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HOW DOES FINE PARTICULATE MATTER IMPACT PUBLIC TRANSIT RIDERSHIP?

Summary. We explore how a rapid rise in air pollutants impacts the ridership of public transportation. Based on the individual purchase history, our comprehensive analyses document evidence that an elevated level of concentrations of fine particulate matter caused a substantial change in individual decisions on public transit ridership in relation to individual social and economic characteristics. The estimated effect primarily arose from the fear of exposure to pollutants and, consequently, is substantially different from other macroeconomic influences. Our empirical results contribute important inferences about commuters' choices of transit modes during the period of ambient air pollution and offer significant guidance for policymakers and practitioners.

1. INTRODUCTION

Fine particulate matter, which is largely derived from economic activities, including construction, industrial processes, the combustion of fossil fuels, and agricultural operations, is closely associated with detrimental health outcomes. Inevitably, their increased levels have been more problematic in different parts of the world, and costs of controlling respiratory and cardiovascular diseases have been rising to a considerable extent. In particular, air pollution was the cause of more than 3 million deaths in 2012, accounting for nearly 7% of all deaths that year. More specifically, it was the cause of 29% of heart disease and stroke deaths and 16% of lung cancer deaths and was responsible for about 13% of deaths from respiratory diseases [1-3]. As a result, ambient air pollution has been a large concern in many developing and developed countries [4-7] and has imposed a substantial burden on economies [8-10]. An important feature of the influences of air pollution on economies is that the disruption in consumers' behaviors resulting from the adverse impact of ambient air pollution on health partially arises from the fear of exposure to particulate matter [11]. For example, consumers reduce unnecessary trips, avoid public places, and attempt to lower their exposure to air pollutants. These indirect effects differ considerably from other macroeconomic influences because the disruption of psychological willingness to pay shrinks economies, unlike inflation or economic growth rate, which leads to the restriction on the economic ability. Therefore, changes in consumer behaviors are not necessarily witnessed in all consumption categories; instead, reductions in expenditures can be limited to particular distributional channels or to individuals with specific socioeconomic characteristics.

Although the adverse effects of fine particulate matter have been extensively investigated, little systematic research has attempted to address how ridership on public transportation has changed during the period of ambient air pollution. Research on the effect of air pollution instead concentrates on its clinical effects and examines how respiratory or cardiovascular diseases are related to the exposure to particulate matter while addressing elements that reduce or intensify the effects of air pollution.

In this paper, we first examine the impact of increased particulate matter on public transportation ridership using microdata and address heterogeneity in consumers' responses across different socioeconomic groups. A series of empirical analyses based on individual transactions allow us to find

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empirical evidence that an elevated level of particulate matter statistically and economically impacts people's choices of transit modes while significant heterogeneity is documented across individuals. Our investigation is important because such differences in individual responses to air pollution would aid predictions and validate the effects of policy interventions. We also believe that the empirical knowledge our paper adds provides effective guidance for practitioners.

The remainder of the paper is organized as follows. Section 2 provides a description of the increased levels of particulate matter, which we will investigate in this research. This section also includes a discussion of the relevant literature. Section 3 describes the data, and Section 4 shows the statistical models and their results. Section 5 discusses the implications of this study, and Section 6 provides the conclusion.

2. BACKGROUND

The causal relation between the long- and short-term exposure to fine particulate matter and respiratory or cardiovascular disease is well established in a number of clinical, mechanistic, and epidemiological studies. Epidemiological studies on pathophysiological data find that air pollution leads to mortality as a result of respiratory and cardiovascular diseases [12-14]. Particulate matters can cause severe health effects [15, 16]. Particulate matters with low diameters, such as fine and ultrafine Particulate matters, are closely linked to adverse effects [17-19]. Furthermore, the detrimental health effects of exposure to fine particulate matter can be intensified, especially in weak populations, including those with extant respiratory diseases and the elderly [20-21]. In turn, these populations are likely to suffer from complicated health problems after air pollution exposure [3, 22, 23].

However, a significant portion of these studies concentrated on the effect of exposure to air pollution and lack information about the effect of air pollutants on consumer behaviors. Among the few exceptions are the findings that a considerable reduction in expenditures was identified during a period of increased particulate matter, that consumers' responses to air pollution differ extensively for different product categories, and that consumers changed their decisions of how and where to shop [24]. Such consumer responses suggest that the fear of exposure to the particulate matter lowered spending at traditional retailers associated with a chance of exposure. This is substantially related to studies on transportation ridership, considering that consumers who try to minimize their exposure to air pollution may have reduced unnecessary trips or switched to private transport.

