(Re)Labeling and Preference:
Evidence from Air Quality Standards and Housing Markets in South Korea

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Abstract

This paper examines how relabeling changes perception and preference by exploiting an unexpected information shock due to the tightening of air quality standards in South Korea. Since March 2018, $PM_{2.5}$ concentrations between 35-50 $\mu g/m^3$ are relabeled from "Normal" to "Bad", while 75-100 $\mu g/m^3$ are relabeled from "Bad" to "Very Bad". We link the information shock with a unique data set on the universe of over 8 million housing sales and rental contracts in 2015-2019. An extra day of $PM_{2.5}$ labeling change from "Normal" to "Bad" and from "Bad" to "Very Bad" over the past 30 days lowers home values by approximately 0.32% ($1,015) and 0.23% ($729), and annual rental costs by 0.22% ($24.8) and 0.17% ($19.2), respectively. Importantly, relabeling not only shifts the Hedonic Price Schedule across categories, but also steepens it by increasing marginal willingness to pay (MWTPs) for clean air within the categories. For home values (rental costs), we discover the MWTPs increased by 0.0005% (0.0008%), 0.0023% (0.0026%), 0.0032% (0.0024%), 0.0036% (0.0029%), and 0.0022% (0.0023%) for the "Normal", "Normal to Bad", "Bad", "Bad to Very Bad", and "Very Bad" categories, respectively. We also observe larger relabeling effects at lower floors and in urban areas compared with their counterparts. Moreover, an extra day of $PM_{2.5}$ labeling change from "Normal" to "Bad" or from "Bad" to "Very Bad" in a month further improves air quality by 0.04% or 0.06% in 6 months after the information shock, which reflects emission reductions in transportation and power plants. A back-of-the-envelope calculation shows that the total welfare gain from the air quality improvement is $892 million in total sales prices and $23 million in total annual rents. Our findings highlight the role of relabeling in shaping risk perception and preferences, contributing to the valuation of information and air quality, and provide important policy implications for the environment, real estate, and beyond.

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Keywords: Relabeling; Risk perception; Information shock; Air pollution; Housing

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1. Introduction

The way information is designed and articulated can shape perceptions, preferences, and behaviors (Stiglitz, 1961, 2017). Labeling is widely adopted in businesses and policies to motivate behavioral changes by reducing information asymmetry and costs as well as mental accounting (Thaler, 1985, 1999; Tadelis, 1999; Koorman, 2000). Identifying its effects is crucial for theories and practices but remains challenging in many domains of social sciences. In particular, causal evidence is further scarce on label changes, i.e., relabeling, due to information complexity and data availability.

This paper examines this question by exploiting a quasi-experiment tightening air quality standards (AQS) that causes sharp and unexpected changes in perceived risks by homeowners and renters in South Korea. AQS labels pollutant concentrations in several ordinal categories, such as "Good", "Normal", "Bad", and "Very Bad", and is commonly adopted as a policy instrument for information dissemination and pollution reduction to protect the public. Since March 27, 2018, daily $PM_{2.5}$ (particulate matter with a diameter smaller than 2.5 micrometers) levels between 35-50 $\mu g/m^3$ are relabeled from "Normal" to "Bad", while daily $PM_{2.5}$ levels between 75-100 $\mu g/m^3$ are relabeled from "Bad" to "Very Bad". This setting has a few unique and appealing features. First, it is a single and pure information shock targeting one air pollutant with wide public access. Second, the comprehensive daily housing data on sales and rentals allow us to fully capture the effects of relabeling over time. Third, we can compare $PM_{2.5}$ levels with varying labels to examine the Hedonic Price Schedule (HPS) and Marginal Willingness to Pay (MWTP) for clean air across categories, which is underexplored in the literature (e.g. Rosen, 1974; Greenstone, 2017).

We first augment the canonical hedonic pricing model by Rosen (1974) with imperfect information and labeling, which leads to higher preferences for clean air and guides our empirical analyses. We then link the abrupt relabeling of air quality to a large dataset on the housing sales and rental market with over 8 million records at the daily level before and after the information shock during 2015-2019.[1] To address the endogeneity of pollution exposure, we use exogenous variation in wind direction as an instrument for $PM_{2.5}$ and control for refined location and time fixed effects along with a rich set of housing and location characteristics. Our main empirical strategy compares the housing values and rental prices between real estate with different numbers of relabeling occurrences across the categories over a 30-day pre-transaction

[1] We trim the period to the end of 2019 before the wide spread of COVID-19 in South Korea to avoid its relevant unusual bias on housing markets. See https://dportal.kdca.go.kr/pot/cv/trend/dmstc/selectMntrgSttus.do.

period before and after the information shock, and the results are robust to alternative specifications. We begin with one simplified illustration by making pairwise comparisons between the relabeled "Normal to Bad" section and the always "Normal" section, as well as between the relabeled "Bad to Very Bad" section and the always "Bad" section. We then move to focus on a full specification that compares all other sections with the always "Good" section in a single regression, allowing for a complete examination with more flexibility in identification.

