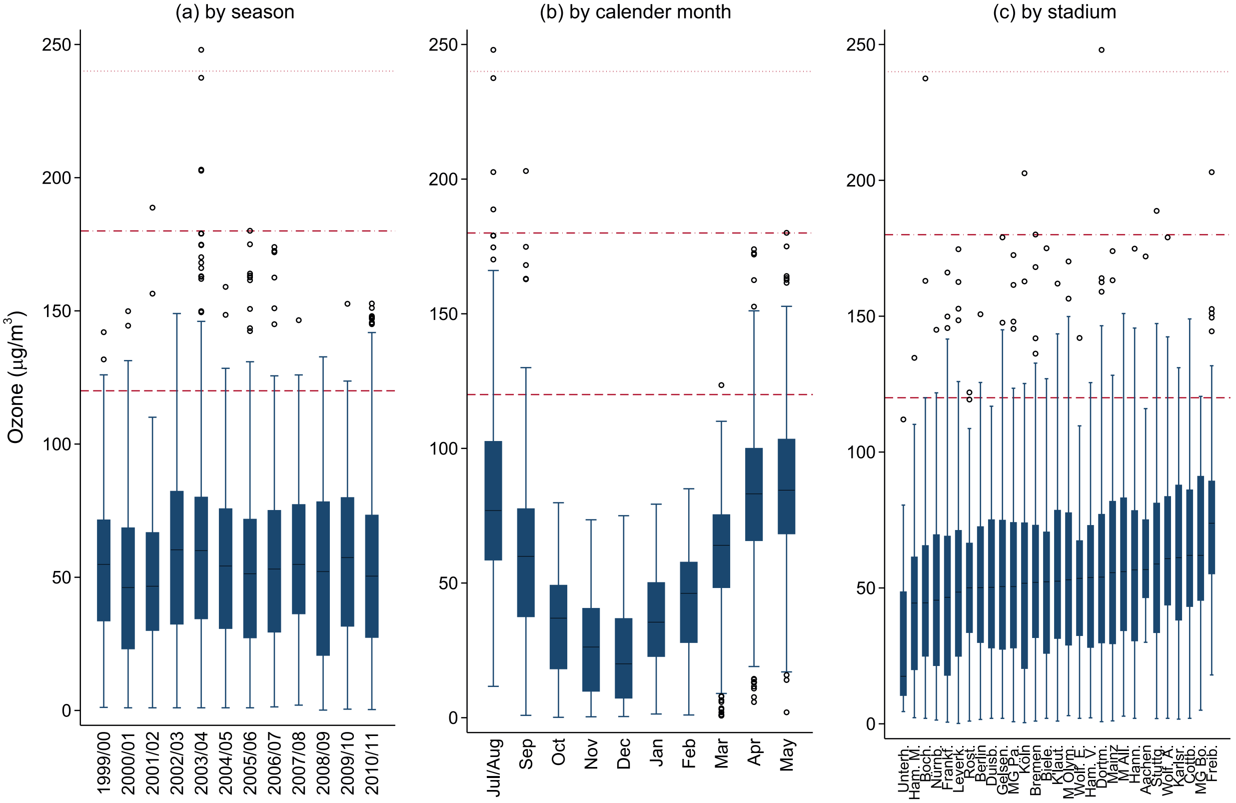

Fig. 3. Variation of ozone across matches.
Note: Boxplots of the concentration of ozone (O_3) at the hour of match kick-off by seasons (panel (a)), calendar months (panel (b)) and across different stadiums (panel (c)). Monitor readings from July ($N = 4$) are merged with August. There are no matches scheduled in June. Stadiums with less than ten match observations are excluded from this graph. The horizontal lines indicate the EU target, information and alert values at 120, 180 and 240 µg/m³. Dots indicate matches where very high levels of O_3 concentration have been observed.

We control for individual player characteristics (X'_{imt}) such as age (age squared), overall tenure (tenure squared), minutes played (minutes squared) and indicators for the position played in a particular match (defender, midfielder or striker).[16] Moreover, X'_{imt} comprises a dummy variable indicating a team's home stadium advantage. Given that weather conditions are important confounding variables for air pollution and may also have a direct effect on individual productivity (Adhvaryu et al., 2014; Graff Zivin and Neidell, 2013), we further include controls for the maximum temperature, total precipitation, humidity, air pressure and wind speed at a daily level in spatial proximity to the stadium for a given match (W'_m). In our baseline specifications, all weather controls are standardized and enter the model in linear and quadratic form.[17] Moreover, match controls M'_m account for features of the particular match: indicators for the day of the week and the time at kick-off as well as stadium attendance (in 1000 s).[18] In addition, we add a fixed effect for each coach c when being in charge for team t in match m ($C_{c(tm)}$), as well as team-by-season fixed effects ($T_{ts(m)}$) to capture all factors that are specific to a team within a season s (defined by match m), such as the squad's composition, style of play or the club's budget. Finally, we add player fixed effects to control for unobserved time-invariant differences across players (α_i). Identification of our model thus relies on variation in players' exposure to pollution at different locations over time. Accordingly, standard errors are clustered at the match level.

