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The Impact of Ambient Fine Particulate Matter on Consumer Expenditures

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Abstract: Airborne particulate matter suspended from industrial facilities, power plants, and automobiles is detrimental to health. Growing concerns about the increasing level of airborne particulate matter have led many industrialized nations to advocate for the transformation of the energy market and investment in sustainable energy products. At the other end, consumers have made individual adjustments and attempted to reduce the exposure to the particulate matter. In this paper, we focus on the effect of ambient air pollution on consumer expenditures based on scanner panel data on consumers' debit and credit card transactions. A series of empirical analyses found robust evidence that the increased level of particulate matter led to considerable disruption in total consumer expenditures with significant heterogeneity across categories. Our findings suggest that consumers alter their spending behaviors in an attempt to reduce the risk of exposures to particulate matter. Such an estimated effect of air pollution is qualitatively different from those of other macroeconomic factors and provides important guidance for policy interventions and practical decisions aimed at sustaining economic growth.

Keywords: ambient particulate matter; sustainable growth; consumption expenditures; consumer behaviors

1. Introduction

Airborne particulate matter suspended from industrial facilities, power plants, and automobiles is detrimental to health [1–4]. More specifically, ambient air pollution is closely associated with increased morbidity and mortality for multiple health indicators, including respiratory, cardiovascular, and chronic allergic diseases [5–7]. Particulate matter, according to WHO, was responsible for 3.7 million deaths worldwide in 2012 [8] and causes more deaths worldwide than AIDS, malaria, breast cancer, or tuberculosis [9,10].

As a result, the costs of treating patients of respiratory and cardiovascular diseases have increased substantially in many developing countries [11–13]. Growing concerns about the increasing level of particulate matter have led industrialized nations to advocate for the transformation of the energy market and investment in sustainable energy products [14,15]. At the other end, in response to the increased level of particulate matter, consumers have made individual adjustments and attempt to reduce the exposure to the particulate matter. Systematic research, as well as anecdotal evidence, suggest that consumers often avoid travels and outdoor activities mainly due to the detrimental adverse effect on health [16].

An interesting aspect of the effects that ambient air pollution imposes on consumer behaviors is that the disruption on consumption arises from psychological factors. Such outcomes are qualitatively different from the effect of other macroeconomic factors that directly restricts the economic ability of an individual. Consequently, the adverse effect of ambient air pollution may not be associated with the

disruption in willingness to buy in all categories. Instead, positive as well as negative spillover effects may simultaneously occur in consumption across categories.

Given this notion, we aim to examine how the increased level of air pollution influences consumer behaviors in this paper. Empirical knowledge on such an indirect but significant effect of ambient air pollution on consumer behaviors is particularly valuable in that its implication would provide important guidance to policy makers, as well as firms' decision makers. Note that the extrapolation from the effects of other macroeconomic effects would yield a misspecification of the impact of air pollution [17,18].

Surprisingly, however, little has been known about the effect of ambient air pollution on individual shopping behaviors and consumption, primarily because restrictions imposed on the data disable the measurement of indirect and behavioral effects of air pollution. In this paper, we explore the economic effect of air pollution based on a unique set of data. We include substantial knowledge on how the increased level of particulate matter impacts the individual consumption and shopping behaviors.

The paper proceeds as follows: Section 2 discusses the related literature, Section 3 explains the data, Section 4 describes preliminary analyses, and Section 5 presents the estimation methods and results. Finally, Section 6 concludes with a summary of our findings.

2. Background

2.1. Literature Review

The adverse health effects of ambient air pollution and particulate matter are well documented in clinical, mechanistic, and epidemiological studies. Exposures to PM with lower aerodynamic diameters, including fine and ultrafine PM, are related to general morbidity and mortality due to respiratory and cardiovascular diseases [11–13]. Particulate matter with an aerodynamic diameter of less than 2.5 and 10 micrometers are associated with serious adverse effects [19–21]. Adverse effects of both short- and long-term exposures to an elevated concentration of pollutants can be exacerbated in vulnerable populations, including those with preexisting cardio-respiratory diseases and the elderly [8,22,23]. The population exposed to ambient air pollution exhibit decreased lung function and increased incidence of chronic cough [9,10,24,25].