Our results document a significant *relabeling effect*, which shifts the HPS within the relabeled categories only. Specifically, compared with the "Normal" or "Bad" section, an additional day of $PM_{2.5}$ labeling change from "Normal" to "Bad" or from "Bad" to "Very Bad" over the past 30 days lowers housing values by approximately 0.32% ($1,015) or 0.30% ($960), and rental prices by 0.27% ($30.5) or 0.25% ($28.2) per year, respectively.[2] The estimates are consistent with the full specification with all sections and more flexible controls. Compared with the always "Good" section, an extra day of $PM_{2.5}$ relabeling in "Normal to Bad" and "Bad to Very Bad" lowers home values by approximately 0.32% ($1,015) and 0.23% ($717), and annual rental costs by 0.22% ($24.8) and 0.17% ($19.2), respectively. The effect is larger for "Normal to Bad" than "Bad to Very Bad", suggesting that the relabeling effect decreases with pollution levels. In categories without relabeling, we find insignificant differences before and after the standard change in both housing values and rental prices, and the estimates are very close to zero with large standard errors. For the non-relabeled sections, we also observe a pre-existing labeling effect before the policy change. Compared with the always "Good" section, an additional day of $PM_{2.5}$ labeling as "Normal", "Bad", and "Very Bad" over the past 30 days lowers housing values by approximately 0.16% ($507), 0.35% ($1,110), and 0.67% (2,124), and rental prices by 0.13% ($15), 0.40% ($45), and 0.47% ($53) per year, respectively. The (re)labeling responses are slightly larger for the sales market than the rental market. Lastly and importantly, the event-study estimates reveal parallel pre-trends before the information shock and immediate price drops afterwards, which persists for up to 21 months till the end of the study period.

On top of the direct and local relabeling effect within the relabeled sections, we also find increased MWTP for clean air across the sections, suggesting higher risk perception over the whole pollution distribution. We frame it as an indirect *perception effect*, which steepens the

[2] We multiply the percentage change by the average of home sales prices ($317,114.21) and rents ($941.4223 per month) to obtain the estimates.

slope of the HPS globally. Compared with the "Good" section, the increases in MWTP for a 1 $\mu g/m^3$ reduction in $PM_{2.5}$ exposure over the past 30 days in the section relabeled from "Normal" to "Bad" or from "Bad" to "Very Bad" are 0.0023% ($7.3) or 0.0036% ($11.4) for home values, and 0.0026% ($0.29) or 0.0029% ($0.33) for annual rental costs, respectively. Within the non-relabeled sections for the always "Normal", "Bad", and "Very Bad", the corresponding MWTP also increased by 0.0005% ($1.6), 0.0032% ($10.1), and 0.0022% ($7.0) for home values and by 0.0008% ($0.09), 0.0024% ($0.27), and 0.0023% ($0.26) for annual rental costs. The size of the perception effect first increases with pollution levels and then decreases in the most polluted section. Overall, the relabeling effect is over 100 times the size of the perception effect in a 30-day window, revealing the salience of labeling and relabeling. Again, the sales responses are slightly larger than the rental responses. In addition, the perception effect not only persists but also enlarges over time, suggesting increasing risk perception and MWTP for clean air. Heterogeneity analyses further show a larger relabeling effect and perception effect on lower floors and in urban areas, consistent with changes in risk perceptions and preferences.

Along with the direct and indirect "cost" of the information relabeling to homeowners, we also examine the potential benefits as measured by air quality improvement. We indeed observe a gradual decline in $PM_{2.5}$ levels, which emerges 6 months after the information shock. Compared with the always "Good" section, an extra day in the two relabeled groups, i.e., the "Normal to Bad" group and the "Bad to Very Bad" group, in a month lowers $PM_{2.5}$ levels 6 months after the information shock and later by around 0.04% and 0.06% on average, respectively, whereas there are no significant changes in other sections. We also observe similar declines for PM_{10} levels, while other pollutants, including NO_2, CO, SO_2 and O_3, remain unchanged for all lag lengths. We further collect additional data on transportation and electricity generated by fossil-fuel power plants, which shows consistent drops in the two relabeled sections after the information shock, suggesting that they are the drivers of air quality improvement in residential areas in the long run. The air quality improvement in the relatively long term also helps explain the slower increases in MWTP later. Lastly, our back-of-the-envelope analysis shows that the welfare gain from pollution reduction equals $892 million in total sales prices and $23 million in total annual rents.

