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Economic effects of ambient air pollution on consumer shopping behaviors

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Abstract

In this paper, we address why the lack of research on the indirect economic effect of air pollution arises and explored the desirable features of data that allow such examination. In light of scanner panel data on individual transactions from a region with significant fluctuations in the level of particulate matters, our empirical investigation reveals that the economic effect of air pollution is statistically and economically significant through the disruption on consumption behaviors. Our discussion on the essential features of the data for the systematic analysis on the economic effect of air pollution and empirical evidence based on such data provides ample guidance for the future research.

Keywords: ambient air pollution; consumer shopping behaviors; extreme events; economic disruption
JEL Classification Codes: E21, I12

1. Introduction

The adverse health effects closely associated with ambient air pollution and particulate matters have been more challenging in many of developing countries and become of a great concern to policy makers (Kang et al. 2016, Delfino et al. 2006, Jung et al. 2015, and Shah et al. 2015). According to the World Health Organization, ambient air pollution was responsible for 3.7 million deaths in 2012, representing 6.7% of total deaths worldwide. In particular, it was the cause of 16% of lung cancer deaths, 29% of heart disease and stroke, and approximately 13% of deaths due to respiratory infection.

Inevitably, costs of treating patients and implementing controls to reduce respiratory and cardiovascular diseases have increased substantially, imposing a substantial burden on the economies (Leem, Kim, and Kim 2015, Fleischer et al. 2014, and Kim et al. 2015). Moreover, the disruption in consumers' willingness to buy resulting from the fear of its detrimental effect on health also shrinks economies to a considerable extent, as psychological factors in response

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to an extreme event such as epidemic outbreaks caused a substantial disruption on consumer expenditures (Jung et al. 2016).

Yet, despite the extensive range of studies on the adverse health effects of ambient air pollution, little systematic research has been conducted to understand how ambient air pollution affects individual consumption behaviors psychologically. Studies, investigating the effect on ambient air pollution, instead, primarily employ clinical data and examine the causal relation between the exposure to particulate matter and respiratory/cardiovascular diseases with a specific focus on factors that moderate or intensify effects of the exposure.

In this paper, we address why the lack of studies on the economic effect of air pollution arises and describe the essential features of data that enable such investigation. Then, we provide the description of the records on the level of particulate matters in a geographic region and discuss how significant fluctuations in the level of particulate matters in a short period of time set desirable states to investigate its economic effect that arises from the disruption in consumers' willingness to buy.

Our paper makes the following contributions. We explore the desirable aspects of the data for the systematic analysis on the economic effect of air pollution and empirically test whether the data of our interests attain such features. The desirable features of the data we discuss in the paper allow extensive line of studies on the indirect economic effect of air pollution that arise from the fear of its adverse health effect. Our paper provides ample guidance for the future research, which can make explicit and direct implications to policymakers and managers for sustainable economic growth.

2. Data

2.1. Background

The relation between air pollution and respiratory/cardiovascular disease is well established. Clinical, mechanistic, and epidemiological studies of the effects of long- and short-term exposure to air pollution and the sizes of PM have provided evidence supporting its adverse health effects. Epidemiological studies and pathophysiological data have also shown that air pollution exposure is related to general mobility and mortality due to respiratory and cardiovascular diseases (Janssen et al. 2003, Kim et al. 2008, Morgenster et al. 2008 and Shima, Nitta, and Adachi 2003). Furthermore, the aerodynamics of PM can affect the severity of adverse health effects (Kan et al. 2010 and Qian et al. 2010). In general, PM with lower aerodynamic diameters, including fine and ultrafine PM, are associated with more serious adverse effects after both short- and long-term exposures to an elevated concentration of pollutants (Revich, Boris, and Shaposhnikov 2010, Stafoggia et al. 2010, and Vichit-Vadakan, Vajanapoom, and Ostro 2010). In addition, adverse effects can be exacerbated in vulnerable populations, including those with preexisting cardio-respiratory diseases and the elderly (Bowatte et al. 2015, Lee, Kim, and Lee 2014, and Nyhan et al 2016). As a result, these populations tend to have more complicated health problem after air pollution exposure than healthy groups (Han et al. 2015, Hwang et al. 2016, Metzger et al. 2004, and Rohde and Muller 2015).