Despite the extensive studies examining the health effect of air pollution and particulate matter, there is limited systematic research available that investigates how the economic burden and increased level of particulate matter influences individual consumers. Instead, studies on macroeconomic factors are limited to those derived primarily from the disruption of financial ability to buy, such as business cycles and gasoline prices [26–29]. As a result, these studies fail to fully explain the economic effect from the increased level of particulate matter. This is primarily because the effect of air pollution on consumption is mostly through psychological factors and, therefore, qualitatively different from those of such other macroeconomic factors.

Under these circumstances, we note that the effect of extreme events, such as an epidemic outbreak, is somewhat similar to the effect of the ambient air pollution on individual shopping behaviors because both arise from psychological factors. Studies on the effect of extreme events document a significant drop in consumer expenditures with considerable heterogeneity in the effect of extreme events across product categories [30]. In particular, consumers reduced the expenditures at traditional distribution channels, which they are likely to consider risky to use during an outbreak. Instead, consumers switched to e-commerce to prevent possible exposure to the disease. Based on this finding, we predict that the effect of air pollution is not prevalent in all components of expenditures, and a statistically and economically significant reduction in the expenditures is witnessed only in limited categories.

To the best of our knowledge, this research is the first to explore the economic effect of the increased level of particulate matter on consumer shopping behaviors. The empirical evidence that ambient air pollution influences consumers to a considerable extent and that such a factor is qualitatively different from other macroeconomic factors offer ample guidance for future research. In addition, the

substantive knowledge in our paper provides important implications for policy interventions and practical decisions aimed at sustaining economic growth.

2.2. Air Pollution

A significant portion of particulate matter is derived from economic activities such as agricultural operations, industrial processes, combustion of fossil fuels, and construction [31,32]. Therefore, to reduce the risk of systematic and endogenous differences in subjects, it is essential to identify a region with significant fluctuations in particulate matter levels within a short period during which its economic condition remains fairly stable.

To understand how an increased level of particulate matter impacts individual shopping behaviors, we focused on the volatile nature of air pollution in Korea. From the Korean National Air Reporting System, we received hourly data on the levels of particulate matter > 2.5 microns (PM2.5), particulate matter <10 microns (PM10), sulfur dioxide (so₂), nitrogen dioxide (no₂), ozone (o₃), and carbon monoxide (co). The levels of so₂, no₂, o₃, and co mostly remained under the WHO guideline values. Particulate matter with an aerodynamic diameter between 0.001 and 500 microns mainly influenced the particles' penetration into, deposition in, and elimination from the respiratory organs [11]. In turn, we focused on the levels of PM2.5 and PM10 in further empirical analyses.

Figure 1 presents a time series of PM2.5 and PM10 in Seoul. With a significant fluctuation, air pollution is extensive in Korea. The highest monthly averages of PM2.5 and PM10 concentrations, respectively exceeded four times and five times their own lowest monthly average levels, while their monthly averages surpassed the WHO guideline values throughout the year. To explain such large fluctuations, Asian Dust and rainfall are shown as the primary cause for such large variances across seasons and the differences caused by artificial impacts to air pollution are also statistically significant [23].

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

Recognizing the considerable fluctuations in PM2.5 and PM10 concentrations across seasons, we also examine daily fluctuations in PM2.5 and PM10 concentrations. Given the prevalent pattern, we found that the daily average also fluctuated significantly. The differences among the daily averages within a month were as large as 70 and 151 µg m⁻³. The differences in levels of PM2.5 and PM10 exceeding 10 and 15 µg m⁻³ between two consecutive days were recorded for more than 10% of the data period. Finally, the largest differences in daily averages of PM2.5 and PM10 concentrations between two consecutive observations imply up to 60% of changes within a day.