The study makes three primary contributions to literature. First, it adds to the extensive literature on labeling and behaviors, which focuses on imperfect information and mental accounting. The topics include names, brands, and labels of products such as foods and drugs, education, energy, taxation, child benefits and cash transfers (e.g., Tadelis, 1999; Kooreman,

2000; Jin and Leslie, 2003; Hastings and Weinstein, 2008; Chetty et al., 2009; Bollinger et al., 2011; Beatty et al., 2014; Roe et al., 2014; Benhassine et al., 2015; Bronnenberg et al., 2015; Abeler and Marklein, 2017; Hastings and Shapiro, 2018; Barahona et al., 2023). In comparison, there are few studies on relabeling, especially public relabeling (Golan et al., 2001; Figlio and Lucas, 2004; Achinstein et al., 2015; Gruber et al., 2021; Higgins et al., 2021). It remains challenging to identify the (re)labeling effects in many contexts, since (re)labeling usually happens nonrandomly and covaries with other changes, and granular data are not common to allow researchers to link (re)labeling with economic behaviors and outcomes in a complete and dynamic manner. Our paper contributes to the existing literature by exploiting a unique setting to casually estimate the labeling and relabeling effects on housing purchase and rental decisions. We are the first to show that relabeling of pollution levels significantly increases risk perception both directly in the relabeled groups (i.e., relabeling effect) and indirectly in the non-relabeled groups (i.e., perception effect) by lowering the sales and rental prices, and the effects are both immediate in the short run and persistent in the long run. Importantly, relabeling can also induce improvement in air quality in the long run. The findings can provide novel and important implications for information design and provision.

Second, this study enriches the discussions on the valuation of environmental quality. There is a growing strand of literature addressing the empirical challenges of hedonic pricing models with quasi-experimental methods during the past two decades, including pollution and the housing sales market (e.g., Gayer et al., 2000; Bui and Mayer, 2003; Chay and Greenstone, 2005; Banzhaf and Walsh, 2008; Greenstone and Gallagher, 2008; Kuminoff and Pope, 2014; Currie et al., 2015; Mastromonaco, 2015; Banzhaf, 2021; Moulton et al., 2024; Sager and Singer, forthcoming). The literature assumes perfect information and treats the hedonic price function as smooth to estimate the average MWTP over the whole pollution distribution, which overlooks potential discontinuities caused by the information design and categorical assignment by pollution standards. Some recent studies highlight the role of the quality and access of pollution information in improving welfare in developing countries (Greenstone et al., 2022; Gao et al., 2023; Barwick et al., 2024). However, changes in information quality and information access often overlap, making it difficult to identify the effects separately. Our paper introduces information labeling and relabeling to the hedonic model with quasi-experimental estimation based on the universe of housing data with fine spatial and temporal resolution over a long period. It is the first to highlight the shift and rotation of the price function due to labeling and relabeling, suggesting biased estimation of the welfare impacts if information and

(re)labeling are neglected. In addition, we utilize both sales and rentals with high frequency to capture the full impacts on the sales and rental markets, the latter of which is underexplored in the literature with mixed evidence (Davis, 2011; Grainger et al., 2012; Bento et al., 2015; Graff Zivin and Singer, 2023). Interestingly, the responses are slightly smaller for rentals than sales. The result is consistent with the length of contract and pass-through from homeowners to renters, leading to differential risk perception and impacts.

Third, our paper offers novel insights into environmental policies. The literature primarily documents the benefits of environmental regulation, whereas observations on the costs are limited and mixed, with a focus on the polluting firms in western countries (e.g., Jaffe et al., 1995; Henderson, 1996; Becker and Henderson, 2000; Berman and Bui, 2001; Greenstone, 2002; Walker, 2011, 2013; Greenstone et al., 2012; Ryan, 2012; Kahn and Mansur, 2013; Isen et al., 2017; Lange et al., 2018; Keiser and Shapiro, 2019; He et al., 2020; Shapiro and Walker, 2020; Anderson et al., 2022; Keiser et al., 2023). We first speak to this literature by highlighting the depreciation of housing value as the cost of information (re)labeling to homeowners. The cost is nontrivial and persistent, which shall be considered in welfare analysis. However, we do not fully quantify such costs given the constraints of data and modeling. That said, our estimates can identify the movement along the ex-post price function, which offers a lower bound on general equilibrium welfare (Banzhaf, 2021). Furthermore, we document the substantial benefits due to air quality improvement in the long run. The findings have useful implications for policies on the environment, real estate, urban planning, and beyond.

The remainder of the paper is organized as follows. Section 2 introduces the institutional background and data. Section 3 describes the research design with theoretical modeling and empirical specification. Section 4 summarizes the results, followed by a discussion on the pollution and welfare implications in Section 5. Section 6 concludes.

2. Background and Data

2.1 Environment and Policy in South Korea

Air pollution is the single largest environmental health risk identified by the World Health Organization (WHO). South Korea is the most polluted OECD country, with an annual average $PM_{2.5}$ of around 24 $\mu g/m^3$ in 2019, leading to substantial health impacts (Jia and Ku, 2019; Heo et al., 2023).[3] The AQS in South Korea was more lenient compared with other developed

[3] South Korea's air quality is better than that in most developing countries. For instance, in 2019, the mean annual concentration levels of $PM_{2.5}$ were 47.7 $\mu g/m^3$ in China and 83.5 $\mu g/m^3$ in India.

countries. In response to the growing concerns over the environment, South Korea has adopted more stringent environmental regulations since 2017. As the cornerstone of the reform, a more stringent AQS was established to inform the public and improve air quality in March 2018.