However, despite its significant adverse health effect, little is known about how the elevated level of air pollutants influences individual consumption behaviors and economies. The lack of studies on the indirect economic effect of ambient air pollution is largely due to the following facts. First, micro data that enable the measurement of indirect and behavioral effects of air pollution are not widely accessible to academics. Consequently, only a restricted perspective of changes in consumption behaviors can be extrapolated from the aggregated sales data, and, therefore, changes in consumption behaviors in response to the ambient air pollution are likely mis-specified (Jung 2017 and Jung, Yu, and Kwon 2016).

Second, the investigation on the indirect economic effect of ambient air pollution requires particular features in the data that are not generally considered essential in the ecological studies. For instance, research on the adverse health effect of air pollution often employ cross-sectional data analysis and compare the differences among the subjects in different geographic regions (Andersen et al. 2010 and Wellenius, Schwartz, and Mittleman 2005). However, risk of the systematic and endogenous differences in consumption behaviors of subjects is high in such research designs, as subjects with considerable differences in the level of particulate matters are likely subject to different economic conditions. This is because a significant portion of particulate matters is derived from economic activities such as agricultural operations, industrial processes, combustion of fossil fuels, and construction (Kan et al. 2010 and Qian et al. 2010).

Analogously, the risk of endogeneity can also be prevalent in the comparison of how consumption behaviors of a group change over time along with fluctuations in the level of particulate matters, because an increase or decrease in the particulate matters in a region can be an outcome of changes in other factors closely related to its economic condition. As a result, identifying a region with significant fluctuations in the level of particulate matters in a short period of time for which its economic condition remains fairly stable is essential to test the economic effect of ambient air pollution.

2.2. Data on air pollution

To find a region with significant fluctuations in the level of air pollution in a short period of time, we focus on Korean national air reporting system that now includes 354 sites in 94 cities. These automated stations report hourly via the internet, and focus on six pollutants: particulate matter>2.5 microns (pm2.5), particulate matters <10 microns (pm10), sulfur dioxide (so2), nitrogen dioxide (no2), ozone (o3), and carbon monoxide (co). As the size of particulate matters, varying from 0.001 to 500 microns, influences the particles' penetration into, deposition in, and elimination from the respiratory organs (Yoon et al., 2003), particulate matter less than 2.5 microns is of the focal interest of our research. Previous studies of regional scale air pollution have generally relied on satellite data, but the high density of hourly data in Korea now allows regional patterns to be constructed directly from ground observations.

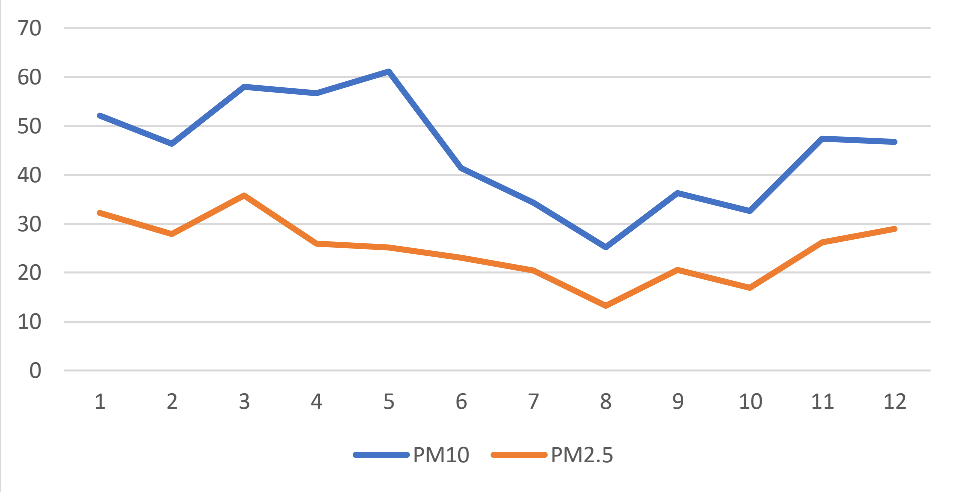
Achieved observations are publicly available on the official Korean air quality reporting system and two-year-long interval from 1 Jan 2017 to 31 Dec 2017 is downloaded. Removing stations with a high percentage of missing values leaves 199 national network sites.