4. Results

4.1. Baseline estimates

In Table 2, we present the results for different specifications of our empirical model laid out in equation (1), using level-level and log-log specifications, respectively (see panels (a) and (b)).[19] We present the results from our leanest specification in column (1), controlling for player characteristics only. We find statistically significant negative effects of both PM10 and ozone on players' productivity. In column (2), we add player fixed effects to our model and thus identify the effect of air pollution on productivity by using within-player variation only. Both coefficients of interest remain statistically significant and of similar magnitudes, suggesting that there is no systematic selection of players with respect to the degree of air pollution on matchdays. Next, we add the defined set of weather controls in column (3). While the effect of PM10 becomes even more negative, the coefficient for ozone (in panel (b)) and its statistical significance (in both panels) slightly decline. This is not particularly surprising because high temperatures act as a precondition for the

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(*footnote continued*)
Appendix Table A.1, we show that our results are robust to using log-level specifications of the pollution-productivity relationship or focusing on passes per minutes played as an alternative outcome.

[16] The minutes played may be affected by the level of pollution in cases where coaches selectively substitute at an earlier stage of the game. If this were true, the variable would be a "bad control". However, estimates presented in Table A.2 indicate that there is no effect of pollution on the minutes played or the probability of playing the full duration in a given match. Note that our results are robust when including higher order polynomials of the minutes played in the regressions.

[17] Appendix Table A.3 shows that results for the baseline regression model are robust to different specifications of the set of weather controls.

[18] We do not find any evidence that stadium attendance is significantly affected by air pollution. Hence, we can rule out that our results are driven by pollution-induced reductions in support from the spectators.

[19] For the sake of clarity, we refrain from reporting the coefficients of the control variables. Detailed regression outputs are available upon request.

Table 2
The effect of air pollution on productivity: baseline effects.

	(1)	(2)	(3)	(4)	(5)	(6)
Panel (a): Level-level specifications						
PM10 (μg/m^3)	−0.022***	−0.018***	−0.024***	−0.022***	−0.023***	−0.024***
	(0.004)	(0.004)	(0.004)	(0.004)	(0.004)	(0.004)
Ozone (μg/m^3)	−0.005***	−0.006***	−0.007**	−0.005	−0.005	−0.005
	(0.002)	(0.002)	(0.003)	(0.003)	(0.003)	(0.004)
Adjusted R-Squared	0.516	0.436	0.436	0.444	0.454	0.465
Panel (b): Log-log specifications						
Ln(PM10)	−0.021***	−0.019***	−0.023***	−0.019***	−0.020***	−0.021***
	(0.005)	(0.004)	(0.005)	(0.005)	(0.005)	(0.005)
Ln(Ozone)	−0.008***	−0.008***	−0.007**	−0.004	−0.004	−0.005
	(0.003)	(0.003)	(0.003)	(0.003)	(0.004)	(0.004)
Adjusted R-Squared	0.770	0.746	0.746	0.749	0.752	0.756
Player controls	Yes	Yes	Yes	Yes	Yes	Yes
Player FE	No	Yes	Yes	Yes	Yes	Yes
Weather controls	No	No	Yes	Yes	Yes	Yes
Match controls	No	No	No	Yes	Yes	Yes
Coach FE	No	No	No	No	Yes	Yes
Team × Season FE	No	No	No	No	No	Yes
Observations	75,163	75,163	75,163	75,163	75,163	75,163

Note: Dependent variable: (Log) number of passes. Player controls: age (squared), tenure (squared), position (defender, midfielder, striker), minutes played (squared) and home match indicator. Weather controls on daily basis: maximum temperature (squared), precipitation (squared), dew point (squared), wind speed (squared), air pressure (squared). Match controls: day of week, kick-off time and stadium attendance. Standard errors are clustered at the match level ($N = 2956$). The usual significance levels apply: 0.1 (*), 0.05 (**), and 0.01 (***).

emergence of ozone in ambient air. Hence, the inclusion of temperature as a control variable substantially reduces the remaining variation of ozone conditional on weather conditions. However, when further controlling for match-level characteristics (see column (4)), in particular the time of kick-off, the effect of ozone declines even more and becomes statistically insignificant. By contrast, the estimated coefficient for PM10 remains almost unchanged when including this additional set of controls. In columns (5) and (6), we subsequently add coach and team × season fixed effects to our model. Point estimates are not affected by either set of controls. Overall, the results from our preferred specification presented in column (6) of panel (a) show a statistically significant effect of PM10 concentration on the number of passes of −0.024, which implies that a one-standard-deviation increase in PM10 concentration (by roughly 16 μg/m^3) lowers passes by around 2.4% of a standard deviation on average.[20] Put differently, an increase in PM10 concentration by 1% hence reduces the number of passes by 0.021% (see column (6) of panel (b)). In turn, we find a small and negative – albeit statistically insignificant – effect of ozone on the number of total passes.