3. Data

Our data comes from a mobile phone application design and development firm, which developed a household account book application. The application automatically records users' expenditures using text messages they receive from credit card companies and banks. The application is offered exclusively in Korean. The data contains the records of credit and debit card transactions of individual purchases. The available information for each transaction includes customer identifiers, date, time, the amount paid, and the name of the retail store. Afterward, a retailer's type was identified based on their names. The demographic information includes users' gender and age.

Given its construct, the data includes all credit and debit card transactions with text message alerts but fails to record how much of users' expenditures were made through other channels. Furthermore, the data does not have lists of the products purchased in a transaction nor does it show the price or promotional information in stores. However, the data includes a variety of expenses, ranging from expenditures at restaurants, grocery stores, and online stores to payments for public transit. As a result, we can observe extremely detailed information on consumers' shopping behaviors and expenditures on goods and services. Such data has not been widely accessible by academics.

Table 1 summarizes the transaction records of 1284 application users, which the application design and development firm randomly selected from the entire user pool, and our data maintains the complete records of the retail transactions. While 1755 customers appeared on our data, the complete transaction data in 2017 is only available for 1284 customers, and we restrict our attention to these individuals in further empirical analyses. An average individual in this group engaged 29.90 transactions and spent 595,005 won for a week. More specifically, expenditures on food outside the home account for the largest share of the total expenditures, followed by expenditures at grocery stores and e-commerce.

Table 1. Number of transactions and amount of expenditures.

	Number of Transactions (per Week)	Amount of Expenditures (per Week)
Recreation and Leisure	1.68	62,445
Department Stores	1.36	45,881
Food Outside the Home	4.45	173,541
Grocery Stores	4.31	95,149
Health/ Medical Expenses	2.11	20,541
E-Commerce	3.87	87,448
Gasoline/ Transportation	7.56	64,552
Others	4.56	45,448
Sum	29.90	595,005

Note that most individuals are below 50 (98.52%), and individuals in 20s (35.12%) and 30s (39.56%) are the largest components of the sample. This particular construct is largely due to the method of data collection based on a mobile phone application. It may result in systematic biases in the inferences for the entire population. However, given the absence of the microdata that would enable systematic research on the economic burden imposed by ambient air pollution, our data still provides a unique opportunity to conduct such research by observing consumer purchase and consumption behaviors in considerable detail. We believe that the inferences we make by analyzing the current data would be useful for practitioners and policymakers and provide critical guidance for sustainable growth in different industries.

4. Preliminary Analysis

Figure 2 describes the level of particulate matter and consumer expenditures in 2017. A noteworthy feature in Figure 2 is that there is high seasonal variability. For example, in December, the weekly transaction volume was approximately 19.36% higher than its average in the entire period. Such a clear pattern found in the transaction volume is consistent with findings in previous studies [30] and implies that the significant holiday effect is prevalent in consumers' expenditures. Thus, we take the effect into account in our empirical investigation.

Figure 2. Weekly average total expenditures in 2017.

Another noteworthy feature in Figure 2 is that the expenditures appear somewhat lower than the average during the period with increased levels of particulate matter. More specifically, the transaction volumes turned out the lowest between March and June, which coincide with the period with ambient air pollution. Considering that a similar pattern was observed in the past studies [30], however, it may not be appropriate to conclude that the changes in transaction volumes are evidence for the economic burden imposed by the ambient air pollution. Therefore, in further empirical analyses, we exploit significant daily changes in the level of particulate matter to draw meaningful inferences about how consumers adjust their shopping behaviors in response to ambient air pollution, while explicitly controlling for the seasonal variations in consumers' expenditures.