It is important to understand that the effects of elevated levels of particulate matter on the economy are mainly psychological and, consequently, extensively differ from other factors such as inflation and growth rates. The effects of these factors have been well established in an extensive line of studies. For instance, Currie and Phung [25] and Bhat, Sen, and Eluru [26] found that fluctuations in business cycles affect consumers' decisions about public transit ridership. Golub [27] and Machemehl [28] documented that gasoline prices have a considerable impact on commuters' decisions of transit mode in general, but the effects were not prevalent in all commuters. The conventional understanding of the effect of a macroeconomic factor in these studies is that consumers lowered the consumption and purchases of goods and services mainly due to increased financial constraints [29]. Note that such a critical mechanism may not be necessary to understand the effect of ambient air pollution.

Our paper contributes to these streams of research in the following regards. First, we focus on the disruption of psychological willingness to spend to address how an elevated concentration of pollutants influences consumers. Second, we explore the individual decision of transit modes based on the distinctive feature of the data and provide a comprehensive understanding of how consumers' behaviors change across different categories. Third, our paper contributes significant and evident implications for policy interventions and practical judgments, and it offers an opportunity to design counterfactual policy interventions.

3. DATA

The national air reporting system in South Korea collects data on six pollutants: sulfur oxide (SO2), nitrogen oxide (NO2), ozone (O3), carbon monoxide (CO), and particulate matter (PM2.5 and PM10) in nearly 100 cities and makes hourly reports. We removed stations with too many missing observations; as a result, observations from 199 national network sites in 2017 were used for the current research.

Note that our study relied on the high density of hourly data that allows regional patterns to be constructed directly from ground observations, unlike previous studies that employed satellite data to collect regional-scale air pollution data. Finally, large particulate matter hardly penetrates and is efficiently eliminated from the respiratory organs [30]; therefore, only PM2.5 and PM10 are of interest to our research. For approximately 20% of our data period, the levels of PM2.5 or PM10 exceeded the level at which increased long-term mortality was reported compared to the air quality guideline level[2]. The PM2.5 and PM10 reached up to 81.11 μgm^{-3} and 180.84 μgm^{-3}, respectively.

Fig. 1 describes the PM2.5 and PM10 levels during the data-collection period, showing the volatile nature of air pollution. The monthly average level of PM2.5 ranged between 13 μg m^{-3} and 35 μg m^{-3}, and that of PM10 ranged between 25 μg m^{-3} and 57 μg m^{-3}. The levels of PM2.5 and PM10 were negatively related to temperature, consistent with the patterns observed in the work of Lodovici [31], in which large differences in air pollution across seasons were largely due to Asian Dust and rainfall.

Given such variations in PM2.5 and PM10 concentrations during the data-collection period, we then looked at daily averages of PM2.5 and PM10 concentrations. Fluctuations were also witnessed in the daily averages; for 90% of our observations, differences in PM2.5 and PM10 between two consecutive days remained less than 15 μgm^{-3}. We understand that air pollution is mostly emitted from construction, industrial production, uses of fossil fuels, and other human activities. However, it is hard to believe that fluctuations in PM2.5 and PM10 concentrations in such a short period are caused by economic conditions. Thus, we focused on substantial fluctuations in daily averages of particulate matters concentrations in the following empirical analyses. We aimed to study how commuters' daily consumption behaviors are affected by air pollution and provide a comprehensive understanding of how changes in consumers' decisions of public transit ridership arose from the fear of exposure to pollutants.

3.1. Microdata on Consumption Behaviors

Our data contains credit and debit card transaction information. Accordingly, the data contain expenses at various retail stores, allowing us to observe how consumers make shopping decisions on different occasions and to empirically examine how their decisions on transit modes are made in relation to the level of particulate matter.

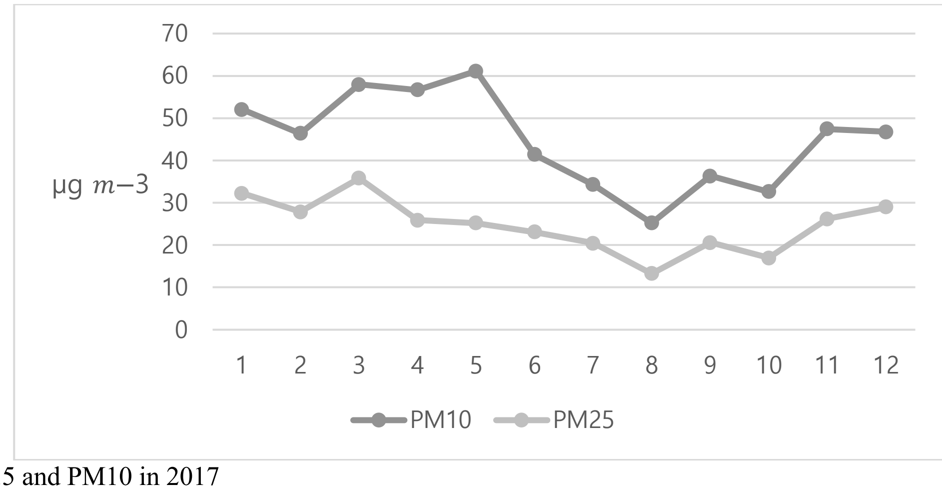

Fig. 1. PM2.5 and PM10 in 2017

[2] WHO global air quality guidelines: particulate matter, ozone, nitrogen dioxide, sulfur dioxide and carbon monoxide (https:// https://apps.who.int/iris/handle/10665/345329)