Our setting has a few unique features to address potential empirical concerns. First, AQS does not apply to all countries and its updates do not happen often. Over one-third of the world's countries have no legally mandated ambient air quality standards (UNEP, 2021). Major developed countries in America and Europe have recent revisions at least 20 years ago with limited data and attention to the relabeling effect. For example, WHO updated its air quality guidelines in 2021 after the last revision in 2005. The United States has just updated part of its National Ambient Air Quality Standards (NAAQS) in 2024 since 2006 (US EPA, 2024). China updated its AQS in 2013 since its establishment in 2000 and planned to pilot a revision recently. Second, the tightening of AQS usually occurs jointly with other covarying factors and policies, covering multiple pollutants or Air Quality Index (AQI), coupled with emission abatement efforts. For example, US EPA enforces stricter regulations on emission reduction alongside AQS updates, with changes in thresholds for multiple pollutants and AQI. In China's recent AQS update in 2013, three new pollutants were added to construct a new AQI in place of the Air Pollution Index (API), with tightened thresholds, wider and easier public access, and lower scope of hidden manipulation (Greenstone et al., 2021). As such, it is difficult to causally link changes in behaviors or pollution to a specific channel, such as relabeling pollution levels. Third, public access to AQS and air quality information was limited in many countries before the wide adoption of the Internet and 3G/4G network. During our study period, residents in South Korea have wide access to air quality information through various platforms, such as news media, the Internet, and mobile apps. As shown in Appendix Figure A1, we find a salient spike in Google search of $PM_{2.5}$ right after the information shock with persistent attention over time, revealing public awareness of air quality information in South Korea.[4]

In the new AQS, the only significant change is the relabeling of measured $PM_{2.5}$ levels in 35-50 μg/m³ and 75-100 μg/m³, as shown in Figure 1. Specifically, the intervals are divided into four sections: "Good," "Normal," "Bad," and "Very Bad." Prior to the policy change, the "Good" interval was defined for $PM_{2.5}$ levels ranging from 0 to 15 μg/m³, and the "Normal"

[4] The Google Search Index tracks the relative frequency of specific search terms over time, serving as a proxy for public interest in particular topics. In this study, we analyze search data related to particulate matter in South Korea from January 2016 to December 2019 to explore trends in public awareness and concern. The Google search index originally ranges from 0-100, which is deseasonalized by month to explore a clear pattern. See: https://trends.google.co.kr/trends/

forecast interval spanned from 15 to 50 μg/m³. The interval from 50 to 100 μg/m³ was labeled as “Bad”, and levels exceeding 100 μg/m³ were “Very Bad.” After the policy, the intervals were redefined. The “Good” category remained the same. However, the “Normal” interval was narrowed to cover from 15 to 35 μg/m³. The “Bad” interval was redefined to include levels from 35 to 75 μg/m³, and levels exceeding 75 μg/m³ were classified as “Very Bad.” This adjustment means that $PM_{2.5}$ levels that fall between 35 μg/m³ and 50 μg/m³, which were previously classified as “Normal” under the old forecasting standards, are now reclassified as “Bad.” Similarly, $PM_{2.5}$ levels between 75 and 100 μg/m³ were previously classified as "Bad" but are now labeled as “Very Bad” following the policy change. The original information poster on the changes of AQS by the government is shown in Appendix Figure A2.

[Figure 1. Old vs New AQS of $PM_{2.5}$ in South Korea]

2.2 Data

Our housing data are provided by Ministry of Land, Infrastructure, and Transport of South Korea (MOLIT).[5] The data include sales prices, rents, type of rental contracts, areas and floors of apartments, construction years, as well as the specific date on which apartments are sold or rented out. Beyond the standard sales and rental markets, there is another unique type of rental contract in South Korea, which is the Jeonse rental market. In the market, tenants pay a lump-sum deposit named Jeonse, which typically amounts to 60 to 80 percent of the unit's sale price, directly to the landlord. In return, the tenant is not required to pay monthly rent, and the deposit is fully refunded at the end of the contract period. As such, the Jeon-Seh market lies between the regular sales and rental markets, allowing us to test the differences and linkages between these markets. We obtain the rental data of both types and transfer the Jeon-Seh rental costs to rent equivalent comparable to regular rents.[6]

We also collect district-level data from the Korean Statistical Office to account for time-varying characteristics. The data involves the number of vehicles registered, population, municipal area, and student-faculty ratio at the district-month level. There are 229 districts,

