



Real-time information on air pollution and avoidance behavior: evidence from South Korea

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Abstract

This study provides new empirical evidence on the relationship between information about air pollution and avoidance behavior. Many countries provide real-time information to describe the current level of air pollution exposure. However, little research has been done on people's reactions to that real-time information. Using data on attendance at professional baseball games in South Korea, this study investigates whether real-time information on particulate matter affects individuals' decisions to participate in outdoor activities. Regression models that include various fixed effects are used for the analysis, with the results showing that real-time alerts reduce the number of baseball game spectators by 7%, and that the size of the effect is not statistically different from that of air pollution forecasts. The study demonstrates that providing real-time information can be a way to protect the public's health from the threat of air pollution. Moreover, the findings suggest that having easy access to the relevant information and an awareness of the risks involved are necessary for a real-time information policy to succeed.

Keywords Air pollution · Avoidance behavior · Particulate matter · Real-time information

JEL classification I12 · I18 · Q53 · Q58

Introduction

The hazards of air pollution are well known, and government authorities worldwide have implemented various policies to protect their people from the threat it presents. Providing information on the level of air pollution is one of these efforts and is based on the expectation that people will adjust their behavior in response to the information.

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Thus, the information provided typically includes behavioral guidelines to explain the actions the public should take in response to elevated levels of air pollution. A number of studies have shown that providing information on air pollution, such as forecasts, prompts avoidance behavior (Neidell 2009; Graff Zivin and Neidell 2009; Janke 2014; Altindag et al. 2017).

With developments in information and communication technologies, providing and acquiring information have become easier, and the type of information that can be exchanged has become more diverse than ever before. Many countries now provide the public with real-time information on air pollution, which more accurately describes the current level of pollution exposure than what air pollution forecasts can offer. In addition, individuals can obtain this information easily and immediately through smart devices (mobile phones, tablets, etc.). While the expectation is that people will adjust their behavior based on real-time information, little has been studied on people's actual reactions to that information. Providing access to information in real-time does not guarantee that people will respond to it. Therefore, this study analyzes whether real-time information about air pollution triggers avoidance behavior, based on data about air pollution levels and baseball game attendance in South Korea from 2012 to 2016.

Since the mid-2000s, the South Korean government has been providing real-time information on air pollutants via a website created for this purpose (www.airkorea.or.kr). The information has also been disseminated through an open API system since December 2013, enabling the public to access the information from various portals or mobile applications. This study focuses on information regarding particulate matter (PM) among the various air pollutants tracked by the South Korean government. Many studies have investigated the health effects of PM, which is associated with morbidity and mortality from cardiovascular and respiratory diseases (Pope and Dockery 2006; EPA 2014). PM also negatively affects non-health aspects, such as human capital formation, cognitive abilities, and labor productivity (Neidell 2017; Roth 2017; Shier et al. 2019). PM is the most significant threat among the air pollutants in South Korea. The annual average PM10 concentration in South Korea as of 2016 was $47 \mu\text{g}/\text{m}^3$, more than double the World Health Organization (WHO) standards for acceptable risk. Kim et al. (2016) reported that South Koreans perceived “micro dust” as the most significant among public health threats. The most popular mobile application that presents real-time information on PM in South Korea, named “Misemise,” has been downloaded more than one million times from the Google Play Store (as of April 2020). Therefore, it is reasonable to assume that some South Koreans would adjust their behavior based on real-time PM information. This study focuses on PM10, an aerodynamic particle with a diameter smaller than $10 \mu\text{m}$ because information about PM2.5, the other form of particulate matter, was made available only after 2015.

Given that the typical avoidance behavior in response to air pollution is to reduce one's outdoor activities, the reaction to real-time PM10 information is measured using the change in attendance at professional baseball games. Baseball is one of the most popular sports in South Korea.¹ Focusing on data about attendance at professional baseball games has some useful attributes for this study. First, since the baseball season runs from March to October, we observe the extensive variations in PM levels

¹ The average number of spectators per baseball game in South Korea is 11,583, compared to soccer (7872) and basketball (3471) as of 2016 season.

throughout the season. Second, given that baseball games are typically held at night during the summer, the effects of ozone, another type of pollutant that triggers avoidance behavior, can be eliminated (Neidell 2009).² Third, the data are suitable for investigating avoidance behavior considering that the amount of time it takes to play a baseball game (approximately 3 h) is generally longer than for other sports, and the amount of time spent at an outdoor event is directly linked to an individual's exposure to air pollution on highly polluted days.

The results of this study show that people do adjust their behavior in response to real-time PM10 information. I find that attendance at baseball games decreases by approximately 7% when real-time information shows the level of PM10 to be bad or very bad, and the results are highly robust to alternative specifications. The effects of real-time information have increased drastically since 2014 due to the greater accessibility of the information and heightened sensitivity to PM. I also find that the size of the effect of real-time information is not statistically different from that of air pollution forecasts. These results demonstrate that providing real-time information can be a way to protect people's health from the threat of air pollution and suggest that having easily accessible channels of information and awareness of the risk are necessary for a real-time information policy to succeed.

Previous research

The risks created by air pollution provide incentives to avoid it, and a typical avoidance behavior is to reduce one's outdoor activities. Previous studies investigated the relationship between information on levels of air pollution and changes in outdoor activities. Neidell (2009), Janke (2014), and Altindag et al. (2017) reported that information about air pollution such as smog alerts led people to reduce their outdoor activities, reducing the adverse health effects of air pollution.³ The scope of those studies was more comprehensive than what this study addresses in that they focused not only on the existence of avoidance behavior but also on the health effects. However, the previous studies did not consider real-time information, which is of growing importance. In this way, this study offers a new perspective.