Table 1
Summary of Weekly Transactions

	Number of Transactions (per week)	Expenditures (per week) in wons (KPW)
Recreation and Leisure	1.63	33,621 wons
Department Stores	1.12	21,507 wons
Food Outside the Home	4.28	110,475 wons
Grocery Stores	4.68	63,529 wons
Health/Medical Expenses	0.83	5,421 wons
E-Commerce	4.24	69,283 wons
Gasoline/Transportation	7.38	35,427 wons
Others	5.46	12,527 wons
Sum	29.62	351,790 wons

The data was obtained from a company that developed a mobile application. The application helps users bookkeep expenditures based on text messages from credit card companies. Although the data included 7,311 customers, those with incomplete transaction information were removed; thus, we focused on 2,041 customers. The transaction records of these customers are summarized in Table 1. Customers in this sample, on average, made 29.62 transactions and spent 351,790 won per week. The average customer spent the most money at restaurants and on e-commerce.

3.2. Weekly and Daily Volumes of Public Transportation Uses

Fig. 2 describes the average weekly transactions for public transit in 2017. Throughout the data period, certain trends were clearly identified in public transit ridership. In particular, the weekly volume remained fairly stable during spring and fall and reached its highest and lowest levels in the summer and winter, respectively. Note that this is highly similar to the pattern documented in the previous studies on public transit use in Korea [11].

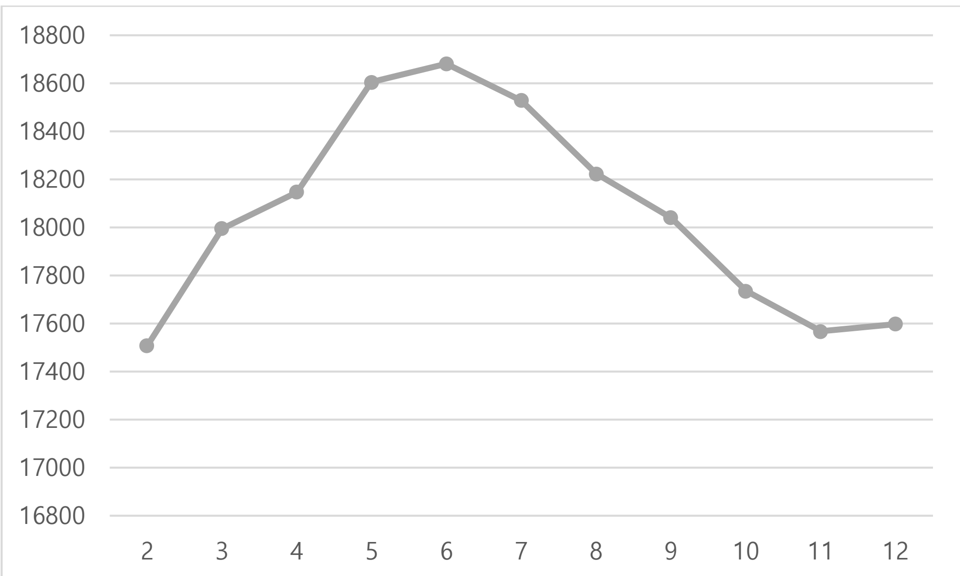

Fig. 2. Weekly public transportation expenditures (d)

Table 2
Daily Transactions for Public Transportation

	Number of Daily Transactions for Public Transportation
Weekday	0.413 (17.44%)
Saturday	0.164 (6.92%)
Sunday	0.139 (5.86)

Upon identifying considerable time trends in public transit ridership, we turned to the daily volume of public transit uses and found that there are also significant fluctuations across days. For example, as shown in Table 2, the average daily transit use rate is much higher on weekdays than on Saturdays and Sundays. This suggests that seasonal variability is strong in the daily volume of public transit use and must be considered when examining the impact of ambient air pollution on individual public transit decisions. Thus, we explicitly addressed this seasonality in our empirical analysis.

In the following analyses, we investigated how an increased level of fine particulate matter influenced consumers' decisions of public transit ridership with explicit control for the above seasonal variabilities using formal statistical models.