The data show the volatile nature of air pollution and the role of weather patterns in redistributing pollution on short timescales. More specifically, the level of PM2.5 or PM10 exceeded the level associated with a 15% higher long-term mortality risk relative to the air quality quideline level[1] for 73 days among 365 days of our observations, and the highest levels of PM2.5 and PM10 reached 81.11 $\mu g m^{-3}$ and 180.84 $\mu g m^{-3}$, respectively. On the other hand, the levels of so2, no2, o3, and co mostly remained under the WHO guideline values.

Upon identifying the above features, we focus on monthly averages and seasonal averages of PM2.5 and PM10 concentrations, presented in Figure 1, and find a clear pattern that the levels of PM2.5 and PM10 concentration reached up to 35$\mu g\, m^{-3}$ and 57$\mu g\, m^{-3}$ during the spring and winter and down to 13$\mu g\, m^{-3}$ and 25$\mu g\, m^{-3}$ in the summer, respectively. The analysis of monthly averages of PM2.5 fluctuations conducted by Lee (2014) suggests that Asian Dust and rainfall are the primary cause for such large differences across seasons and that differences caused by artificial impacts to air pollution are also statistically significant.

[1] WHO Air quality guidelines for particulate matter, ozone, nitrogen, dioxide and sulfur dioxide, Global update 2005 (https://apps.who.int/iris/bitstream/handle/10665/69477/WHO_SDE_PHE_OEH_06.02_eng.pdf?sequence=1).

Figure 1. Monthly Averages of PM2.5 and PM10 in 2017.



Recognizing the considerable fluctuations in PM2.5 and PM10 concentrations across seasons, we then analyze daily averages of PM2.5 and PM10 concentrations. Interestingly, the daily averages also fluctuated to a significant extent, and the differences in PM2.5 and PM10 concentrations within a month is as large as 70 µg m^{-3} and 151 µg m^{-3}; and differences in levels of PM2.5 and PM10 exceeding 10 µgm^{-3} and 15 µgm^{-3} between two consecutive days were recorded for more than 10% of the data period. Although emission of particulate matters is closely associated with human economic activities, there is little reason to believe that fluctuations in daily averages of PM2.5 concentrations are the outcome of or can be penetrated into changes in economic conditions. Accordingly, such substantial fluctuations in daily averages provide an opportunity to empirically examine how elevated level of particulate matters impact consumption behaviors.

Given the ambient air pollution, note that 83.2 percent of respondents in a survey[2] reported to pay attention to the fine dust related news; the volume of Google search results we, on Dec 7 in 2020, retrieved with 'fine dust' in Korean as a search keyword during the period of 2017 exceeds 74.4 million; according to 2017 national survey[3], respondents cited the fine particulate matters as the largest stressor in life; and each of the two most popular mobile phone applications monitoring the levels of fine particulate matters in Korea has more than 1 million users. Such facts provide strong empirical evidence that Korean consumers are concerned about air pollution.

2.3. Microdata on Consumption Behaviors

To test whether an elevated level of particulate matter caused changes in consumption behaviors on a particular day, researchers need to observe them in a considerable detail. Especially with the presence of significant fluctuations in the daily averages of PM2.5 and PM10 concentrations, daily transaction information is essential for comprehensive understanding about how changes in shopping and consumption behaviors arose from the fear of air pollution, as consumption behaviors are strongly influenced by time trends (Jung et al. 2016).

Accordingly, we focus on data that maintain records of credit and debit card transactions. Our data come from a mobile phone application design and development firm, which developed a

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[2] Share of individuals who are interested in news reporting about fine dust in South Korea as of January 2018 (https://www.statista.com/statistics/872696/south-korea-fine-dust-awareness/).
[3] South Koreans more worried about air pollution than Kim's nukes (https://www.theguardian.com/world/2018/may/16/south-koreans-more-worried-about-air-pollution-than-kims-nukes).

household account book application. The application automatically bookkeeps the household expenditures based on text message its users receive from credit card companies and banks. With advances in the application of smart phones and increased adoption of them, such microdata on purchase histories of consumers are not uncommon types of data start-up firms are accumulating, and, unlike established firms that capable of conducting analyses for efficient decision makings, these firms often allow researchers to use their data on academic purposes.