Finally, to understand consumer behaviors more comprehensively, we focus on categories that accompany high and low risk of exposures to ambient air pollution and explore how consumers changed their expenditures in these domains. Importantly, in Figure 3, consumer expenditures exhibit considerably distinctive patterns during the period of ambient air pollution across all categories. In particular, expenditures on food outside the home exhibited marginal decreases; expenditures on e-commerce were approximately 2.45% higher than its annual average, and, lastly, recreation and leisure expenses decreased by up to 5%. Together with the fact that no statistically significant changes have been witnessed in the average sizes of transactions in three categories, changes in consumers' total and categorical expenditures empirically suggest that individuals avoided travels and outdoor activities during the period of increased level of particulate matter due to the fear of its adverse effects.

Figure 3. Weekly average expenditures by categories in 2017.

5. Models and Results

5.1. Total Expenditures

Upon finding descriptive evidence for the effect of particulate matter on consumers' shopping behaviors at a number of dimensions, we first examine the effect of fear of exposure to the fine particulate matter against the total expenditures of individuals, based on credit and debit cards transaction information on individual purchases. In determining estimation methods, we understand that the Almost Ideal Demand System (AIDS) model has enjoyed great popularity in empirical demand analysis. However, our data maintain the records of credit and debit card transactions with text message alerts and, given its construct, includes only a portion of an individual's expenditures. Thus, we use an ordinary least squares regression and estimate the effect of ambient pollution on consumers' shopping behaviors using the following specification:

$$\log \text{Exp}_{it} = \alpha^0 + \alpha^1 \log \text{Exp}_{i0} + \alpha^2 \text{PM2.5}_t + \alpha^3 \text{PM10}_t + \text{AX}_{it} + \varepsilon_{it}^1. \quad (1)$$

Exp_{it} is consumer i 's total expenditures during day t ; Exp_{i0} is the average daily expenditure of consumer i during the first three weeks of our data, and PM2.5_t and PM10_t are the concentration levels reported in day t . Finally, X_t is a set of controls, including dummies for time trends and demographic information of consumers. The dependent variable is specified in log-linear form to control for considerable variation in the magnitude of the expenditures across consumers and over time.

The average daily expenditure of consumer i during the first three weeks of our data addresses the effect of heterogeneity in preferences across consumers using individual consumers' value of the dependent variable during a three-week initialization period along with their demographic information [29,33,34].

On the other hand, α^2 and α^3 measure the effect of PM2.5 and PM10 on consumer expenditures, which are of central interest to our research. Based on the pattern witnessed in the preliminary analysis, we expect a negative effect of PM2.5_t and PM10_t . Finally, based on the significant seasonal variations documented in the preliminary analyses, we predict that the controls for time trends turn out statistically and economically significant.

Table 2 reports the estimation results. Supporting our expectation, the estimates of α^2 and α^3 are statistically significant and negative, and imply that customers lowered their expenditures by 0.045% and 0.032%, with a 1% increase in the levels of PM2.5 and PM10 , respectively. Considering that the highest levels of PM2.5 and PM10 exceed twice their own lowest levels, such results suggest that consumers reduced their expenditures by up to 8% in response to the increased levels of particulate

matter in 2017. Turning to variables controlling for the time trends and the holiday effect, the effects were all statistically significant and intuitive. In addition, we found that individual consumers' value of the dependent variable during the three-week initialization period has a statistically significant effect and has the best predicting power in terms of t-value.

Table 2. Estimation results for Model 1.

Variable		Variable	
Expenditures during Initialization Period	0.33819** (0.0026)	Sep	0.01227 (0.00883)
PM2.5 _t	−0.00044** (0.00003)	Oct	0.01446 (0.00942)
PM10 _t	−0.00032** (0.00003)	Nov	0.04714** (0.01018)
Holiday	0.10982** (0.01125)	Dec	0.03220** (0.01183)
Feb	−0.01382 (0.00744)	Weekend	0.06204** (0.01179)
Mar	−0.00914 (0.00698)	Gender	0.00394 (0.00435)
Apr	−0.03824** (0.01248)	30s	0.03361** (0.0081)
May	−0.00846 (0.01063)	40s	0.04728** (0.01027)
Jun	−0.03386** (0.00974)	50s	0.05105** (0.01471)
Jul	0.01401** (0.00604)	60s	0.04863** (0.01631)
Aug	0.01386** (0.00596)	Intercept	6.9286** (0.40927)
N	468,634	Adjusted R-Squared	0.2049

Standard errors in parentheses: *** p < 0.001, ** p < 0.01, * p < 0.05.