Nam and Jeon (2019) examined the effect of PM on the number of spectators in attendance at professional baseball games in South Korea. The authors reported that a high level of PM on the morning of a game day decreased the number of spectators. They concluded that poor visibility due to the high level of PM caused the reduced attendance but did not consider the effect of information. In contrast, this study shows that information about the level of PM is a key factor in the decline in spectators.

There are other notable studies concerning avoidance behavior. Moretti and Neidell (2011) estimated the welfare costs of avoidance behavior using daily boat traffic as an instrumental variable. Graff Zivin et al. (2011) showed that responses to information about water quality violations led people to buy bottled water. Sheldon and Sankaran

² Neidell (2009) demonstrated that O₃ did not affect attendance at evening baseball games due to the nature of ozone, which disappears quickly as the sun sets.

³ Even though these studies focused primarily on showing that avoidance behavior can be a source of bias when estimating the health effects of air pollution, in the process they showed that avoidance behavior existed.

(2019) reported that poor air quality due to forest fires in Indonesia induced people to stay indoors, resulting in increased electricity demand by households in Singapore. Zhang and Mu (2018), and Liu et al. (2018) found that a high level of PM increased online searches for and sales of anti-PM2.5 masks and air filters. Kim (2019) showed that estimates of health effects based on data from South Korea could be biased when avoidance behavior is not considered. Yoon (2019) reported that retail sales declined when the level of PM becomes worse than the “bad” category, which indicated that people were reacting to government-enacted air quality standards. Eom and Oh (2019) demonstrated that an ambient level of PM10 indirectly affects avoidance behavior by changing subjective risk perceptions.

Data

The South Korean government and its local agencies operate more than 250 air quality monitoring stations (as of 2017) and collect hourly data on various pollutants, including SO₂, NO₂, CO, O₃, PM10, and PM2.5.⁴ The National Institute of Environmental Research (NIER) of Korea receives data from these monitoring stations and disseminates it to the public via various channels, such as a government-operated website (www.airkorea.or.kr), portals, and mobile applications. Real-time PM10 information is provided as numerical values and by categories that are determined by the numerical values as follows: 0–30, good; 31–80, moderate; 81–150, bad; and over 151, very bad.⁵ Each of these categories is represented by different colors, i.e., blue, green, yellow, and red, to express these risk levels visually and intuitively. Behavioral guidelines associated with each category that are provided along with the real-time information are shown in Table 1. The NIER distributes real-time information on PM at various levels, from the individual monitoring station to province-level data. This study uses county-level information that is generated by averaging the PM10 concentration of monitors within a county.⁶

Information about air pollution forecasts is also considered in this study. The South Korean government has been operating an air quality forecasting system since 2014 that provides forecasts of PM and ozone levels for the next day, four times a day at the following times: 5 a.m., 11 a.m., 5 p.m., and 11 p.m. This study uses information from the 5 p.m. forecast because it is disseminated via the main evening news, which is presumed to be the most widely viewed news source. These forecasts are provided in terms of the four categories, namely, good, moderate, bad, and very bad, but not as numerical values. Since the forecast is disseminated at the province level, all counties within a province receive the same forecast information. Data on PM10 forecast are available on www.airkorea.or.kr.

Data on professional baseball games is obtained from the Korea Baseball Organization, including information about the ballpark, the home team, the away team, and the number of attendees per game. The baseball season in South Korea runs from March to October, and each team plays approximately 140 games per season. The

⁴ PM2.5 data have been available since 2015.

⁵ This classification follows the standard of the South Korean government, which is less stringent than the WHO standard.

⁶ The average number of monitoring stations linked to a ballpark is 2.36, and each monitor is linked to only one ballpark.

Table 1 Behavioral guidelines corresponding to categories

	Good	Moderate	Bad	Very Bad
PM10 ($\mu\text{g}/\text{m}^3$)	0–30	31–80	81–150	Over 150
Designated Colors	Blue	Green	Yellow	Red
Behavioral Guidelines	–	No particular restriction during outdoor activities.	Limit extended or strenuous outdoor activities.	People should avoid strenuous outdoor activities. Sensitive people should stay indoors.

Source: www.airkorea.or.kr. The PM10 classification follows the standard of the South Korean government, which is less stringent than the WHO standard

league consisted of eight teams in 2012, and two teams were added during the analysis period; thus, there were ten teams in the Korean professional baseball league as of 2016.⁷ Three teams changed their home ballparks during the analysis period.⁸ Only data from the regular season was used; in other words, post-season (playoff/championship) games were not considered. Occasionally, a home team plays at a substitute field rather than at its home ballpark. These cases are also excluded from the sample because the number of such games is negligible.

Weather data are obtained from the climate data open portal (data.kma.go.kr) operated by the Korea Meteorological Administration. This portal provides hourly data from more than 90 weather monitors across the country. For the several counties that have no weather stations, the weather observed from the station nearest to the administrative office of a county is defined to be the weather of that county.