4. MODELS AND RESULTS

4.1. Expenditures on Public Transportation and Gasoline

An array of empirical research on demand analysis has employed the almost ideal demand system for their estimation methods. However, the construct of our data allowed us to observe only a few restricted aspects of consumers' expenditures. Thus, we employed an Ordinary least squares regression in the following specification and examined how the elevated level of particulate matter influenced consumers' transit ridership in Korea based on the following specification:

$$log\ Exp_{it}^{c} = \alpha^{0} + \alpha^{1}\ log\ Exp_{i0}^{c} + \alpha^{2}\text{PM2.5}_{t} + \alpha^{3}\text{PM10}_{t} + \alpha^{4}\text{PM2.5}_{t}I(category_{it} = gas) + \alpha^{5}\text{PM10}_{t}I(category_{it} = gas) + ZX_{it} + \epsilon_{it}^{1} \quad (1)$$

This model formally tests the effect of ambient air pollution on individual decisions about transit modes with the following key variables:

Exp_{it}^{c}: consumer *i*'s expenditures in the category *c* on day *t;*
Exp_{i0}^{c}: consumer *i*'s average daily expenditures for the category *c* during the initialization period;
PM2.5_{t}/ PM10_{t}: levels of PM2.5 and PM10 on day *t;*
$I(c_{it} = gas)$: indicator of whether consumer *i*'s expenditures on day *t* are on gasoline;
X_{it}: control variables such as time trends and individual demographic characteristics;
Exp_{i0}^{c}: estimates the effect of heterogeneity in preferences across consumers [34, 35].
$\sum \text{PM2.5}_{t}I(c_{it} = gas)$ and $\sum \text{PM10}_{t}I(c_{it} = gas)$: account for the effect of air pollution and are of our focal interest.
X_{it}: addresses time trends and heterogeneity in preferences across consumers using time dummies, the holiday effect, and individual demographic information.

Finally, in the current analysis, we use log-linear specification because large differences have been observed across individual expenditures and over time. Accordingly, coefficient estimates are presented as percentages instead of absolute terms. Log-log linear or log-linear specification is widely used in studies investigating how macroeconomic factors impact consumer expenditures [32,33].

To help interpret the key estimation results, coefficients estimate of PM2.5_{t}, PM10_{t}, $\sum \text{PM2.5}_{t}I(c_{it} = gas)$, and $\sum \text{PM10}_{t}I(c_{it} = gas)$ were utilized to measure the effect of fine particulate matter concentrations on consumer expenditures. In particular, α^2 and α^3 were used to estimate the percentage change in expenditures for public transportation by level increases in $\mathrm{PM2.5}_t$ and $\mathrm{PM10}_t$, and $\alpha^2+\alpha^4$ and $\alpha^3+\alpha^5$ were used to estimate the percentage change in gasoline expenditures by level increases in $\mathrm{PM2.5}_t$ and $\mathrm{PM10}_t$, respectively.

Based on growing concerns about the increased level of particulate matter described in the previous section, we expect that $\alpha^{2,pt}/\alpha^{3,pt}$ and $\alpha^{2,gas}/\alpha^{3,gas}$ were negative and positive, respectively.

The estimation results are presented in Table 3, and the data are generally in line with our expectations. First, the effects of α^2 and α^3 were statistically significant and negative, implying that the expenditures on public transits dropped by 0.40% and 0.37% when levels of $\mathrm{PM2.5}_t$ and $\mathrm{PM10}_t$ increased by one unit, respectively. On the other hand, the estimates of α^2+α^4 and α^3+α^5 suggest that the expenditures on gasoline did not exhibit statistically significant changes with a change in the levels of $\mathrm{PM2.5}_t$ and $\mathrm{PM10}_t$.

Regarding the control variables, we found that the coefficients' estimates of time dummies and individual demographic information were all statistically significant and expected based on the pattern observed in the previous section. Finally, the coefficient estimates of Exp_{i0}^c was also statistically significant, implying the presence of strong heterogeneity across individuals.

Table 3

Estimation Results for Model 1

Variable		Variable	
Expenditures during the Initialization Period	0.3612** (0.0018)	Sep	0.0168** (0.0021)
$\mathrm{PM2.5}_t$	−0.0040** (0.0005)	Oct	0.0144** (0.0026)
$\mathrm{PM10}_t$	−0.0037** (0.0005)	Nov	0.0110** (0.0028)
$\mathrm{PM2.5}_t I(category_{it} = gas)$	0.0038** (0.0006)	Dec	0.0015 (0.0024)
$\mathrm{PM10}_t I(category_{it} = gas)$	0.0036** (0.00005)	Weekend	-0.0351** (0.0104)
Feb	0.0128 (0.0071)	Gender	0.0021 (0.0033)
Mar	0.0092 (0.0062)	30s	0.0224** (0.0061)
Apr	0.0152** (0.0024)	40s	0.0403** (0.0087)
May	0.0168** (0.0043)	50s	0.05151** (0.0041)
Jun	0.0192** (0.0021)	60s	0.0422** (0.0031)
Jul	0.0201** (0.0022)	Intercept	4.5214** (0.5144)
Aug	0.0184** (0.0024)		
N	1,489,930	Adjusted	R-Squared 0.2104

4.2. Heterogeneity in Consumers' Responses

Based on the findings that the ambient air pollution exhibited a significant effect on the public transit ridership, we focused on separate expenditures across product categories and attempted to more comprehensively identify how the total consumption expenditures changed. We believed that our attempt to understand consumers would provide substantive implications for efficient managerial decisions during the period of ambient air pollution, given the fact that understanding individual consumer behaviors is critical to successful managerial practices [33].