Our data have the records of credit and debit card transactions for 1,500 consumers. However, the complete transaction data through 2017 were available only for 469 consumers, to who we restrict our attention. The data include customer identifiers, date, time, amount paid, and the name of the retail store. The data also have consumers' gender and age, and, additionally, retailer's type was identified based on the name. Given the construct, the data contain a variety of expenses, ranging from expenditures at restaurants, grocery stores, cafes, and online stores to payments for gas and electricity. Although the data do not take into account the list of products purchased in a transaction nor show price or promotion information at stores, the extensive range of our data enable us to observe extremely detailed information on consumers' shopping behaviors and expenditures on goods and services.

3. Methods

Based on credit and debit cards transaction information on consumers' shopping behaviors, with a particular focus on PM2.5 and PM10, we explore the economic effect of ambient air pollution in Korea using an ordinary least squares regression in the following specification:

$$\log Exp_{it} = a_0 + a_1 \log Exp_{i0} + a_2 \log PM2.5_{it} + a_3 \log PM10_t + AX_{it} + \varepsilon_{it}^1. \quad (1)$$

Exp_{it} is consumer i's is total expenditures during week t; Exp_{i0} is the average weekly expenditures of consumer i during the first six weeks of our data, and $PM2.5_t$ and $PM10_t$ are the average levels of PM concentrations on the week t. Finally, X_t is a set of controls, including dummies for holidays and demographic information of consumers. Note that the dependent variable is specified in log-linear form. This is because we observe considerable variations in the magnitude of the expenditures across consumers and over time.

The individual consumers' value of the dependent variable during a six-week initialization period along with their demographic information estimates the effect of heterogeneity in preferences across consumers (Briesch, Chintagunta, and Fox, 2009; Bucklin, Gupta, and Han, 1995; Ma et al. 2011); the levels of PM2.5 and PM10 measure their effect on consumers' expenditures, which was of the central interest to our research; and X_{it}, controls for time trends using time dummies and the holiday effect.

To help interpreting the coefficient estimates, note that the estimates of a_2 and a_3, the coefficients of our primary interests, measure the effect of the elevated PM2.5 and PM10 concentrations on consumer expenditures. If a considerable drop in expenditures was caused by the increased levels of particulate matters, we expect the negative effect of PM2.5 and PM10.

In investigating the effect of the elevated PM2.5 concentrations, we check the robustness of our results. First, there could be other measures that we can consider such as categorical measures of the PM2.5 and PM10 concentrations, as frequently employed in Korean weather forecasts. Secondly, we employed the log-linear specification in the previous model, but a linear specification may better describe the effects of the PM2.5 and PM10 concentrations. Thus, using a categorical variables indicating the levels of the PM2.5 and PM10 concentrations and a linear model specification, we developed two additional models in the following forms:

$$\log Exp_{it} = \beta_0 + \beta_1 \log Exp_{i0} + \sum \beta_{2k} \log Cat2.5_{kt} + \sum \beta_{3k} \log Cat10_{kt} + BX_{it} + \varepsilon_{it}^2, \quad (2)$$

and

$$Exp_{it} = \gamma_0 + \gamma_1 Exp_{i0} + \gamma_2 PM2.5_t + \gamma_3 PM10_t + \Gamma X_{it} + \varepsilon_{it}^3. \quad (3)$$

Note that $k \in \{1,2,3\}$ and $Cat2.5_{1t}$/ $Cat10_{1t}$ is 1 if PM2.5/ PM10 concentrations are above the third quartiles and 0 otherwise; $Cat2.5_{2t}$/ $Cat10_{2t}$ is 1 if PM2.5/ PM10 concentrations are between the second and third quartiles and 0 otherwise; and $Cat2.5_{3t}$/ $Cat10_{3t}$ is 1 if PM2.5/ PM10 concentrations are between the first and second quartiles and 0 otherwise. Finally, $\beta_{2k}'s/\beta_{3k}'s$ and γ_2/γ_3 are again the variables of our key interests and measure the effects of the elevated PM2.5 and PM10 concentrations on consumers' expenditures.

4. Results

Table 1 reports estimation results of the first model specification. Consistent with our expectation, the estimates of a_2 and a_3 is statistically significant and negative. The results imply that customers lowered their expenditures by 0.074% and 0.044% with a 1% increase in the PM2.5 and PM10 concentrations, respectively. Such changes in consumers' expenditures strongly suggest that the effect of ambient air pollution is economically as well as statistically significant. In addition, we find that individual consumers' value of the dependent variable during the six-week initialization period has a statistically significant effect and has the best predicting power in terms of t-value.