Table 2 shows summary statistics for the data. The study covers 3004 baseball games, and all variables were linked based on location and day. The average number of fans in attendance per game was 11,579, and the average PM10 concentration for the overall sample was approximately $43 \mu\text{g}/\text{m}^3$. Over 90% of real-time PM information was categorized as good or moderate.⁹ Real-time alerts indicating that real-time PM10 information was in the “bad” or “very bad” category occurred for 257 games. Forecast alerts, referring to instances when the forecasted level of PM10 on a game day was expected to be bad or very bad, occurred for 110 games. Forecast alerts have a value of 0 before 2014, when the air pollution forecast system did not exist. For those days where real-time alerts occurred, only 26.1% of them were simultaneously affected by forecast alerts. Even if the time period is limited to 2014 or later, in which the forecasting system was in operation, only 37.9% of the real-time alerts appeared together with forecast alerts.¹⁰ This means that the correlation between the types of alerts may not cause problems of multicollinearity in estimations. Figure 1 displays the

⁷ Eight teams existed in 2012, and two teams joined the league in 2013 and 2015.

⁸ One team moved its ballpark in 2014, and two teams moved in 2016.

⁹ This summary statistic is of real-time information available at the reservation cancellation deadline of a game. The reason for using this variable is explained in Section 4.

¹⁰ The reason why real-time and forecast alerts do not match each other well is that they cover different regions and periods. The forecast provides information on the daily average pollution levels at provinces, while real-time information represents the hourly information of counties.

Table 2 Summary Statistics

Variables	Overall Mean (std. dev.)/N(%) ^a		Real-time alert			
			No Mean (std. dev.)/N(%)		Yes Mean (std. dev.)/N(%)	
Attendance	11,579	(6325)	11,590	(6365)	11,463	(5893)
PM10 (µg/m ³)	43.08	(22.5)	38.72	(15.7)	89.71	(30.17)
Real-time info.						
Good	1056	(35.15)	1056	(38.44)	0	(0)
Moderate	1691	(56.29)	1691	(61.56)	0	(0)
Bad	237	(7.89)	0	(0)	237	(92.22)
Very Bad	20	(0.67)	0	(0)	20	(7.78)
Forecast alert	110	(3.66)	43	(1.57)	67	(26.07)
Temperature (°C)	21.6	(5.2)	21.77	(5.19)	19.73	(4.93)
Precipitation (mm)	2.49	(9.87)	2.67	(10.26)	0.6	(3.07)
Wind speed (m/s)	2.35	(0.97)	2.35	(0.97)	2.42	(0.97)
Humidity (%)	67.26	(15.22)	67.57	(15.1)	63.99	(16.15)
N	3004		2747		257	

^a This is for categorical variables such as real-time information and forecast alert. Real-time alert indicates that real-time information on PM10 is categorized as bad or very bad. Forecast alert indicates that the forecasted level of PM10 is categorized as bad or very bad. The sample period is from 2012 to 2016. The air quality forecast system began in 2014

variations in attendance, frequency of real-time alerts as a percentage of games played, and the average PM10 concentration by year and by month. PM pollution is more severe in the spring; therefore, real-time alerts appear more frequently in the first half of the baseball season. The number of attendees per game is especially large in March and May. The reason for the high average number of spectators in March is that the season starts at the end of March and many people are eager to attend a baseball game at the start of the season, especially the popular first game of the year. May has a large average number of spectators because it is family month in Korea. Figure 2 shows the locations of the ballparks. The average annual PM10 levels in counties that have a ballpark ranged from 35 to 50 during the analysis period. A total of ten teams

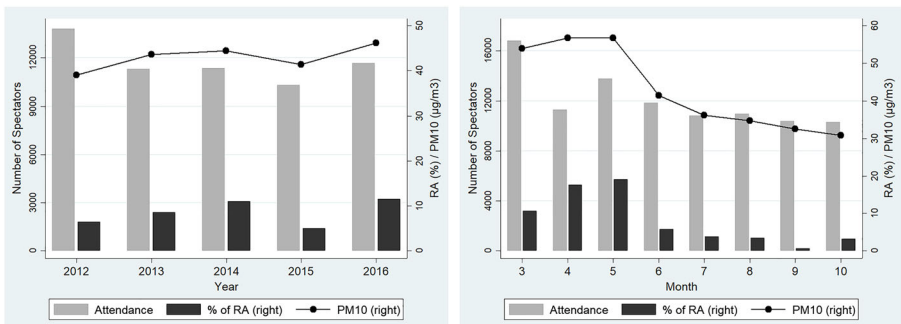


Fig. 1 Number of attendance, PM10 concentration, and % of real-time alerts occurred