[5] See the official website of MOLIT: http://www.mlit.go.jp/en/index.html

[6] In South Korea, the Korea Real Estate Board provides data on the monthly lease-to-rent conversion rates for apartments by city, county, and district nationwide. This data enables the calculation of monthly rent from a Jeonse (lump-sum deposit lease) contract by applying the lease-to-rent conversion rate to the deposit of the Jeonse and then dividing by 12 to convert it into monthly rent. In the case of monthly rent contracts that also have a deposit, the same formula is applied to convert the deposit into a monthly rent value, which is then added to the base monthly rent to calculate the total monthly rent amount.

which are municipal-level divisions under provincial-level cities in South Korea.[7]

Our environmental data cover detailed daily pollution and meteorological conditions observed from local monitoring networks in South Korea. The pollution data are collected from 650 stations by the Korean Ministry of Environment, including PM_{10}, $PM_{2.5}$, ozone (O_3), carbon monoxide (CO), sulfur dioxide (SO_2), and nitrogen monoxide (NO). The weather data are obtained from 91 local stations provided by NOAA, which include temperature, humidity, precipitation, wind speed, and wind direction. We then match the housing data with the pollution and weather data using the nearest neighbor method, and our results are robust to alternative matching methods. The distances between the apartments and environmental monitors are very small in South Korea, alleviating concerns over potential measurement errors.[8]

Table 1 presents the summary statistics of variables on housing sales transactions, rental contracts, air pollution, weather, and local attributes. There are more than 4 million records of both housing sales transactions and rental contracts. The sales and rental prices have a wide distribution, reflecting the heterogeneity in housing types in South Korea. The pollution levels also show significant variations, with the average daily $PM_{2.5}$ centered around 21.5 $\mu g/m^3$. Most of the observations fall in the "Good", "Normal", and "Bad" sections. Figure 2 plots the geographical distribution of air pollution, housing prices, and rents at each community in our sample. The data are nationally representative with over 40 thousand communities, each of which has a unique address with one or several residential buildings.

[Table 1. Summary Statistics]

[Figure 2. Geographical Variations in Average $PM_{2.5}$ and Housing Costs]

We plot the linear correlations between lagged monthly $PM_{2.5}$ and home sales/rental price before and after the policy shock at the district-month level in Appendix Figure A3. We observe significant and negative relationships between air pollution and sales/rental prices both before

[7] South Korea includes 17 provincial-level administrative units: (1) Gyeonggi Province, (2) Gangwon Province, (3) Seoul City, (4) Incheon City, (5) Chungcheongnam Province, (6) Chungcheongbuk Province, (7) Sejong City, (8) Daejeon Province, (9) Gyeongsangbuk Province, (10) Jeollabuk Province, (11) Daegu Province, (12) Ulsan City, (13) Busan City, (14) Gyeongsangnam Province, (15) Jeollanam Province, (16) Gwangju City, and (17) Jeju City. See: https://www.korea.net/Government/

[8] The average distance between ground-based monitors and residential apartments is only 0.89 km in South Korea.

and after the information shock. Importantly, there is a clear increase in the slope *ex post*, suggesting a higher public perception of pollution risk.

3 Research Design

3.1 Conceptual Framework

Since Rosen's seminal paper (1974), economists have used hedonic techniques to estimate the value of a wide range of amenities, including clean air. The standard model treats the information as perfect if labeling would not affect the housing costs. However, people may not be fully aware of actual pollution levels and understand what the levels mean for them. Individual perceptions of the pollution levels and impacts may also be incomplete or biased. As such, we introduce labeling to a housing-hedonic model:

$$HC = f(X, \text{Label}, a) \tag{1}$$

where housing costs *HC*, i.e., home sales or rental prices, are determined by ambient air pollution level (*X*), labeling of the pollution level, and all other housing and local attributes (a). Labeling can reduce information asymmetry and improve quality of information by allowing the public to directly perceive pollution in desirable intervals, such as "Good", "Normal", "Bad", and "Very Bad". Therefore, public perception of air pollution would increase because of labeling, which may generate price premiums on housing services. Figure 3 conceptually illustrates a simple version of (re)labeling and perception changes on home values in two categories: "Good" and "Bad". The blue line describes the relationship between housing costs and air quality without labeling. Compared with the "Good" label, the (re)labeled "Bad" would impose a negative impact on home value, thus the blue line would shift downwards, as denoted by the dashed yellow line. In addition to (re)labeling effects, Figure 3 also illustrates how perception changes, following a classic Cobb-Douglas utility function for an individual: $u = c^{1-\theta}h^{\theta}X^{-\gamma}a^{\delta}$. c is the composite good whose price is one, and h is the quantity of housing service. *X* represents the pollution level, and a is a vector of levels of all housing attributes and other local amenities that affect housing costs. θ is the fraction of housing expenditure in wage income. The individual's preference towards clean air, γ, depends on both the pollution levels and labels of pollution levels as below:

$$\gamma = \gamma(X, \text{ label}\{\text{section, AQS}\}) \tag{2}$$

where *label* is simultaneously determined by the section and AQS, as shown in Figure 1. Given the indirect utility function $\mathcal{V} = Ir^{-\theta}X^{-\gamma}a^{\delta}$, in which *I* and *r* represent income and cost of one unit of housing service respectively, the marginal willingness to pay for a one-unit abatement