As indicated before, these results suggest that the observed differences in the impact of weather and match-level controls on the coefficients of PM10 and ozone reflect the fact that variation in ozone concentration in our sample is rather limited, especially when conditioning on temperature and the time of kick-off. This is mainly because only a tiny number of matches takes place during June or July, when levels of ozone peak in Germany due to long sunshine duration and high temperatures (see panel (b) of Fig. 3). By contrast, elevated levels of particulate pollution are observed throughout the year (see panel (b) of Fig. 2). For this reason, we will focus on the effect of PM10 in the remainder of the paper, while controlling for ozone concentration at kickoff time in all specifications.

4.2. Non-linear dose-response relationship

We next test for non-linear effects in the relationship between particulate matter and player productivity. Moderate levels of PM10 might not affect individual productivity, while substantial negative effects may arise once pollution levels exceed a given threshold. In order to investigate this relationship more explicitly, we first examine potential non-linear effects in a non-parametric way, running a kernel-weighted local fourth-order polynomial regression of match-level PM10 concentration on players' total passes without any further controls. The results of this regression are presented in Fig. 4, which plots the predicted number of passes against the level of pollution. At low levels of pollution (up to approximately 15 μg/m^3, equivalent to around the bottom third of the observed distribution of PM10 concentration), player productivity does not seem to be impeded. Beyond this value, we observe a negative effect of PM10 on the number of total passes. This negative effect becomes larger for PM10 levels around 55 μg/m^3 and above.[21]

Based on this non-parametric evidence, we further test whether the observed non-linear effect is confirmed in our regression framework by allowing for different marginal effects below and above the identified thresholds (cf. Fig. 4). As displayed in columns (1)–(3) of Table 3, the results of our analysis first confirm that player productivity is not impeded at low levels of air pollution ($\text{PM10} < 15$ μg/m^3), estimates being small and not statistically significantly different from zero. By contrast, productivity significantly decreases at higher levels of PM10 concentration. We explore this relationship in more detail in columns (4)–(6), where we additionally allow for different marginal effects below and above the second identified threshold at around 55 μg/m^3. We still observe that significant negative effects of PM10 already emerge at moderate levels of air pollution commonly experienced in Germany. Ceteris paribus, the coefficient estimate from our most comprehensive specification displayed in column (6) implies that an increase in

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[20] In Appendix Table A.1, we present baseline estimates for the subsample of full-time players. The results are virtually identical. In an unreported specification, we additionally control for stadium × home field fixed effects. The results are hardly affected by the inclusion of these additional control variables, the point estimate being −0.022 (0.004). However, as this specification limits the identifying variation in PM10 to home matches within one season, we refrain from controlling for these fixed effects in the remainder of this paper.

[21] For the sake of clarity, we exclude information from the bottom and top 1% of the PM10 distribution in the polynomial regression underlying Fig. 4. These observations are outliers with respect to the overall distribution and would inflate the confidence intervals at the tails to a considerable extent. However, we include these observations in all other regressions.

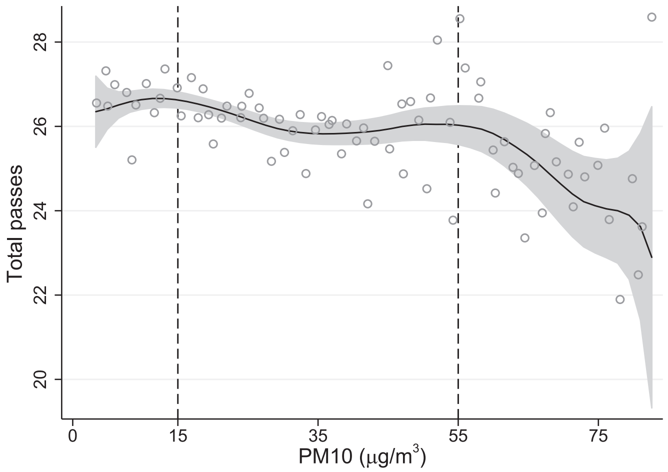

Fig. 4. The effect of particulate matter on productivity: Non-linear relationship. *Note:* Non-linear relationship between PM10 concentration and players' number of total ball passes. The line shows the result from a kernel-weighted local fourth-order polynomial regression of players' passes on the concentration of particulate matter in ambient air absent any further controls. For the sake of clarity, the bottom and top percent of the PM10 distribution are discarded from this particular analysis. Dots indicate the mean number of passes at a given level of PM10 concentration rounded to the nearest integer value.