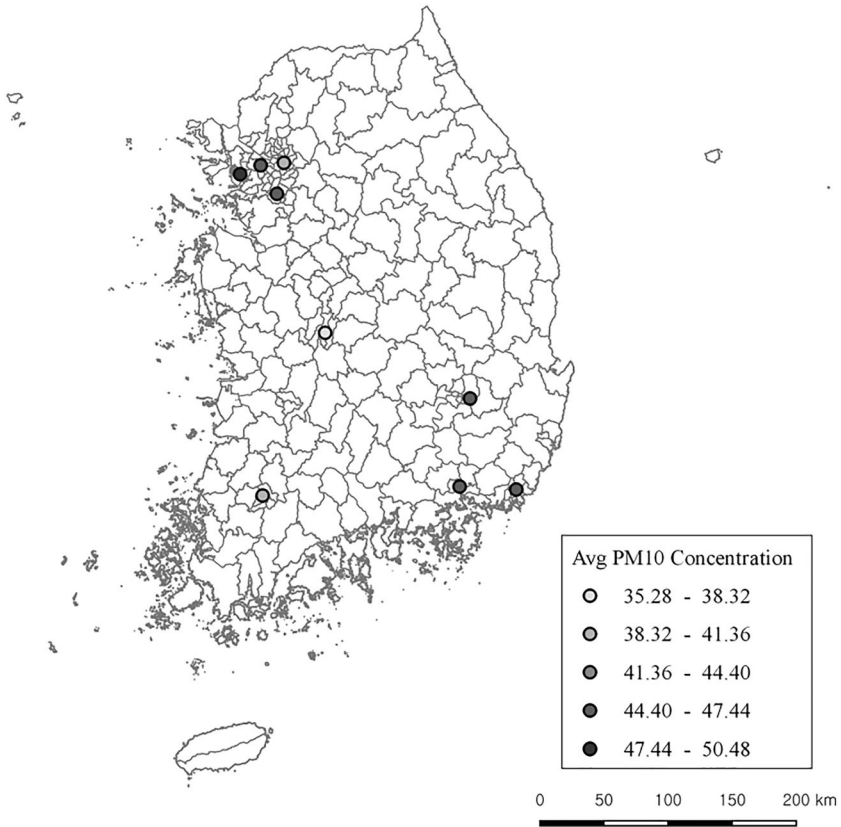


Fig. 2 Location of baseball ballpark and its average PM10 concentration. Note: The location of the ballpark was based on 2016. A total of 10 teams are in the Korea baseball league, but the two teams share one ballpark. Thus, nine ballparks are displayed on the map

participate in the Korean baseball league, but two of them share the same ballpark, so only nine ballparks are shown on the map. Figure 3 shows the distribution of the percentage of real-time alert occurrences among games held on the same day (days when the percentage is zero are excluded from the figure). The histogram shows variation in the real-time alerts within a given day, not only for the entire country but also in areas where a number of ballparks are clustered, such as the northwest region.

Identification strategy

The influence of real-time information is estimated using the real-time PM10 information available as of the reservation cancellation deadline in the county where the game is to be held. The assumption behind the use of this variable is that people adjust their behavior by canceling their reservations, and they refer to real-time PM information available at the deadline by which ticketholders must decide whether or not to cancel. Later in the analysis, I verify this

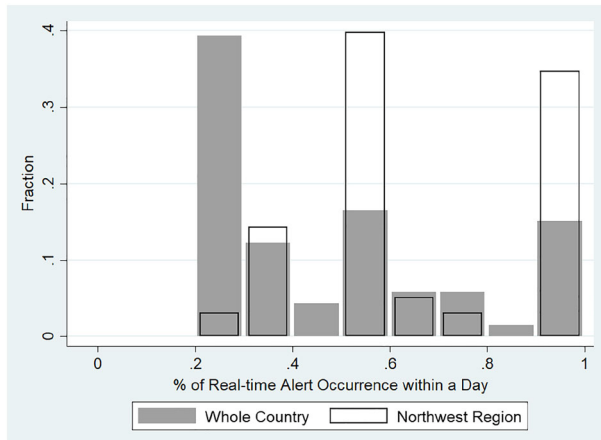


Fig. 3 % of real-time alerts in a day. Note: Days, when the percentage is zero, are not included in the histogram. There are ten teams across the country and four teams in the northwest region

assumption. Only those seats that have not been reserved can be purchased on-site and people have to line up for on-site purchases; therefore, those who want to go to a ball game usually make reservations in advance. A report on professional sports in South Korea revealed that for the 2016 season, only 20.5% of people purchased baseball game tickets on-site (KPSA 2017). Although the rules for canceling a reservation differ across teams, all reservations can be canceled up to 2 to 4 h before the game. The cost of canceling is approximately \$1 plus 10% of the ticket price, which varies from \$10 to \$80, and cancelation is not possible after the deadline. Actual data on canceled reservations would be helpful in this analysis but none was available; therefore, I was only able to use the number of attendees in the study.

As mentioned above, real-time PM₁₀ information is provided not only as numeric values but also as categories. Although the actual level of PM and the associated category are both pieces of information, people are more likely to respond to the category than the actual level of PM₁₀ because each category has its own color and behavioral guidelines corresponding to the risk level. Moreover, high levels of PM are directly related to poor visibility or physical reactions, so the effect estimated from the actual level of PM could not be considered entirely as the result of viewing the information. On the other hand, people's reactions to a category can be interpreted as the direct effect of information, as the thresholds for each category are arbitrarily determined by authorities. Therefore, a dummy variable indicating whether the real-time PM₁₀ is categorized as bad or very bad as of the cancelation deadline is used to estimate the real-time information effects.

A number of previous studies have used air pollution forecasts to identify avoidance behavior (Neidell 2009; Janke 2014; Altindag et al. 2017). In this study, however, forecasts can be a confounding factor that affects the estimation of the impact of real-time information. The forecast is associated with both real-time information and with the number of attendees simultaneously, so omitting it would cause omitted variable bias. Therefore, all regression models in this study include a forecast alert variable

indicating whether the forecasted PM for a ballpark location is categorized as bad or very bad.

The regression model controls for the average PM10 level before the game starts. The PM10 level before the game can affect the number of attendees because people can identify a high level of pollution based on poor visibility or physical reactions (e.g., difficulty breathing, eye irritation). Also, the higher the level of PM10 before a game, the more likely a real-time alert will occur. Although PM10 levels during a game can also be associated with real-time alerts, this is less likely to affect the number of attendees. The attendance data only show the number of people who enter the ballpark; therefore, if people leave the game early due to high levels of pollution it does not influence the number of attendees.