Accordingly, in the next analysis, we aimed to explain whether the effect of ambient air pollution also results in a disruption of purchasing and consumption behaviors across different categories. To do this, we quantified changes in customer expenditures in the following categories: public transit, recreation and leisure, gasoline, e-commerce, and food outside the home.

The model of categorical expenditures is similarly specified as the previous model, as it is defined as a function of the similar independent variables in the following log-log form:

$$log\ Exp_{it}^{c} = \beta^{0} + \beta^{1}\ log\ Exp_{i0}^{c} + \beta^{2}\mathrm{PM2.5}_{t} + \beta^{3}\mathrm{PM10}_{t} + \sum \beta^{4,k}\mathrm{PM2.5}_{t}\ I(category_{it} = k) + \sum \beta^{5,k}\mathrm{PM10}_{t} I(category_{it} = k) + WX_{it} + \epsilon_{it}^{2} \quad (2)$$

The dependent variable, Exp_{it}^{c}, is individual i's expenditures in category c on day t; Exp_{i0}^{c} is individual i's daily expenditures for category c during the six-week-long initialization period; $PM2.5_{t}$ and $PM10_{t}$ are the average daily levels of $PM2.5$ and $PM10$ on day t; and X_{t} includes time dummies and customers' demographic characteristics.

The current model enables us to examine mutually exclusive marginal effects of air pollution on consumer expenditures in four categories. For example, β^{2} and β^{3} estimate the effect of $PM2.5$ and $PM10$ levels on expenditures on public transportation, and $\beta^{2} + \beta^{4,c}$ and $\beta^{3} + \beta^{5,c}$ estimate the effect on expenditures in category c. The main goal of the current model is to measure the differences in changes individuals made in their expenditures on public transit, recreation and leisure, gasoline, e-commerce, and food outside the home.

Table 4 documents the estimation results. Regarding the variables of interest, we found that when the levels of $PM2.5$ and $PM10$ changed by one unit, consumers lowered their expenditures on public transportation by 0.41% and 0.037%, respectively, while gasoline expenditures remained fairly stable. Finally, we also found that consumers lowered their spending on recreation and leisure by about 0.7%, spent more on e-commerce by about 0.3%, and went out to eat by about 0.4. Note that the current empirical findings are nearly equivalent to the previous findings, as consumers reduced their public transit ridership and maintained their gasoline consumption at a relatively stable level.

We interpret the above marginal effects as follows. On the day with ambient air pollution, consumers may have tried to lower their exposure to this pollution by not engaging in outdoor activities and modifying their primary shopping channel. Furthermore, consumers might have switched from public transit to private transportation for some necessary recurrent trips (the reduced usage of private transportation due to reduced recreation or leisure activities offset the increase of its usage from this substitution). As a result, these modifications to consumers' behaviors caused a decrease in the use of public transportation and the fairly constant spending on gasoline. This is partly because consumers increased their use of private vehicles for daily commutes to work while decreasing needless non-recurrent trips for leisure activities.

In summary, we found through a series of analyses with explicit controls for exogenous variables that consumers considerably adjusted their consumption behaviors in response to ambient air pollution. The results are particularly interesting in that implications drawn from the effects of other macroeconomic factors likely lead to ineffective policy interventions and practical decisions. We believe that the guidance we inferred from the disaggregate analyses is important for practitioners and managers.

Finally, given the substantial effect of air pollution, we focused on the fact that consumers' adjustments to their shopping behaviors may differ depending on their socioeconomic characteristics. Especially, we note that marginal costs (when gasoline prices rise) become more significant for households with more financial constraints [27]. Thus, in our next analysis, we explicitly controlled for the effect of consumers' income and explored the interaction effects between air pollution and financial constraints. Due to the lack of direct measures for financial constraints in the data, we employed consumption expenditures to approximate them [36, 37].

Table 4

Estimation Results for Model 2

Variable		Variable	
Expenditures during the Initialization Period	0.3704** (0.0018)	$\text{PM2.5}_t I(category_{it} = \text{recreation and leisure})$	-0.0027** (0.0012)
Intercept	3.9824** (0.2884)	$\text{PM10}_t I(category_{it} = \text{recreation and leisure})$	0.0031** (0.0009)
PM2.5_t	−0.0041** (0.0005)	$\text{PM2.5}_t I(category_{it} = \text{e Commerce})$	0.0067** (0.0012)
PM10_t	−0.0037** (0.0005)	$\text{PM10}_t I(category_{it} = \text{e Commerce})$	0.0068 (0.0004)
$\text{PM2.5}_t I(category_{it} = gas)$	0.0039** (0.0005)	$\text{PM2.5}_t I(category_{it} = \text{food outside the home})$	0.0004 (0.0001)
$\text{PM10}_t I(category_{it} = gas)$	0.0037** (0.0006)	$\text{PM10}_t I(category_{it} = \text{food outside the home})$	0.0003 (0.0001)
N	3,724,825	Adjusted R-Squared	0.1998

We report total individual expenditures in Table 5, in which large differences can be seen across the estimation sample, strongly suggesting that considerable socioeconomic heterogeneity is present in the current data.