the level of PM10 from 20 to 30 μg/m³ (i.e. from the median value to the 75% quantile) would reduce a player's number of total passes by 0.23. In line with the graphical evidence presented in Fig. 4, this negative effect becomes even larger for very high levels of PM10 concentration (PM10 ≥ 55 μg/m³) although differences are not statistically significant.[22]

4.3. Effects on pass accuracy and the style of play

As indicated before, our reduced-form effect of air pollution on the total number of passes may comprise both physiological as well as behavioral responses. In order to disentangle the importance of these two mechanisms, we next investigate the effect of pollution on players' pass accuracy and their style of play, measured by the ratio of long over short passes.

Displayed in columns (1)–(3) of Table 4, we find a small but statistically significant negative effect of PM10 concentration on pass accuracy. A one standard deviation increase in PM10 concentration reduces pass accuracy by around 0.2 percentage points. We further find that players also adjust their style of play in response to air pollution, by slightly increasing the ratio of long over short passes (see columns (4)–(6) of Table 4). We take these findings as suggestive evidence that air pollution may impair workers' productivity by both limiting physical ability and inducing behavioral adjustments in effort provision to reduce the pollution-induced physical strain.

4.4. Heterogeneity by player characteristics

Against the backdrop of these estimates, we next investigate whether the observed effects of air pollution vary for different types of players. While professional soccer players constitute a rather homogeneous group that is positively selected with respect to their overall physical condition, we proxy general physiological status by age and test whether (slightly) older athletes may be more sensitive to pollution and thus respond more strongly than their younger counterparts. For the purpose of this analysis, we again focus on the number of total passes as our preferred measure of productivity.

When interacting PM10 with the players' age in columns (1) and (2) of Table 5, our findings suggest that the negative effect of PM10 slightly increases with age, although the interaction term is not statistically significant. Interestingly, the results displayed in columns (3) and (4), however, reveal that the productivity of the youngest group of players (athletes aged below 20) is not impaired by PM10, whereas all other players are negatively affected. The estimated effect is strongest for players aged 30 and above, although differences are not statistically significant among the age groups. Nevertheless, we take these results as suggestive evidence that older individuals appear more responsive to detrimental environmental conditions, even among this group of professional athletes.

We further account for differential effects of PM10 concentration by players' position, given that strikers, midfielders and defenders generally fulfill varying tasks during a game and may thus exert different levels of physical effort. This is partly reflected in the number of passes played, ranging from an average of 15.7 passes per match for strikers to 32.7 for defenders. However, our results in columns (5) and (6) of Table 5 show that PM10 affects the productivity of all players irrespective of their position. At most, we find that defenders and midfielders are slightly more strongly affected than strikers. While differences are not statistically significant, this finding is consistent with the notion that defenders and midfielders exhibit more physically demanding tasks and play a more active role in the game than strikers, and that pollution generally affects the productivity of workers with more strenuous tasks to a larger extent.

4.5. Team- and match-level effects

So far, our analysis has been conducted at the individual level. A given soccer player's productivity may, however, also depend upon his team-mates' and opponents' productivity levels, which are also affected by pollution in turn. Hence, we might miss important interactions within a player's team and/or with the opponent when using variation at the player level. While negative effects of pollution on opponents' passes should bias our estimates towards zero (as it becomes easier to pass), the opposite may be true for the effect of pollution on team-mates' passes. To account for this potential concern, we estimate equation (1) at the aggregate team and match level, respectively. Interaction effects between levels of PM10 concentration, the individual's and his team-mates' and/or opponents' productivity are implicitly accounted for at these aggregate levels.

As displayed in Table 6, our findings hold true at the team and match level. Moreover, elasticities are of similar magnitude as in our baseline specification (see panel (b)). Controlling for average player characteristics and weather conditions, column (1) of panel (b) suggests that a 1% increase in the level of pollution reduces the total number of team passes by around 0.03%. This effect declines to −0.015% when subsequently adding match-level, team × season or opponent × home fixed effects to the model (see columns (2) and (3) of panel (b)), but remains highly statistically significant. A similar conclusion arises when turning to the match-level regressions displayed in columns (4) to (6). The number of match-level passes decreases statistically significantly with higher concentrations of particulate matter in ambient air, even in our most comprehensive specification including season fixed effects. Overall, these findings suggest that interaction effects between pollution, the individual's and his team-mates' and/or opponents' productivity either cancel out or are of minor importance.