The regression model used to estimate the effect of real-time information is as follows:

$$Y_{ct} = \alpha + \beta_1 RA_{ct} + \gamma_1 PM_{ct} + \gamma_2 FA_{pt} + \gamma_3 W_{ct} + Team_{ct} + Time_t + \epsilon_{ct}, \quad (1)$$

where Y_{ct} is the (log) number of attendees in the game held in county (or ballpark) c on day t .¹¹ RA indicates that the real-time information available at the cancelation deadline is categorized as either bad or very bad. If real-time information affects attendance, the effect will be shown in β_j . PM is the average level of PM10 before the game starts and is included as a quadratic function or as 20 $\mu\text{g}/\text{m}^3$ interval dummies. FA is the indicator for forecast alerts, which indicates that the forecasted PM is categorized as bad or very bad. FA is provided at the province level (p), so counties within the same province have the same FA . W represents a set of weather variables, including temperature, precipitation, wind speed, and relative humidity. Omitting weather variables could also create omitted variable bias because weather affects both attendance and level of air pollution. Weather variables are included as second-order polynomials.

$Team$ is a vector of home team fixed effects, away team fixed effects, and home-away team fixed effects. Home team and away team fixed effects capture the time invariant characteristics of teams when they are the home team or an away team. The unique relationships between teams can influence the number of attendees. As shown in Fig. 2, some teams are clustered in the northwest and southeast regions of the country, and two teams share a ballpark. This indicates that the number of fans for the away team is likely to vary depending on the location of the home team's ballpark. In addition, rivalries between two teams can affect game attendance. Home-away fixed effects, measured by the interaction terms of the home team and away team dummies, account for the unique relationships between teams. $Time$ represents a set of time fixed effects including year, month, day of the week, holiday, and the MERS outbreak, to capture temporal and seasonal trends in baseball game attendance and real-time alerts.¹² During the analysis period, a few teams changed their ballparks; the interaction terms

¹¹ Given that all of the counties included in this analysis have only one ballpark, the subscript c indicates both the county and the ballpark.

¹² Middle East respiratory syndrome (MERS) was prevalent in Korea for 68 days from May 20, 2015, to July 28, 2015. The high infectivity of this disease caused people to reduce their outdoor activities. Therefore, the model specifically controls for this period.

for the home team and year dummy variables are included in the model to account for such changes.

Results

Main results

The results obtained from the regression specified in Eq. (1) are shown in Table 3. Each column provides results for different specifications of the model, but weather, team fixed effects, and time fixed effects are included in all of the specifications. Results show that real-time information available about PM at the cancellation deadline reduces baseball game attendance by approximately 7%. Moreover, the coefficient of the impact of real-time alerts is largely unaffected by the functional form of the average PM level before the start time of the game and is not sensitive to the forecast alert. The results suggest that the issuance of real-time alerts affects participation in outdoor activities independently of the actual PM level or the forecast. Considering Nam and Jeon (2019)'s results reporting that the number of baseball spectators decreased by 8.9% when the average PM10 on the morning of the game day is high (81 $\mu\text{g}/\text{m}^3$ or over), we can infer that real-time information is a key factor for the decrease.

In this analysis, reverse causality can exist in that the regional air pollution level could be influenced by game-related traffic (Locke 2019). Although home team fixed effects capture the average level of local traffic, the daily traffic variations due to baseball games can affect the level of air pollution and, consequently, real-time alerts. However, even if reverse causality does exist, it would only cause a downward bias on the effect of real-time information because traffic and air pollution are positively

Table 3 Effects of real-time alerts on baseball game attendance

	(1)	(2)	(3)	(4)
Real-time alert	-0.0753*** (0.0269)	-0.0729*** (0.0268)	-0.0686** (0.0329)	-0.0708** (0.0328)
PM	-0.000426 (0.000597)	-0.000438 (0.000600)		
PM (squared)	3.30e-06 (2.56e-06)	5.48e-06** (2.65e-06)		
Forecast alert	No	Yes	No	Yes
Functional form of PM	Quadratic	Quadratic	Interval dummies	Interval dummies
Observations	3004	3004	3004	3004
R-squared (adj)	0.711	0.711	0.711	0.711

Robust standard errors in parentheses. *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$. The analysis period is from 2012 to 2016. Real-time alert indicates that real-time information on PM10 is categorized as bad or very bad. Forecast alert indicates that the forecasted level of PM10 is categorized as bad or very bad. PM indicates the average level of PM10 before the game starts and is included as a quadratic function or 20 $\mu\text{g}/\text{m}^3$ interval dummies. Weather, team-FE, and time-FE are controlled

correlated. Despite the possibility of underestimation, the results of the analysis are statistically significant.

Validity check of the underlying assumption

This study uses the information available as of the cancellation deadline as the real-time information to which people respond. The underlying assumption is that people adjust their behavior in response to information about the level of PM by canceling their reservations, and they refer to the information that is available as of the cancellation deadline to make their decision. I check the validity of this assumption by including all of the real-time PM10 information available before and after the cancellation deadline. Real-time alerts occurring within 6 h before and after the deadline are included in the model. Since real-time information at a given time can be highly correlated with that of adjacent times, real-time alerts around the deadline are included at 2- to 3-h intervals in

Table 4 Reaction to real-time alerts around the deadline

	(1) 2-h intervals	(2) 3-h intervals
Before 6 h	0.00782 (0.0317)	0.00847 (0.0296)
Before 5 h		
Before 4 h	−0.00226 (0.0323)	
Before 3 h		−0.0296 (0.0292)
Before 2 h	−0.0485 (0.0320)	
Before 1 h		
Deadline	−0.0662* (0.0349)	−0.0546* (0.0316)
After 1 h		
After 2 h	0.0320 (0.0336)	
After 3 h		−0.0240 (0.0287)
After 4 h	0.00208 (0.0332)	
After 5 h		
After 6 h	−0.0188 (0.0263)	−0.00276 (0.0247)
Observations	3004	3004
R-squared (adj)	0.711	0.711