Given the significant effect of ambient air pollution, we recognize that there could be other specifications that may better describe the effect. Accordingly, to test the robustness of the above findings, we use linear and fixed effect models and develop additional models specifications in the following forms:

$$Exp_{it} = \beta^0 + \beta^1 Exp_{i0} + \beta^2 PM2.5_t + \beta^3 PM10_t + BX_{it} + \varepsilon_{it}^2, \quad (2)$$

$$\log Exp_{it} = \gamma_0 + \gamma_i^1 + \gamma^2 PM2.5_t + \gamma^3 PM10_t + \Gamma Z_{it} + \epsilon_{it}^3. \quad (3)$$

Again, β^2/β^3 and γ^2/γ^3 are the variables of our key interests and measure the effect of the ambient air pollution on consumers' expenditures.

The results are reported in Table 3. The estimates of β^2/β^3 and γ^2/γ^3 turned out statistically significant and negative in the replication, indicating that the primary findings in the first model survived the robustness check. More specifically, consumers, on average, reduced their expenditures by 11.42 and 8.83 won in the second model specification and by 0.052% and 0.039% in the third model specification for a unit increase in the levels of PM2.5 and PM10, respectively. Furthermore, estimates of all other variables, including the controls for time trends, were also consistent with the previous estimation results and intuitive. The robust and significant effects of PM2.5 and PM10, after the explicit control for time trends and heterogeneity across individual customers, strongly confirm that consumers reduced their expenditures during the period of ambient air pollution.

Table 3. Estimation results for Models 2 and 3.

Variable	Model 2	Model 3
Expenditures during Initialization Period	0.3237** (0.0023)	-
PM2.5 _t	−11.42** (1.66)	−0.00052** (0.00003)
PM10 _t	−8.83** (2.83)	−0.00039** (0.00003)
Holiday	550.38** (70.63)	0.09032** (0.01833)
Feb	−6.16 (3.44)	0.01022 (0.00820)
Mar	−5.01 (3.65)	−0.01068 (0.00523)
Apr	−15.97** (3.08)	−0.03875** (0.00806)
May	−8.96** (2.94)	−0.00738 (0.00962)
Jun	−11.62** (3.03)	−0.04860** (0.01394)
Jul	5.84** (2.68)	0.01846** (0.00548)
Aug	4.11 (2.74)	0.01649** (0.00604)
Sep	4.16 (2.68)	0.01053 (0.00892)
Oct	8.94** (2.80)	0.01482** (0.00684)
Nov	12.82** (3.16)	0.04820** (0.01607)
Dec	16.17** (3.42)	0.04061** (0.01138)
Weekend	364.87** (16.27)	0.05762** (0.00847)
30s	183.69** (13.51)	-
40s	197.48** (16.72)	-
50s	211.88** (20.40)	-
60s	199.82** (18.63)	-
Gender	8.84 (5.68)	-
Intercept	23.34** (1.62)	10.5074** (1.12170)
N	468,634	468,634
Adjusted R-Squared	0.2031	0.1997

Standard errors in parentheses: *** p < 0.001, ** p < 0.01, * p < 0.05.

In conclusion, the ambient air pollution impacted customers considerably and resulted in significant disruption on their consumption. Nevertheless, the findings are partly limited in explaining how such a disruption arises. We address this issue in the following subsection.