in pollution ($MWTP_X$) can be expressed as the marginal rate of substitution between wage and clean air: $MWTP_X = \frac{\partial V/\partial X}{\partial V/\partial I} = \gamma\left(\frac{I}{X}\right)$. Eventually, if a new air quality standard changes the preference, γ, from the old to a new level, as suggested by $\gamma_1(\text{old}) < \gamma_2(\text{new})$, we then have:

$$MWTP_X(\text{old}) = \gamma_1\left(\frac{I}{X}\right) < \gamma_2\left(\frac{I}{X}\right) = MWTP_X(\text{new}) \quad (3)$$

It implies that, due to the increased perceived risk of air pollution after the information shock, the public's marginal willingness to pay for a one-unit abatement in pollution becomes larger under the new AQS given stronger preferences for clean air. As such, the "Bad" label would also strengthen the preferences towards clean air, which is reflected in the steeper red line in the "Bad" section in Figure 3.

[Figure 3. A Conceptual Illustration of the (Re)labeling Effect and Perception Effect]

3.2 Empirical Strategy

A major empirical challenge to the identification of the HPS and MWTP is the conflation bias, which involves both the shift of the HPS and movement along the HPS. We overcome the empirical challenge with a quasi-experimental setting employing a difference-in-differences (DID)-type approach with air pollution instrumented by wind directions. The hedonic DID allows for estimation of the movement along the HPS and provides a lower-bound of the welfare impacts for non-marginal changes (Banzhaf, 2021). The detailed empirical strategy is specified below.

3.2.1 A Simplified Specification: Section 2 *vs* 3

Regarding relabeling, we observe substantial variations in switching between different pollution categories. Appendix Figure A4 presents three representative cases with switching days from "Normal" to "Bad", "Bad" to "Very Bad", and across all sections. We first start with a simplified specification by zooming in to compare one relabeled Section 3 with its neighboring benchmark, Section 2. We use it to showcase the robustness of our reduced-form estimation before focusing on the full specification with all sections. Specifically, we restrict the sample to apartments whose daily average $PM_{2.5}$ levels are always in either Section 2 or 3.[9] Housing units with daily means of $PM_{2.5}$ levels ever in Section 3 after the policy shock are considered as "treated" since they have experienced the relabeling from "Normal" to "Bad"

[9] Figure A6 in Appendix shows the districts whose daily average $PM_{2.5}$ levels are always in either Section 2 or 3 in our setup.

due to the new standard. Housing units whose daily average $PM_{2.5}$ levels remain in Section 2 are considered as "control" since their pollution labels remain "Normal" after the standard change.

Using a moving 30-day window[10], we first examine the effects of (re)labeling and perception change on housing costs with apartments in Section 2 or Section 3 in the DID-type model with continuous treatments as follows:

$$\begin{aligned} ln\left(HC\right)_{ict} = {} & \beta_0 + \beta_1 \text{Section3}_{i,t-30:t} \times \text{Post}_{i,t-30:t} + \beta_2 \text{Section3}_{i,t-30:t} + \beta_3 \text{Post}_{i,t-30:t} \\ & + \beta_4 \text{PM2.5}_{i,t-30:t} + \beta_5 \text{PM2.5}_{i,t-30:t} \times \text{Post}_{i,t-30:t} + \beta_6 \text{PM2.5}_{i,t-30:t} \times \text{Section3}_{i,t-30:t} \\ & + \beta_7 \text{PM2.5}_{i,t-30:t} \times \text{Section3}_{i,t-30:t} \times \text{Post}_{i,t-30:t} + Z_{it}\Gamma + Y_{ct}\Theta + \eta_c + \lambda_{\text{Year/Month}} + \grave{o}_{ict} \end{aligned} \quad (4)$$

where HC_{ict} is the housing cost, i.e., sales price or monthly rent, for apartment *i* in community *c* sold or paid on day *t*. There are 41,589 communities in South Korea, which is the smallest geographical unit with one or several residential buildings. $\text{Section3}_{i,t-30:t}$ represents the number of days in which the daily average $PM_{2.5}$ lies in Section 3 over the past 30 days at apartment *i*. $\text{PM2.5}_{i,t-30:t}$ represents the average $PM_{2.5}$ concentration over the past 30 days of transaction. To address the endogeneity concerns over air pollution, we use random variations in wind direction to instrument $PM_{2.5}$ (Deryugina et al., 2019; Anderson, 2020). We then compare and report the OLS and IV estimates. $\text{Post}_{i,t-30:t}$ equals one if the period from *t*-30 to *t* is after the standard change for apartment *i* transacted on day *t*. We drop the observations with the previous 30-day period across the policy shock.