Robust standard errors in parentheses. *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$. The analysis period is from 2012 to 2016. Real-time alert indicates that real-time information on PM10 is categorized as bad or very bad. PM, forecast alerts, weather, team-FE, and time-FE are controlled

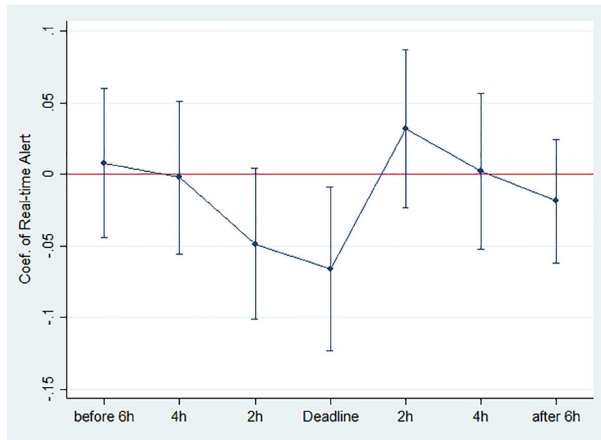


Fig. 4 Effect of real-time alerts near the deadline (2-h interval). Note: The vertical bar of a point represents 90% confidence intervals

the model. Table 4 and Fig. 4 present the estimation results showing how the effects of real-time information change as the cancellation deadline approaches and passes.

Table 4 and Fig. 4 show that real-time alerts occurring after the cancellation deadline have no significant effect on attendance. This supports the hypothesis that the people who do respond to real-time information adjust their behavior by canceling their reservations prior to the deadline. In addition, although the effects of real-time alerts increase as the deadline approaches, the alert as of the deadline has the largest effect and is the only statistically significant source of information. Therefore, we conclude that our underlying assumption, namely, that people adjust their behavior by canceling their reservation and that they refer to information as of the cancellation deadline to decide whether or not to cancel, is reasonable.

Differential effects of real-time alert over time

The effects of real-time information can differ by year if factors such as accessibility and sensitivity to real-time information vary over time. The South Korean government began to publish air pollution data through an open API system in December 2013, allowing people to easily check PM information in real-time via various portals and mobile applications.¹³ Furthermore, the International Agency for Research on Cancer (IARC) classified PM as a Group 1 carcinogen in October 2013 (IARC 2013). Figure 5 shows the Google search trend for PM10 in South Korea, revealing significant increases after these events.¹⁴ Therefore, in this section, I examine whether the effect of real-time information differs before and after 2014. The interaction term of real-time alerts and a dummy variable indicating the years after 2014 is included in the main regression model to estimate this effect.

¹³ Before the launch of the open API system, people could only check real-time information via the government-operated website (airkorea.or.kr).

¹⁴ The Google search trend data are taken from www.trends.google.com. The graph shows the relative frequency of the search normalized to a range of 0–100.

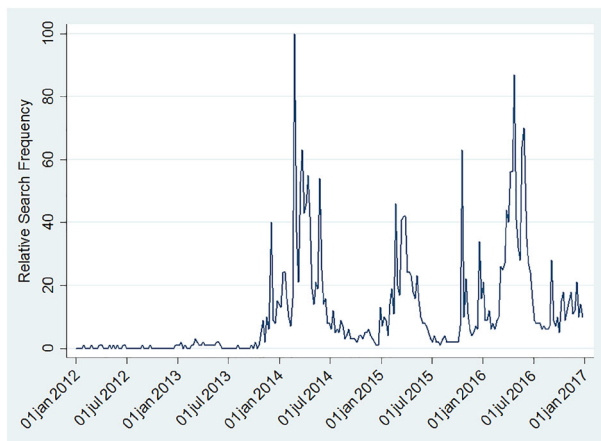


Fig. 5 Google Search trend of PM10 by week. Note: The Google search trend data are available at www.trends.google.com. This graph shows the relative frequency of the search normalized to the 0–100 range

Column (1) of Table 5 shows the result of the main regression model, which estimates the average impact of real-time alerts over the entire analysis period. Column (2) shows the differential effect over time. The results show that real-time alerts on PM10 do not have a noticeable effect prior to 2014 and that the impact increases dramatically after 2014. This finding confirms that the increased accessibility of real-time information and sensitivity to the risks of PM exposure have changed the way people respond to real-time information about PM levels. Unfortunately, it is not possible to decompose the contributions of accessibility and sensitivity to the overall change due to data limitation. However, we can infer that easily accessible information and education about risks are necessary to the success of a real-time information policy. Figure 6, which displays the real-time information effects by year, also supports this finding.