Table 5

Weekly Expenditures during the Initialization Period

	Weekly Expenditures (won)
3rd Quartile	401,486
Median	289,176
1st Quartile	183,165

Accordingly, we defined "baseline expenditures" similar to previous models and constructed a categorical variable identifying the baseline levels of individual expenditures such that four mutually exclusive groups were determined by the 25th, 50th, and 75th percentiles of their total spending.

$Group_i = 1$ if below the 25th percentile
$Group_i = 2$ if between the 25th and 50th percentiles
$Group_i = 3$ if between the 50th and 75th percentiles
$Group_i = 4$ if above the 75th percentile

To address the possibility of heterogeneity in the effect of ambient air pollution, we added interaction effects between the levels of PM concentrations and the categorical variables for the baseline level of individual expenditures to our following model specification. Based on previous studies investigating the effects of other macroeconomic changes, we predicted that the effect of increasing levels of particulate matter is considerably different across households from different income classes.

$$log\,Exp_{it}^{pt} = \gamma^0 + \gamma^1 \,log\,Exp_{i0}^{pt} + \gamma^2 \text{PM2.5}_t + \gamma^3 \text{PM10}_t + \sum \gamma^{4,q} \text{PM2.5}_t\, I(Group_i = q) + \sum \gamma^{5,q}\, I(Group_i = q) + \Gamma X_{it} + \epsilon_{it}^3 \quad (3)$$

$\mathrm{I}(Group_i = q) = 1$ if $Group_i = q$, and $\mathrm{I}(Group_i = q) = 0$ otherwise. The interaction term helped us to account for differences in how individuals from different income classes responded to the ambient air pollution; again, γ^2, γ^3 $\gamma^{4,q}$ and $\gamma^{5,q}$ are the primary variables we investigated.

The coefficient estimates and their standard errors are summarized in Table 6. The most important feature is that, consistent with our expectation, considerable differences were documented in the adjustments made by individuals with different levels of financial constraints. For example, consumers with the second-largest baseline total expenditures exhibited the largest changes in their behaviors, and they decreased their expenditures on public transportation by 0.62% and 0.73% when the levels of PM2.5 and PM10 increased by one unit, respectively. Interestingly, consumers with the smallest and largest baseline total expenditures kept their expenditures on public transportation fairly stable, and no statistically significant differences were found in their decisions regarding public transit ridership in relation to changes in PM2.5 and PM10 concentrations.

The current pattern witnessed in the baseline total expenditures across different income classes suggests the following. Consumers with strict financial constraints mainly use public transportation to commute to work or school and do not possess an alternative private means of transportation. Meanwhile, consumers in the highest income class hardly ever use public transportation. As a result, these consumers are not significantly affected by fluctuations in PM2.5 and PM10 levels and maintained their decisions about transit ridership. Consumers in other income classes, however, use both public and private transportation and adjusted their decisions about public transit ridership in response to the levels of particulate matter concentrations.

Table 6

Estimation Results for Model 3

Variable		Variable	
Expenditures during the Initialization Period	0.3382** (0.0012)	Intercept	4.0741** (0.3384)
$\mathrm{PM2.5}_t$	0.0004 (0.0011)	$\mathrm{PM2.5}_t I(Group_i = 3)$	0.0048** (0.0013)
$\mathrm{PM10}_t$	−0.0003 (0.0014)	$\mathrm{PM10}_t I(Group_i = 3)$	0.0052** (0.0014)
$\mathrm{PM2.5}_t I(Group_i = 2)$	−0.0062** (0.0016)	$\mathrm{PM2.5}_t I(Group_i = 4)$	-0.0002 (0.0016)
$\mathrm{PM10}_t I(Group_i = 2)$	0.0073** (0.0015)	$\mathrm{PM10}_t I(Group_i = 4)$	0.0001 (0.0001)
N	3,724,825	Adjusted R-Squared	0.1998

Given the scope of our paper, it is not feasible to validate our interpretations in the current research, and there could be other scenarios that are equally plausible. However, the current findings provide empirical evidence suggesting that increased levels of particulate matter impact consumers' decisions on transit ridership and confirm the role of income in relation to the significant heterogeneity present in its effect.