In a last exercise, we test whether air pollution impairs the overall attractiveness of a game, focusing on the number of scored goals per match and a potential asymmetric effect on the odds of winning the game, i.e., whether high levels of pollution affect the probability of an “underdog victory”.[23] The

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[22] Note that the observed PM10 concentration exceeds the level of 55 μg/m³, which is just above the EU's limit value for the daily mean, in 4.8% of our observations only.

[23] We speak of an underdog victory in case a team finishing among the top three in a given season loses against a lower-ranked team. Out of 839 matches, 18% are won by the underdog.

Table 3
The effect of air pollution on productivity: non-linear effects.

	(1)	(2)	(3)	(4)	(5)	(6)
PM10 × (PM10 < 15)	0.026	0.034	0.053	0.026	0.033	0.053
	(0.036)	(0.037)	(0.037)	(0.036)	(0.037)	(0.037)
PM10 × (PM10 ≥ 15)	−0.011**	−0.018***	−0.020***			
	(0.005)	(0.005)	(0.005)			
PM10 × (15 ≤ PM10 < 55)				−0.013	−0.023**	−0.023**
				(0.009)	(0.009)	(0.009)
PM10 × (PM10 ≥ 55)				−0.027*	−0.031**	−0.034**
				(0.014)	(0.013)	(0.014)
Player controls	Yes	Yes	Yes	Yes	Yes	Yes
Weather/Ozone controls	No	Yes	Yes	No	Yes	Yes
Match controls	No	Yes	Yes	No	Yes	Yes
Coach FE	No	No	Yes	No	No	Yes
Team × Season FE	No	No	Yes	No	No	Yes
Observations	75,163	75,163	75,163	75,163	75,163	75,163
Adjusted R-Squared	0.436	0.444	0.465	0.436	0.444	0.465

Note: Dependent variable: Number of passes. All regressions include player fixed effects. Player controls: age (squared), tenure (squared), position (defender, midfielder, striker), minutes played (squared), home match indicator. Weather controls on daily basis: maximum temperature (squared), precipitation (squared), dew point (squared), wind speed (squared), air pressure (squared). Match controls: day of week, kick-off time, stadium attendance. Standard errors are clustered at the match level (N = 2956). The usual significance levels apply: 0.1 (*), 0.05 (**), and 0.01 (***).

Table 4
The effect of air pollution on pass accuracy and style of play.

	Pass accuracy			Long/Short passes		
	(1)	(2)	(3)	(4)	(5)	(6)
Standardized PM10	−0.002*	−0.001*	−0.002**	0.002**	0.001	0.002**
	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)
Player characteristics	Yes	Yes	Yes	Yes	Yes	Yes
Player FE	No	Yes	Yes	No	Yes	Yes
Weather/Ozone controls	No	No	Yes	No	No	Yes
Match controls	No	No	Yes	No	No	Yes
Coach FE	No	No	Yes	No	No	Yes
Team × Season FE	No	No	Yes	No	No	Yes
Observations	73,832	73,832	73,832	73,718	73,718	73,718
Adjusted R-Squared	0.022	0.002	0.026	0.133	0.019	0.036

Note: This table provides regression results for a one standard deviation increase in PM10, which is equivalent to around 16 $\mu g/m^3$. Player characteristics: age (squared), tenure (squared), position dummies (defender, midfielder, striker), minutes played (squared), home match indicator. Weather controls on daily basis: maximum temperature (squared), precipitation (squared), dew point (squared), wind speed (squared), air pressure (squared). Match controls: day of week, kick-off time and stadium attendance. Standard errors are clustered at the match level. The usual significance levels apply: 0.1 (*), 0.05 (**), and 0.01 (***).

corresponding results are displayed in Appendix Table A.4. While the linear effect on goals per match is close to zero and not statistically significant, very high levels of pollution (55 $\mu g/m^3$ and above) substantially reduce the number of scored goals per match. Ceteris paribus, the coefficient indicates that an increase in the level of pollution from 55 to 65 $\mu g/m^3$ would reduce the number of goals per match by 0.14, which is sizable compared to the overall mean of 2.9 goals per match. At the same time, we do not find evidence of underdogs being more likely to win when air pollution is higher. This is consistent with the notion that pollution has a symmetrical effect on players of both teams and does not affect their relative strength.

5. Conclusion

In this paper, we estimate the causal effect of ambient air pollution on individual productivity. Using panel data on the universe of soccer players in the German *Bundesliga* and hourly information on the concentration of particulate matter and ozone in spatial proximity to the stadium at the hour of kick-off, we exploit exogenous variation in players' exposure to air pollution due to match scheduling rules that are beyond the control of the players and teams.

Our results show that the concentration of particulate matter in ambient air has a negative effect on players' productivity, measured by the total number of passes. While the dose-response relationship is non-linear in nature and larger effects emerge at high concentrations of particulate pollution, we already detect significant negative impacts at moderate levels. When accounting for heterogeneous effects across players, we further find the overall effect to be mainly driven by players of relatively older age and those playing in positions that require more physical exertion. We further provide suggestive evidence that this reduced-form effect is driven by impaired physiological ability and behavioral effort responses in light of the additional physical strain.