Table 5 Differential effects of real-time alerts over time

	(1) Main result	(2) Differential effects over time
Real-time alert	−0.0729*** (0.0268)	−0.0255 (0.0391)
Real-time alert * after 2014		−0.0741* (0.0438)
Observations	3004	3004
R-squared (adj)	0.711	0.711

Robust standard errors in parentheses. *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$. The analysis period is from 2012 to 2016. Real-time alert indicates that real-time information on PM10 is categorized as bad or very bad. In all analyses, PM, forecast alerts, weather, team-FE, and time-FE are controlled

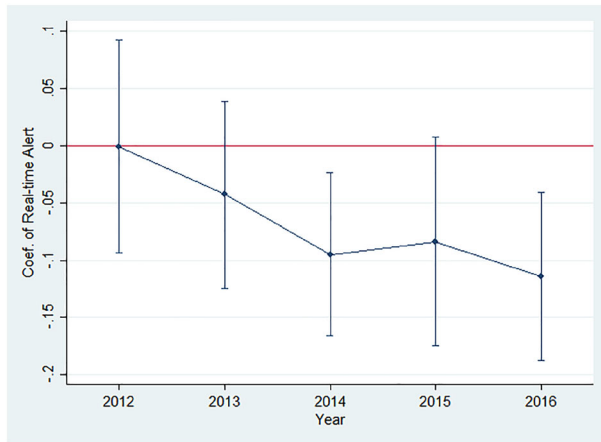


Fig. 6 Change of the effects of real-time alerts by year. Note: The vertical bar of a point represents 90% confidence intervals

Differential effects by the importance of the game

The effect of real-time information can also be differentiated by the importance of the particular baseball game. For example, more people may decide to go to the ballpark despite a high level of air pollution when the game is crucial for their team. This section investigates whether there are differentiated effects based on the importance of specific games by including the ranking of the home team and the difference in ranking between

Table 6 Differential effects of real-time alerts by the importance of the games

	(1)	(2)	(3)
Real-time alert	-0.0773*** (0.0271)	-0.135*** (0.0401)	-0.117*** (0.0410)
Ranking of home team	0.0450*** (0.00438)	0.0461*** (0.00443)	0.0451*** (0.00438)
Ranking difference	0.0122*** (0.00328)	0.0122*** (0.00328)	0.0134*** (0.00338)
Real-time alert * ranking of HT		-0.0125* (0.00724)	
Real-time alert * ranking Diff.			-0.0136 (0.00896)
Observations	3004	3004	3004
R-squared (adj)	0.723	0.723	0.723

Robust standard errors in parentheses. *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$. The analysis period is from 2012 to 2016. Real-time alert indicates that real-time information on PM10 is categorized as bad or very bad. In all analyses, PM, forecast alerts, weather, team-FE, and time-FE are controlled. The home team’s ranking ranges from 1 to 10, with 10 representing first place and 1 representing last place. Ranking differences range from 0 to 9—the larger the value, the closer the ranks of home and away teams

the home and away teams. Variables related to ranking are converted as follows: The home team's ranking ranges from 1 to 10, with 10 representing first place and 1 representing last place. Ranking differences range from 0 to 9—the larger the value, the closer the ranks of the home and away teams.

Table 6 shows the results. Consistent with our expectations, fans are more likely to attend a baseball game when their team is highly ranked, or when their team is playing another team with a similar ranking. However, real-time information about PM levels does have a greater impact on more crucial games. The real-time alert decreases the number of spectators by an additional 1.25% when the home team's ranking increases by one unit. This may be because those spectators whose behavior is affected by the importance of the game are relatively less devoted to their team and therefore are more likely to abandon going to a ballpark on a high pollution day. Considering that a one-unit increase in ranking increases the number of spectators by 4.6% when the PM level does not trigger an alert, a real-time alert reduces approximately 27% of this increase. Column (3) shows that the effect of real-time information is greater for fans who decide to attend a game based on the ranking difference (i.e., the importance of the game to their team).

Comparison of effects of real-time alerts and forecast alerts

This section compares the magnitude of the effects of real-time alerts and forecast alerts using data after 2014. Given that the forecast system was implemented in 2014 and that the effects of real-time alerts have surged since then, the data after 2014 are deemed most appropriate for this comparison. Column (2) includes the interaction term of real-

Table 7 Comparison of effects of real-time alerts and forecast alerts

	(1) Baseline	(2) Including interaction	(3) w/o FA days	(4) w/o RA days
Real-time alert	-0.0624* (0.0365)	-0.0753* (0.0393)	-0.0844** (0.0427)	
Forecast alert	-0.0696** (0.0350)	-0.0982** (0.0385)		-0.0993** (0.0412)
Real-time alert * Forecast alert		0.0697 (0.0652)		
# of real-time alert	177	177	110	0
# of forecast alert	110	110	0	43
Observations	1951	1951	1841	1774
R-squared (adj)	0.696	0.696	0.688	0.695

Robust standard errors in parentheses. *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$. This analysis is conducted using data after 2014 when forecast information started providing. Real-time alert (RA) indicates that real-time information on PM10 is categorized as bad or very bad. Forecast alert (FA) indicates that the forecasted level of PM10 is categorized as bad or very bad. In this table, the average PM10 concentrations before the game starts are included as 20 $\mu\text{g}/\text{m}^3$ interval dummies. Weather, team-FE, time-FE are controlled

time alerts and forecast alerts.¹⁵ Column (3) and (4) estimate the effect of one type of alert on days when the other type of alert does not appear.

Table 7 shows that real-time alerts reduce baseball game attendance by approximately 6–8%, which is comparable to the main results. Forecast alerts are shown to decrease the number of spectators by approximately 7–9%. Although the regression coefficient of forecast alerts is slightly greater than that of real-time alerts across all specifications, the difference is not statistically significant. Therefore, the results suggest that people adjust their behaviors in response to real-time information and the extent to which they depend on that information is almost the same as their dependence on forecasts.