Z_{it} represent the vectors of housing attributes at the apartment level, while Y_{ct} includes community attributes, other pollutants, and climatic amenities.[11] η_c is community fixed effect, which controls for time-invariant differences across the communities. $\lambda_{\text{Year/Month}}$ is the year-by-month fixed effect. Our estimates are also robust to multiple types of fixed effects, including Tier-1 city-by-year[12], provincial-level division-by-year, day-of-the-week, week-of-month, and day-of-month fixed effects, as shown in Appendix Tables A4 and A5. ϵ_{ict} is the error term clustered at the district level.

β_1 and β_7 are the key coefficients of interest that capture the relabeling effects and

[10] We also present later in Appendix Table A7 the results of heterogeneity analysis by lag length, considering all Sections for the lag length of 10, 30, 90, 180, and 360 days, respectively.

[11] We include age, area, floor, and rental type at the apartment level, community attributes, i.e.., number of cars, car density, population, municipal area, student faculty ratio at district level, other pollutants, i.e., SO_2, CO, O_3, NO_2, PM_{10}, and climatic attributes, i.e., precipitation, temperature, dew point, and wind speed.

[12] As shown in Appendix Figure A5, there are 8 tier-1 cities in South Korea, including Seoul, Busan, Daegu, Incheon, Gwangju, Daejeon, Ulsan, and Sejong.

perception change, respectively. Specifically, β_1 represents that, controlling for the actual $PM_{2.5}$ levels, how much an extra day of $PM_{2.5}$ labeling change from "Normal" to "Bad" over the past 30 days due to the more stringent $PM_{2.5}$ standard affects home values. Additionally, β_7 describes the wedge between pre- and post-shock revealed preferences towards actual $PM_{2.5}$ level. Controlling for the relabeling effect of $PM_{2.5}$, an extra day of $PM_{2.5}$ relabeling change from "Normal" to "Bad" over the past 30 days due to the new air quality standard increases, as expected, the MWTP for a one-unit-decrease in $PM_{2.5}$ level by β_7*100%. Furthermore, β_5 examines if homebuyers become more susceptible to $PM_{2.5}$ levels in general after the information shock at the national scale. If $\beta_5<0$ and $\beta_7<0$, individuals perceive more risk of air pollution after the shock and need to be compensated with a larger reduction in housing costs for a one-unit increase in $PM_{2.5}$.

3.2.2 The Full Specification with All Sections

The simplified specification in Equation (4) compares the relabeled "Normal to Bad" Section 3 with the always "Normal" Section 2 as an illustration of the intuition behind our identification. There could be one concern that apartments with days in Section 2 may also be affected by the information shock, being more (or less) preferred to the "Bad" and "Very Bad" (or "Good") sections. To alleviate this concern, we first show that apartments with more days in Section 2 or Section 3 are comparable ex-ante with parallel trends in prices. We further include the full sample with all sections to explore the impact of information shock on housing costs as below:

$$\begin{aligned} ln(HC)_{ict} = {} & \beta_0 + \beta_1 \mathrm{PM2.5}_{i,t-30:t} + \sum_{k=2}^{6} \beta_k \mathrm{Section}k_{i,t-30:t} + \sum_{k=2}^{6} \alpha_k \mathrm{Section}k_{i,t-30:t} \times \mathrm{Post}_{i,t-30:t} \\ & + \sum_{k=2}^{6} \delta_k \mathrm{PM2.5}_{i,t-30:t} \times \mathrm{Section}k_{i,t-30:t} \times \mathrm{Post}_{i,t-30:t} + \theta \mathrm{PM2.5}_{i,t-30:t} \times \mathrm{Post}_{i,t-30:t} \\ & + \sum_{k=2}^{6} \gamma_k \mathrm{PM2.5}_{i,t-30:t} \times \mathrm{Section}k_{i,t-30:t} + Z_{it}\Gamma + Y_{ct}\Theta + \eta_c + \lambda_{\mathrm{Year/Month}} + \grave{o}_{ict} \end{aligned} \quad (5)$$

where $\alpha_2 \sim \alpha_6$ describe the relabeling change, among which α_3 and α_5 represent the effect from "Normal" to "Bad" and "Bad" to "Very Bad". $\delta_2 \sim \delta_6$ measure changes in MWTP referred to as perception change, among which δ_3 and δ_5 represent how much an extra day of $PM_{2.5}$ relabeling change from "Normal" to "Bad" and "Bad" to "Very Bad" over the past 30 days due to the new air quality standard increases the MWTP for a one-unit decrease in $PM_{2.5}$ on housing costs, respectively. The rest of the specification is the same as the Equation (4). Equation (5) differs from Equation (4) by comparing an additional day in all other sections with an additional day in the always "Good" Section 1. We find that the coefficients of key variables of interest in both specifications are quantitatively similar, alleviating potential

concerns over the control group and sorting, which is also unlikely in the short run. We use the full specification as the baseline to report the main results.