Overall, our analysis complements previous empirical evidence on the negative effects of air pollution on the productivity of low-skilled agricultural and factory workers from single-plant case studies (Chang et al., 2016; Graff Zivin and Neidell, 2012; He et al., 2016). Even moderate concentrations of particulate matter commonly experienced in developed countries impede the productivity of professional athletes to a considerable extent. While our data allows us to consistently measure individual productivity over a long period, generalizing our findings beyond the realm of sports is not straightforward. As young professional athletes are in better shape than the average individual, we might expect to observe even stronger effects of pollution on other workers' productivity. However, professional sports is also associated with substantially higher physical strain compared to more common occupations, suggesting that athletes are particularly

Table 5
The effect of air pollution on productivity: heterogeneous effects by player characteristics.

	(1)	(2)	(3)	(4)	(5)	(6)
PM10	−0.016***	−0.025***				
	(0.004)	(0.005)				
PM10 × Age	−0.001	−0.001				
	(0.001)	(0.001)				
PM10 × (Age < 20)			−0.000	−0.012		
			(0.013)	(0.013)		
PM10 × (Age 20–24)			−0.013**	−0.021***		
			(0.005)	(0.006)		
PM10 × (Age 25–29)			−0.018***	−0.027***		
			(0.005)	(0.005)		
PM10 × (age ≥ 30)			−0.019***	−0.029***		
			(0.006)	(0.006)		
PM10 × Defender					−0.023***	−0.032***
					(0.006)	(0.007)
PM10 × Midfielder					−0.015***	−0.024***
					(0.005)	(0.005)
PM10 × Striker					−0.008**	−0.018***
					(0.003)	(0.004)
Player controls	Yes	Yes	Yes	Yes	Yes	Yes
Weather/Ozone controls	No	Yes	No	Yes	No	Yes
Match controls	No	Yes	No	Yes	No	Yes
Coach FE	No	Yes	No	Yes	No	Yes
Team × Season FE	No	Yes	No	Yes	No	Yes
Observations	75,163	75,163	75,163	75,163	75,163	75,163
Adjusted R-Squared	0.436	0.465	0.436	0.465	0.436	0.465

Note: Dependent variable: Number of passes. All regressions include player fixed effects. Player controls: age (squared), tenure (squared), position (defender, midfielder, striker), minutes played (squared), home match indicator. Weather controls on daily basis: maximum temperature (squared), precipitation (squared), dew point (squared), wind speed (squared), air pressure (squared). Match controls: day of week, kick-off time, stadium attendance. Standard errors are clustered at the match level (N = 2956). The usual significance levels apply: 0.1 (*), 0.05 (**), and 0.01 (***).

Table 6
The effect of air pollution on productivity: team- and match-level effects.

	Team-level regressions			Match-level regressions		
	(1)	(2)	(3)	(4)	(5)	(6)
Panel (a): Level-level specifications						
PM10 (μg/m^3)	−0.381***	−0.275***	−0.224***	−0.659***	−0.744***	−0.441***
	(0.060)	(0.057)	(0.053)	(0.120)	(0.122)	(0.115)
Adjusted R-Squared	0.091	0.310	0.437	0.073	0.095	0.190
Panel (b): Log-log specifications						
Ln(PM10)	−0.029***	−0.020***	−0.015***	−0.025***	−0.030***	−0.017***
	(0.005)	(0.005)	(0.005)	(0.005)	(0.005)	(0.005)
Adjusted R-Squared	0.093	0.310	0.428	0.075	0.098	0.193
Player controls	Yes	Yes	Yes	Yes	Yes	Yes
Weather/Ozone controls	Yes	Yes	Yes	Yes	Yes	Yes
Match controls	No	Yes	Yes	No	Yes	Yes
Coach FE	No	Yes	Yes	No	No	No
Team × Season FE	No	Yes	Yes	No	No	No
Opponent × Home FE	No	No	Yes	No	No	No
Season FE	No	No	No	No	No	Yes
Observations	5912	5912	5912	2956	2956	2956

Note: Dependent variable: (Log) number of passes. Player characteristics: mean age (squared) and tenure (squared) at team or match level, respectively. Weather controls on daily basis: maximum temperature (squared), precipitation (squared), dew point (squared), wind speed (squared), air pressure (squared). Match controls: day of week, kick-off time, stadium attendance. Standard errors are clustered at the match level. The usual significance levels apply: 0.1 (*), 0.05 (**), and 0.01 (***).

vulnerable to ambient air pollution. Against this backdrop, future research on the effects of air pollution for different types of workers may broaden our knowledge on the benefits of environmental regulation.