5.2. Expenditures by Categories

Upon identifying the significant effects of particulate matter, we attempt to provide a more comprehensive understanding of how a significant change in the expenditures occurred. Such an analysis is essential because consumer behaviors are at the root of changes at an aggregate level (Ma et al. 2011) and, therefore, understanding consumers is necessary to provide meaningful guidance on effective managerial decisions during a period with severe air pollution.

To do so, we focus on customer expenditures on three categories chosen from the preliminary analysis. Similar to the total expenditure models, we explicitly control for the heterogeneity in the effect of the ambient air pollution across the categories, while the effects of control variables for time trends and demographic information are assumed the same for different categories. The model employs the following specification:

$$\log \text{Exp}_{it}^c = \zeta^0 + \sum \zeta^{1c} \log \text{Exp}_{it}^c + \zeta^2 \text{PM2.5}_t + \zeta^3 \text{PM10}_t + \sum \zeta^{4c} I^c + \sum \zeta^{5c} \text{PM2.5}_t * I^c + \sum \zeta^{6c} \text{PM10}_t * I^c + \text{ZX}_{it} + \epsilon_{it}^1. \quad (4)$$

In addition to other explanatory variables, defined the same as the previous models, I^c is a dummy indicating whether expenditures are made for the category c . This specification allows us to identify mutually exclusive marginal effects of ambient air pollution on consumer expenditures across the categories. In particular, ζ^2 and ζ^3 estimate the effects of PM2.5 and PM10 on expenditures on food outside the home, and $\zeta^2 + \zeta^{5c}$ and $\zeta^3 + \zeta^{6c}$ estimate the effects of PM2.5 and PM10 in category C , respectively. Based on behavioral patterns documented in the preliminary analysis, we expect that there are significant differences across categories.

Table 4 gives the coefficients estimates of the category expenditure model and their standard errors. Turning to our focal variables, we found that consumers would reduce their expenditures on recreation and leisure by almost up to 0.063% and 0.050%, respectively, with a unit increase in the levels of PM2.5 and PM10. By contrast, consumers would increase their e-commerce expenditures by 0.032% and 0.036% won with a unit increase in the levels of PM2.5 and PM10, respectively. Finally, statistically significant differences were not witnessed in the expenditures on food outside the home according to the increased/decreased levels of PM2.5 and PM10.

Remember that the expenditures that exhibit reduction with ambient air pollution generally accompany the risk of exposure to the airborne particulate matter. Subsequently, an increase in e-commerce expenditures, together with the disruption of expenditures on recreation and leisure activities, confirms from the significant psychological impact on consumers' sentiment and consumption resulting from the ambient air pollution.

In summary, our empirical analyses provide substantial implications about how consumers alter their shopping behaviors in response to the increased levels of fine particulate matter concentrations. The considerable decrease in the total expenditures, as well as the presence of significant heterogeneity in consumer response across categories, suggest that the fear of exposure to ambient air pollution strongly influenced consumer shopping behaviors and resulted in a significant interference on spending of goods and services in particular categories.

In general, the studies on macroeconomic factors and their effects on consumer shopping behaviors and consumption focus on disruption of economic abilities to explain the decrease in spending and the change in store and brand choices. However, what we found in this paper indicates that the increased levels of fine particulate matter influence consumer behaviors through the fear of exposure and psychological willingness to spend. Thus, practitioners and managers need to comprehend

the qualitatively different effects of ambient air pollution from other macroeconomic factors such as business cycle and gasoline prices.

Table 4. Estimation results for Model 3.