The results for the second and third model specifications are reported in Table 2. The estimates of β_{21}/β_{31} and γ_2/γ_3 turned out statistically significant and negative in both replications, indicating that the primary findings in the first model survived the robustness checks. More specifically, in the second model specification, customers, on average, reduce their expenditures by 0.63 % or 0.69 % more when the PM2.5 and PM10 concentrations measures are categorized the highest than when they are the lowest, respectively while the disruption in the expenditures turns out limited othwerwise; and a unit increases in the levels of the PM2.5 and PM10 concentrations, on average, decreased customers' expenditures by 3,654 won and 1,695 won per week, respectively. In addition, estimates of all other variables are also consistent with the previous estimation results and intuitive.

To sum, after explicitly controlling for the time trends and heterogeneity across individual customers, the PM2.5 and PM10 concentrations influenced customers considerably and resulted in significant disruption on their consumption. The results are consistent with past

Table 1. Estimation Results for Model 1.

Regression Coefficients			
PM2.5	-0.074** (0.011)	Gender	0.007 (0.008)
PM10	-0.044** (0.015)	30's	0.633**(0.032)
Previous Average Expenditures	0.154** (0.021)	40's	0.687** (0.033)
Holidays	0.2078** (0.018)	50's	0.511** (0.031)
2nd Quarter	0.187** (0.012)	60's	0.578** (0.033)
3rd Quarter	0.132** (0.013)	Intercept	6.951** (0.001)
4th Quarter	0.313** (0.012)		
Observations	21,574	Pseudo R2	0.12

Note: Standard Errors are shown in parentheses. * p < 0.05, ** p < 0.01

Table 2. Estimation Results for Models 2 and 3.

Regression Coefficients		Model 2	Model 3
Previous Average Expenditures		0.163**	0.591**
		(0.019)	(0.032)
PM2.5			3,654**
			(258)
PM10			1,695**
			(154)
PM2.5	2nd Lowest Category	-0.008	
		(0.007)	
	2nd Highest Category	-0.012	
		(0.007)	
	Highest Category	-0.063**	
		(0.009)	
PM10	2nd Lowest Category	-0.010	
		(0.009)	
	2nd Highest Category	-0.015	
		(0.011)	
	Highest Category	-0.069**	
		(0.012)	
Holidays		0.6984**	6,513**
		(0.1186)	(2,081)
2nd Quarter		0.6324**	2,634**
		(0.0144)	(361)
3rd Quarter		0.5571**	2,011**
		(0.0142)	(393)
4th Quarter		0.8193**	3,184**
		(0.0141)	(410)
Gender		0.0098	1,683
		(0.0071)	(1,391)
30's		0.6743**	1,839**
		(0.0094)	(694)
40's		0.7010**	2,042**
		(0.0113)	(682)
50's		0.5419**	2,329**
		(0.0109)	(647)
60's		0.5814**	2,371**
		(0.0121)	(688)
Intercept		-0.038**	843,658**
		(0.009)	(15,864)
	Observations	21,574	21,574
	Pseudo R2	0.14	0.13

Note: Standard Errors are shown in parentheses. * $p < 0.05$, ** $p < 0.01$.

studies on macroeconomic factors such as business cycle or gasoline prices (Jung 2017 and Jung, Yu, and Kwon 2016). Yet the findings are particularly important, because the effect of air pollution primarily comes from the psychological factors and is therefore different from other macroeconomic effect in how it influences consumer expenditures.

5. Conclusion

In this paper, we have addressed why the lack of research on the indirect economic effect of air pollution arises and explored the desirable features of data that allow such examination. Recognizing that the studies on the adverse health effects of ambient air pollution primarily employ cross-sectional data and micro data that enable the measurement of indirect and behavioral effects of air pollution are not widely available (Jung 2017), we learn that data on a region with significant fluctuations in the level of particulate matters in a short period of time for which its economic condition remains fairly stable is essential.

Based on this notion, we identified that significant fluctuations in particulate matters are present in Korea and test whether an elevated level of particulate matter changed individual consumption behaviors. A series of empirical analyses find that the economic effect of air pollution is statistically significant and confirms that psychological factors shrink individual consumption behaviors.

The essential features of the data for the systematic analysis on the economic effect of air pollution and empirical evidence based on such data paper provides ample guidance for the future research that can provide important implications for policymakers and managers.

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