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Appendix A

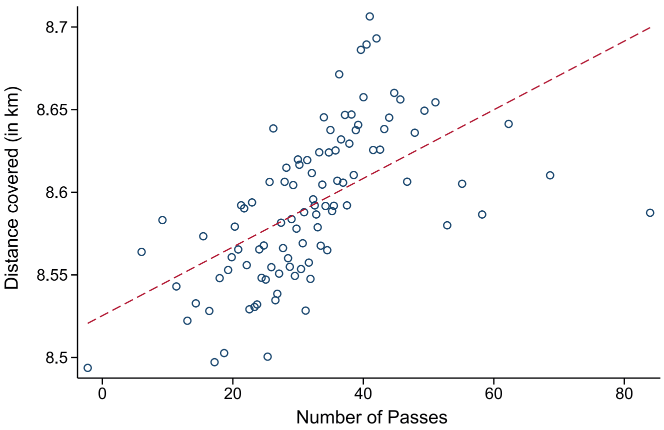

Fig. A.1. Relationship between passes and running distance.
Note: Relationship between players' running distance and number of passes, controlling for player fixed effects and the number of minutes played. The data stem from the seasons 2013/2014 to 2015/2016 and were obtained from the German soccer magazine "Kicker", see www.kicker.de. The graph is based on Stata's "binscatter" command, which groups the number of passes into 100 equally sized bins. Data bins are depicted by circles, the dashed line indicates a linear fit.

Table A.1
The effect of air pollution on productivity: alternative specifications.

	All players				Full-time players			
	Ln(passes)		Passes per minute		Passes		Ln(passes)	
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
PM10 (μg/m^3)	−0.0007***	−0.0010***			−0.0189***	−0.0318***		
	(0.0002)	(0.0002)			(0.0055)	(0.0063)		
Ln(PM10)			−0.0052***	−0.0074***			−0.0150***	−0.0210***
			(0.0015)	(0.0019)			(0.0044)	(0.0051)
Player characteristics	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Weather controls	No	Yes	No	Yes	No	Yes	No	Yes
Match controls	No	Yes	No	Yes	No	Yes	No	Yes
Team × Season FE	No	Yes	No	Yes	No	Yes	No	Yes
Coach FE	No	Yes	No	Yes	No	Yes	No	Yes
Observations	75,163	75,163	75,163	75,163	43,346	43,346	43,346	43,346
Adjusted R-Squared	0.683	0.690	0.034	0.060	0.021	0.088	0.017	0.083

Note: All regressions include player fixed effects. Player characteristics: age (squared), tenure (squared), position dummies (defender, midfielder, striker), minutes played (squared), home match indicator. Weather controls on daily basis: maximum temperature (squared), precipitation (squared), dew point (squared), wind speed (squared), air pressure (squared). Match controls: day of week, kick-off time, stadium attendance. Standard errors are clustered at the match level. The usual significance levels apply: 0.1 (*), 0.05 (**), and 0.01 (***).

Table A.2
The effect of air pollution on playing time.

	Minutes played			Playing full-time		
	(1)	(2)	(3)	(4)	(5)	(6)
PM10 (μg/m^3)	0.0031	−0.0051	−0.0037	0.0001	0.0000	−0.0000
	(0.0030)	(0.0037)	(0.0039)	(0.0001)	(0.0001)	(0.0001)
Player characteristics	Yes	Yes	Yes	Yes	Yes	Yes
Player FE	No	Yes	Yes	No	Yes	Yes
Weather/Ozone controls	No	No	Yes	No	No	Yes
Match controls	No	No	Yes	No	No	Yes
Coach FE	No	No	Yes	No	No	Yes
Team × Season FE	No	No	Yes	No	No	Yes
Observations	75,163	75,163	75,163	75,163	75,163	75,163
Adjusted R-Squared	0.104	0.038	0.064	0.133	0.027	0.045

Note: Player characteristics: age (squared), tenure (squared), position dummies (defender, midfielder, striker), minutes played (squared), home match indicator. Weather controls on daily basis: maximum temperature (squared), precipitation (squared), dew point (squared), wind speed (squared), air pressure (squared). Match controls: day of week, kick-off time and stadium attendance. Standard errors are clustered at the match level. The usual significance levels apply: 0.1 (*), 0.05 (**), and 0.01 (***).

Table A.3
The effect of air pollution on productivity: alternative specifications of weather controls.