Variable		Variable	
Expenditures during Initialization Period for Food outside the Home	0.38207** (0.02084)	Apr	−0.03908** (0.01152)
Expenditures during Initialization Period for Recreation and Leisure	0.33824** (0.02162)	May	−0.00709 (0.01142)
Expenditures during Initialization Period for E-Commerce	0.36714 (0.02827)	Jun	−0.03419** (0.00834)
Recreation and Leisure	10.24057** (3.81007)	Jul	0.01382** (0.00571)
E-Commerce	6.84924** (3.04117)	Aug	0.01524** (0.00481)
PM2.5 _t	−0.00021 (0.00013)	Sep	0.01308 (0.00921)
PM10 _t	−0.00014 (0.00011)	Oct	0.01508 (0.00828)
PM2.5 _t *Recreation and Leisure	−0.00042** (0.00010)	Nov	0.05024** (0.01104)
PM10 _t * Recreation and Leisure	−0.00036** (0.00012)	Dec	0.03849** (0.01207)
PM2.5 _t *E-Commerce	0.00053** (0.00011)	30's	0.03815** (0.00781)
PM10 _t *E-Commerce	0.00050** (0.00012)	40's	0.04551** (0.01104)
Holiday	0.10842** (0.00971)	50's	0.05104** (0.01308)
Weekend	0.06780** (0.01086)	60's	0.04482** (0.01584)
Feb	−0.01116 (0.00682)	Gender	0.00546 (0.00388)
Mar	−0.00842 (0.00815)	Intercept	6.82966** (0.10746)
N	115,145	Adjusted R-Squared	0.2004

Standard errors in parentheses: *** p < 0.001, ** p < 0.01, * p < 0.05.

6. Discussion

In an empirical investigation using unique panel data on individual expenditures, we found that an elevated concentration of air pollutants had a significant effect on consumer shopping behaviors, with the presence of considerable heterogeneity across categories. Confirming the significant effect of ambient air pollution on consumers' sentiment and attitude, the analyses yield empirical evidence showing that the fear of exposures to particulate matter primarily influenced consumers' behaviors. To the best of our knowledge, this paper is the first to explore the economic effect of the increased level of particulate matter on individual shopping behaviors.

Our findings have an important implication for policymakers and practitioners. First, the attempt to assess the economic effect that ambient air pollution indirectly imposes on individual consumption behaviors would help the formulation and approval of the national budget. Second, the significant heterogeneity witnessed across categories substantiates the fact that assuming homogeneous consumer adjustment would provide a misleading view of the market and yield misspecification of the impact of air pollution. Third, although the data are restricted to transactions of Korean customers, many

industrialized nations have similar concerns. The level of airborne particulate matter suspended from industrial facilities, power plants, and automobiles have been increasing substantially. Thus, implications of the present research provided can be extrapolated to other countries.

We caution that the implications addressed in this section are more descriptive and may not be well suited to conclusively validate and test them. The primary aim of this discussion is to present certain implications for the relevant fields and to stimulate further research to investigate the argument.

7. Conclusions

In this paper, we addressed the economic effect of ambient air pollution. The unique feature of the scanner panel data on individuals' debit and credit card transactions allowed us to confirm that the effects of ambient air pollution are significant in consumers' sentiment, attitude, and shopping behaviors. We also found strong empirical evidence that consumers' responses to the increased level of fine particulate matter also differ considerably across categories. More specifically, during the period of the increased level of fine particulate matter, the significant disruption on the expenditures has been limited to the categories that accompany the risk of exposures to fine particulate matter. Such findings ensure that the psychological factor due to ambient air pollution influenced consumers' behaviors to a significant extent.

Our findings provide an important suggestion to manufacturers and retailers that a considerable negative economic effect of ambient air pollution can be lessened by developing alternatives that can avoid the exposures to the fine particulate matter. Given the fact that systematic research on macroeconomic factors and their effects generally focus on the disruption of economic abilities, our empirical investigation on psychological factors provides ample guidance for policy intervention and marketing decisions in many relevant fields. Particularly, the substantive empirical knowledge in this paper would help the formulation and approval of the national budget. It also allows the firms' decision makers to enhance marketing efficiency by directing effort specifically toward the designated segment.

Our findings show the short-run effect of the increased level of particulate matter and provide limited implications on how ambient air pollution influences consumers' sentiment and shopping behaviors. Nonetheless, our paper documents robust empirical evidence that ambient air pollution has both economically and statistically significant effect on consumers. As a result, it is essential to understand these effects in the short run.

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