5. DISCUSSION

Based on detailed information about credit card transactions, we investigated the influence of ambient air pollution and documented empirical evidence that the increased level of particulate matter had a statistically significant effect on consumers' decisions regarding transit ridership. Upon identifying that considerable heterogeneity was present across individuals, a series of empirical analyses confirmed that financial constraints are a determining factor in the commitment to ridership on public transit when concerns about fine particulate matter concentrations are high.

Our findings provide an important implication for policymakers. The Korean government has introduced a number of pollution controls, including the provision of mandatory alternate no-driving days for the public fleet, the expansion of road cleaning, and the designation of focused particle pollution control areas. However, the effects of these remedial measures have been fairly limited, and the daily average levels of PM2.5 and PM10 have been consistently growing. Under such circumstances, our findings imply that individuals with strict financial constraints who maintained a relatively stable demand for public transportation are largely exposed to the detrimental risk of fine particulate matter.

Consequently, alternative controls for individuals with strict financial constraints could protect these commuters, who are committed to public transit ridership. In addition to the tasks to reduce emissions g transport, heating, and industry, for example, subsidies for anti-pollution masks may help minimize individuals' exposure to fine particulate matter and the detrimental health effects of air pollution. Our empirical results and their interpretations are restricted in certain aspects, and, therefore, we cannot predict or validate the effects of such a policy intervention. We hope that our discussion stimulates further empirical research to examine our findings and argument.

6. CONCLUSION

The effects of ambient air pollution are devastating in many contexts, and consumers' adjustments differ considerably across categories and income classes. The significant heterogeneity present in consumers' responses suggests that when the level of fine particulate matter rises, significant disruptions of consumers' spending are limited to activities that enhance the risk of exposure to fine particulate matter and the effect of ambient air pollution on transit ridership has been prevalent only for consumers in middle-income classes.

Our findings provide an important implication to policymakers, as they show that the emission of fine particulate matter has not been lessened by a series of government controls, and the commitment to the use of public transportation is strong for consumers in the low-income class. As past studies investigating macroeconomic factors generally limited their primary attention to the disruption of economic abilities, our empirical examination of the effect of ambient air pollution provides important guidance and implications for policymakers and practitioners in many relevant fields.

Acknowledgments

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References

1. Hong, Y.-C. & et al. Air pollution: a new risk factor in ischemic stroke mortality. *Stroke*. 2002. Vol. 33(9). P. 2165-2169.
2. Nyhan, M.M. & et al. Quantifying population exposure to air pollution using individual mobility patterns inferred from mobile phone data. *Journal of exposure science & environmental epidemiology*. 2019. Vol. 29(2). P. 238-247.
3. Mo, Z. & et al. Impacts of air pollution on dry eye disease among residents in Hangzhou, China: a case-crossover study. *Environmental Pollution.* 2019. Vol. 246. P.183-189.
4. Lee, K.K. & Miller, M.R., Shah, A.S.V. Air pollution and stroke. *Journal of stroke*. 2018. Vol. 20(1). P. 2-11.
5. Rusznak, C. & Devalia, J.L. & Davies, R.J. The impact of pollution on allergic disease. *Allergy*. 1994. Vol. (49). P. 21-27.
6. Van Amsterdam, J.G. & et al. Air pollution is associated with increased level of exhaled nitric oxide in nonsmoking healthy subjects. *Archives of Environmental Health: An International Journal.* 1999. Vol. 54(5). P. 331-335.
7. Xia, R. & et al. Ambient air pollution and out-of-hospital cardiac arrest in Beijing, China. *International journal of environmental research and public health.* 2018. Vol. 14(4). No. 423. P. 1-11.