	(1)	(2)	(3)	(4)	(5)	(6)
PM10 (μg/m^3)	−0.021***	−0.022***	−0.024***	−0.024***	−0.021***	−0.022***
	(0.004)	(0.004)	(0.004)	(0.004)	(0.004)	(0.004)
Ozone (μg/m^3)	−0.006**	−0.004	−0.007**	−0.005	−0.007***	−0.006**
	(0.003)	(0.003)	(0.003)	(0.004)	(0.003)	(0.003)
Maximum temperature (°C)	−0.082	−0.141	−0.097	−0.164		
	(0.171)	(0.185)	(0.307)	(0.317)		
Precipitation (mm/m^2)	−0.056	0.003	−0.071	−0.132		
	(0.077)	(0.077)	(0.167)	(0.166)		
Dewpoint (°C)	0.105	0.085	−0.057	−0.003		
	(0.147)	(0.161)	(0.178)	(0.186)		
Wind speed (m/s)	−0.128*	−0.212***	−0.126	−0.239		
	(0.074)	(0.075)	(0.197)	(0.200)		
Air pressure(hpa)	0.167**	0.037	0.169	2.017		
	(0.076)	(0.079)	(5.741)	(5.859)		
Maximum temperature^2			0.042	0.015		
			(0.281)	(0.294)		
Precipitation^2			0.009	0.128		
			(0.162)	(0.155)		
Dewpoint^2			0.217*	0.198		
			(0.128)	(0.129)		
Wind speed^2			0.024	0.054		
			(0.182)	(0.185)		
Air pressure^2			−0.001	−1.983		
			(5.737)	(5.855)		
Air pressure dummies (omitted: Air pressure $<$ 975)						
975 $\leq$ Air pressure $<$ 1000					0.479**	0.250
					(0.206)	(0.213)
1000 $\leq$ Air pressure $<$ 1010					0.648***	0.303
					(0.220)	(0.226)
Air pressure $\geq$ 1010					0.396*	0.035
					(0.219)	(0.227)
Wind speed dummies (omitted: Wind speed $<$ 2.5)						
2.5 $\leq$ Wind speed $>$ 3.5					0.038	−0.073
					(0.185)	(0.189)
3.5 $\leq$ Wind speed $>$ 4.5					0.030	−0.104
					(0.207)	(0.206)
Wind speed $\geq$ 4.5					−0.212	−0.400*
					(0.204)	(0.206)
Precipitation dummies (omitted: Precipitation = 0)						
0 $<$ Precipitation $<$ 2.5					0.114	0.226
					(0.167)	(0.169)
2.5 $\leq$ Precipitation $<$ 10					−0.365*	−0.322
					(0.215)	(0.211)
Precipitation $\geq$ 10					−0.020	0.454
					(0.365)	(0.357)
Max. temperature dummies (omitted: Max. temperature $<$ 7.5)						
7.5 $\leq$ Max. temp. $<$ 15					−0.207	−0.235
					(0.223)	(0.225)
15 $\leq$ Max. temp $<$ 22.5					−0.183	−0.006
					(0.310)	(0.314)
Max. temp. $\geq$ 22.5					−0.255	−0.183
					(0.427)	(0.442)
Player controls	Yes	Yes	Yes	Yes	Yes	Yes
Match controls	Yes	Yes	Yes	Yes	Yes	Yes
Team × Season FE	No	Yes	No	Yes	No	Yes
Coach FE	No	Yes	No	Yes	No	Yes
Observations	75,163	75,163	75,163	75,163	75,163	75,163
Adjusted R-Squared	0.436	0.465	0.436	0.465	0.436	0.465

Note: Dependent variable: Number of passes. All regressions include player fixed effects. Player characteristics: age (squared), tenure (squared), position (defender, midfielder, striker), minutes played (squared), home match indicator. Match controls: day of week, kick-off time, stadium attendance. Standard errors are clustered at the match level (N = 2956). The usual significance levels apply: 0.1 (*), 0.05 (**), and 0.01 (***).

Table A.4
The effect of air pollution on alternative outcomes at the match level.

	Goals per match		Underdog victory	
	(1)	(2)	(3)	(4)
PM10 (μg/m^3)	−0.001	0.002	−0.001	−0.001
	(0.002)	(0.003)	(0.001)	(0.001)
PM10 × (PM10 ≥ 55)		−0.014*		−0.003
		(0.007)		(0.003)
Weather/Ozone controls	Yes	Yes	Yes	Yes
Match controls	Yes	Yes	Yes	Yes
Player controls match level	Yes	Yes	Yes	Yes
Season FE	Yes	Yes	Yes	Yes
Observations	2956	2956	839	839
Adjusted R-Squared	0.009	0.010	0.033	0.035

Note: Player controls: mean age (squared) and tenure (squared) at the match level. Weather controls on daily basis: maximum temperature (squared), precipitation (squared), dew point (squared), wind speed (squared), air pressure (squared). Match controls: day of week, kick-off time, stadium attendance. Standard errors are clustered at the match level. The usual significance levels apply: 0.1 (*), 0.05 (**), and 0.01 (***).

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