Additional robustness checks

In this section, I conduct additional robustness checks on the effect of real-time information and the findings support the main results. Column (1) in Table 8 estimates the regression with the dependent variable expressed in levels rather than log values. It shows that a real-time alert reduced attendance at baseball games in South Korea by approximately 936 individuals, or 8.1% of average attendance. This percentage is slightly larger than the main result but is quite comparable.

Column (2) presents the results where dummy variables representing the week are included instead of month dummies. Although month fixed effects account for seasonal trends, if time trends exist in our dependent and key explanatory variables within a month, the regression results could show a spurious relationship. The result in column (2) shows that the effect of real-time information is not affected by the inclusion of week dummies.

Column (3) in Table 8 represents the result of a multi-pollutant model. PM is associated with other pollutants, given that gases such as sulfur oxides and nitrogen oxides can be transformed into PM through chemical reactions. This model controls for the average levels of SO₂, CO, O₃, and NO₂ before the game, and real-time alerts on these air pollutants are also included.¹⁶ The result is almost unchanged, even when the other pollutants are considered.

In column (4), the games that attract full capacity crowds are excluded from the sample. The main regression model can be considered as a censored model with upper limits because each ballpark has a maximum number of spectators it can accommodate. I perform an analysis that excludes the games that attracted full capacity crowds (318 cases) to remove any distortion related to these upper limits. The result using the restricted sample shows that the effects are still largely negative and statistically significant.

The models in columns (5) and (6) investigate the impact of real-time information on indoor activities. In 2016, Nexen, one of the professional baseball teams in Korea, changed its home stadium to the Gocheok Skydome, the first and only domed stadium in Korea. The influence of information about PM on games played in this stadium

¹⁵ Vector inflation factors (VIF) of real-time alert and forecast alert are 1.92 and 2.91 for Column (1), 3.07 and 3.23 for Column (2). The VIFs reconfirm that the correlation between real-time and forecast alert does not cause a serious problem in the regression.

¹⁶ There were 39 real-time alerts for O₃, while there were no alerts for the other pollutants.

Table 8 Robustness checks for effects of real-time alerts

	(1)	(2)	(3)	(4)	(5)	(6)
	Attendance in levels	Week dummy	Multi- pollutants	w/o maximum crowd	Effect of domed stadium	Basketball
Real-time alert	-936.0*** (326.9)	-0.0764*** (0.0270)	-0.0733*** (0.0269)	-0.0635** (0.0279)	-0.0718*** (0.0275)	-0.126** (0.0600)
Real-time alert * Gocheok Sky Dome					-0.0195 (0.0603)	
Observations	3004	3004	3004	2686	3004	532
R-squared (adj)	0.744	0.717	0.714	0.697	0.711	0.637

Robust standard errors in parentheses. *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$. The analysis period is from 2012 to 2016. Real-time alert indicates that real-time information on PM appears as bad or very bad. In all analyses, PM, forecast information, weather, team-FE, time-FE are controlled. In the multi-pollutants model, SO₂, CO, O₃, and NO₂ is considered. Nexen, one of the Korean professional baseball teams, changed its home stadium to Gocheok Skydome, which is the first and the only domed stadium in Korea in 2016. Data on basketball games of 2014–2015 and 2015–2016 season are used for column (6)

could differ from that of other ballparks if people believe that games held in the domed stadium are not affected, or are significantly less affected by PM. Column (5) estimates the differentiated effect of the domed stadium by including the interaction term of real-time alerts and the Gocheok Skydome dummy in the model.¹⁷ Separately, column (6) examines the effect of real-time PM information on basketball game attendance, as all basketball games are held indoors. The results in columns (5) and (6) show that attendance at games held in the Gocheok Skydome, as well as at basketball games, are negatively influenced by real-time PM alerts. This finding may imply that fewer people are willing to go out on highly polluted days, resulting in a lower number of visitors even to indoor facilities.

Conclusions

This study investigates the impact of real-time information regarding the level of PM on outdoor activities using data on attendance at professional baseball games in South Korea. The main results show that real-time alerts reduced the number of spectators at baseball games by approximately 7%. This result is robust under various model specifications. The finding suggests that people adjust their behavior based on real-time information and the dependence on real-time information about pollution levels is not statistically different from the dependence on air pollution forecasts. This study uses the real-time information about PM levels that is available as of the deadline for canceling baseball game reservations as the real-time information to which people respond, and additional analysis confirmed that the use of this variable is

¹⁷ The Gocheok Skydome fixed effect is already captured in the main model because the interaction terms of home teams and year dummy variables are included in that model.

reasonable. I find that the effect of real-time information has dramatically increased since 2014 due to a change in the accessibility of the information and the public's sensitivity to the risks associated with PM exposure. Real-time information on PM has a greater impact on spectators whose attendance is affected by the importance of the game. In addition, I find that the desire to avoid air pollution affects attendance even at indoor facilities.

With the development of technology, authorities can more easily provide information to the public about air pollution in real-time. Despite its growing importance, little research has been done regarding the impact of real-time information. This study identified that real-time information can be a way to protect people's health from the threat of air pollution by triggering avoidance behavior. These findings may apply not only to air pollution but also to other fields of health policy where real-time information can be provided and applied in a practical way. The results also indicate that for a real-time information policy to succeed, authorities should provide real-time information through easily accessible channels such as mobile applications or portals and should increase people's awareness of health risks through education.

Unlike some previous research, this study focuses only on a behavioral response and does not consider the costs or benefits of a specific action. Unfortunately, I was not able to analyze the discriminatory effects with respect to groups with greater than average health risks. Nevertheless, this study is meaningful in that it provides new empirical evidence on the impact of real-time information and how it can help improve health policy decisions.

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