8. Leem, J.H. & Kim, S.T. & Kim, H.C. Public-health impact of outdoor air pollution for 2nd air pollution management policy in Seoul metropolitan area, Korea. *Annals of occupational and environmental medicine.* 2015. Vol. 27(1). P. 1-9.
9. Ng, Ch.F.S. & et al. Ambient air pollution and suicide in Tokyo, 2001-2011. *Journal of affective disorders.* 2016. Vol. 201. P. 194-202.
10. Lipfert, F.W. & Zhang, J. & Wyzga, R.E. Infant mortality and air pollution: a comprehensive analysis of US data for 1990. *Journal of the Air & Waste Management Association.* 2000. Vol. 50(8). P. 1350-1366.
11. Diab, E. & et al. Current state of practice in transit ridership prediction: Results from a survey of Canadian transit agencies. *Transportation Research Record.* 2019. Vol. 2673(8). P. 179-191.
12. Krämer, Ur. & et al. Eczema, respiratory allergies, and traffic-related air pollution in birth cohorts from small-town areas. *Journal of dermatological science*. 2009. Vol. 56(2). P. 99-105.
13. Spengler, J.D. & et al. Housing characteristics and children's respiratory health in the Russian Federation. *American journal of public health*. 2004. Vol. 94(4*)*. P. 657-662.
14. Zemp, E. & et al. Long-term ambient air pollution and respiratory symptoms in adults (Sapaldia study). *American journal of respiratory and critical care medicine.* 1999. Vol. 159(4). P. 1257-1266.
15. Burnett, R.T. & Cakmak, S. & Brook, J.R. The effect of the urban ambient air pollution mix on daily mortality rates in 11 Canadian cities. *Canadian journal of public health*. 1998. Vol. 89(3). P. 152-156.
16. Schwartz, J. & Dockery, D.W. Particulate air pollution and daily mortality in Steubenville, Ohio. *American journal of epidemiology*. 1992. Vol. 135(1*)*. P. 12-19.
17. Arden Pope 3rd, C. & et al. Cardiovascular mortality and long-term exposure to particulate air pollution: epidemiological evidence of general pathophysiological pathways of disease. *Circulation.* 2004. Vol. 109(1). P. 71-77.
18. Orru, H. & et al. Impact of climate change on ozone-related mortality and morbidity in Europe. *European Respiratory Journal*. 2013. Vol. 41(2). P. 285-294.
19. Samet, J.M. & et al. Fine particulate air pollution and mortality in 20 US cities, 1987-1994. *New England journal of medicine*. 2000. Vol. 343(24). P. 1742-1749.
20. Gehring, U. & et al. Exposure to air pollution and development of asthma and rhinoconjunctivitis throughout childhood and adolescence: a population-based birth cohort study. *The lancet Respiratory medicine.* 2015. Vol. 3(12). P. 933-942.
21. Hoek, G. & et al. Long-term air pollution exposure and cardio-respiratory mortality: a review. *Environmental health.* 2013. Vol. 12(1). No. 43. P. 1-15.
22. Bejot, Y. & et al. Epidemiology of stroke in Europe: geographic and environmental differences. *Journal of the neurological sciences*. 2007. Vol. 262(1-2). P. 85-88.
23. Rohde, R.A. & Muller, R.A. Air pollution in China: mapping of concentrations and sources. *PloS one.* 2015. Vol. 10(8). No. e0135749.
24. Vichit-Vadakan, N. & et al. Part 3. Estimating the effects of air pollution on mortality in Bangkok, Thailand. *Health Effects Institute.* 2010. Vol. 154. P. 231-268.
25. Currie, G. & Phung, J. Transit ridership, auto gas prices, and world events: new drivers of change? *Transportation Research Record.* 2007. Vol. 1992(1). P. 3-10.
26. Bhat, Ch.R. & Sen, S. & Eluru, N. The impact of demographics, built environment attributes, vehicle characteristics, and gasoline prices on household vehicle holdings and use. *Transportation Research Part B: Methodological*. 2009. Vol. 43(1). P. 1-18.
27. Golub, A. Welfare and equity impacts of gasoline price changes under different public transportation service levels. *Journal of Public Transportation*. 2010. Vol. 13(3*)*. P. 1-21.
28. Maghelal, P. Investigating the relationships among rising fuel prices, increased transit ridership, and CO2 emissions. *Transportation Research Part D: Transport and Environment*. 2011. Vol. 16(3). P. 232-235.
29. Lorusso, M. & Pieroni, L. Causes and consequences of oil price shocks on the UK economy. *Economic Modelling*. 2018. Vol. 72. P. 223-236.
30. Breton, C.V. & et al. Particulate matter, DNA methylation in nitric oxide synthase, and childhood respiratory disease. *Environmental health perspectives.* 2012. Vol. 120(9). P. 1320-1326.

31. Lodovici, M. & Bigagli, E. Oxidative stress and air pollution exposure. *Journal of toxicology.* 2011. Vol. 2011. No. 487074.
32. Gicheva, D. & Hastings, J. & Villas-Boas, S. *Revisiting the income effect: gasoline prices and grocery purchases*. National Bureau of Economic Research. 2007. 43 p.
33. Villas-Boas, S.B. & Gicheva, D. & Hastings, J. Revisiting the income effect: gasoline prices and grocery purchases. *American Economic Review: P and P*. 2010. Vol. 100(2). P. 1-7.
34. Broniarczyk, S.M. & Hoyer, W.D. & Mcalister, L. (1998). Consumers' perceptions of the assortment offered in a grocery category: The impact of item reduction. *Journal of marketing research.* 1998. Vol. 35(2). P. 166-176.
35. Bucklin, R.E. & Gupta, S. & Siddarth, S. Determining segmentation in sales response across consumer purchase behaviors. *Journal of Marketing Research*. 1998. Vol. 35(2). P. 189-197.
36. Cutler, D.M. & et al. Macroeconomic performance and the disadvantaged. *Brookings papers on economic activity.* 1991. Vol. 2. P. 1-74.
37. Hurd, M. & Rohwedder, S. *The retirement-consumption puzzle: Anticipated and actual declines in spending at retirement*. National Bureau of Economic Research. 2003.

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