3.2.3 Dynamic Effects

Our identification strategy assumes no *ex-ante* differences between the comparison groups. The long study period allows us to test it and check the dynamic effects of relabeling after the information shock. Specifically, we explore the dynamic relabeling effects and perception change over pollution distribution with an event-study approach for all sections:

$$\begin{aligned} ln(HC)_{ict} = & \sum_{k=2}^{6} \sum_{j=\underline{T},\, j\neq -1}^{\bar{T}} \alpha_{kj} 1\left(j*30+T_0 \le t \le (j+1)*30+T_0\right) \times \text{Section}k_{i,t-30:t} \\ & + \sum_{k=2}^{6} \sum_{j=\underline{T},\, j\neq -1}^{\bar{T}} \lambda_{kj} 1\left(j*30+T_0 \le t \le (j+1)*30+T_0\right) \times \text{PM2.5}_{i,t-30:t} \times \text{Section}k_{i,t-30:t} \\ & + \sum_{j=\underline{T},\, j\neq -1}^{\bar{T}} \theta_j 1\left(j*30+T_0 \le t \le (j+1)*30+T_0\right) \times \text{PM2.5}_{i,t-30:t} \\ & + \sum_{k=2}^{6} \beta_k \text{PM2.5}_{i,t-30:t} \times \text{Section}k_{i,t-30:t} + \delta \text{PM2.5}_{i,t-30:t} + \sum_{k=2}^{6} \rho_k \text{Section}k_{i,t-30:t} \\ & + Z_{it}\Gamma + Y_{ct}\Theta + \eta_c + \lambda_{\text{Year/Month}} + \grave{o}_{ict} \end{aligned} \tag{6}$$

where α_{kj} and λ_{kj} denote the dynamic relabeling effects and perception change in 30-day time windows j over $[\underline{T}, \bar{T}]$ for section k relative to section 1, respectively. We take j = -1 as the reference period, which is the 30-day time window before the initial hit by the policy shock. $\text{Section}k_{i,t-30:t}$ represents the number of days in which the daily average $PM_{2.5}$ lies in Section k over the past 30 days near apartment i. T_0 denotes the date in which the air quality standard adjustment occurs. $1(j*30+T_0 \le t \le (j+1)*30+T_0)$ is an indicator function that equals one if the transaction on day t occurs from j*30 to (j+1)*30 days after (when j is a positive integer or zero) or before (when j is a negative integer) the standard adjustment.[13] The estimates of α_j and λ_j for the period $[\underline{T}, -2]$ are equal to zero, this would provide evidence in support of the parallel trend assumption.

4. Empirical Results on Housing Costs

4.1 Section 2 *vs* Section 3

Following the Equation (4), Table 2 presents the relabeling effects and perception change of $PM_{2.5}$ on housing sales prices, considering apartments only in Section 2 and Section 3. Columns

[13] For instance, when j=1, $1(30+T_0 \le t \le 60+T_0) = 1$ if the transaction on the day t occurs from 30 to 60 days after the air quality standard adjustment.

(1) to (6) in Panel A report the OLS estimates, with more flexible controls from the left to the right. First, the OLS estimates are very sensitive to different controls. Second, the estimated coefficients of $PM_{2.5}$, $PM_{2.5}$ × Post, and $PM_{2.5}$ × Section 3 × Post in most columns of Panel A are not significantly different from zero. Such relationships shall be interpreted with caution since there can be other confounding factors influencing the level of $PM_{2.5}$ and home values simultaneously, making air pollution endogenous.

We then focus on the IV estimates in Columns (7) to (12) in Panel B of Table 2, with the first-stage results reported in Appendix Table A2. The IV estimates are very robust to different fixed effects, and the coefficients of the terms with $PM_{2.5}$ are negative and statistically significant at 1% level. Our preferred specification with more flexible controls in Column (12) shows that the estimated coefficient of Section 3 × Post (β_1 in Equation 4) is around -0.0032. The result indicates that an additional day of $PM_{2.5}$ labeling change from "Normal" to "Bad" over the past 30 days lowers home values by approximately 0.32% (equivalent to $1,015). It suggests that people perceive higher risks of the same level of $PM_{2.5}$ after it is relabeled from "Normal" to "Bad", which is captured by the housing market with a shift in HPS. Moreover, the coefficient of Section 3 in Column (12) is significantly indifferent from zero, consistent with the fact that housing units in Section 2 and Section 3 had the same label of "Normal" under the old standard. The relabeling effect is only significant after the information shock.

In addition to the direct relabeling effect, relabeling also increases the MWTP for a 1 $\mu g/m^3$ reduction in $PM_{2.5}$ exposure within the relabeled category of Section 3. As shown by the estimates of $PM_{2.5}$ × Section 3 × Post (β_7 in Equation 4) in Column (12) in Table 2, an extra day of $PM_{2.5}$ relabeling change from "Normal" to "Bad" over the past 30 days due to the new air quality standard increases the MWTP for a one-unit-decrease in $PM_{2.5}$ level by 0.002% (equivalent to $7). We frame it as the indirect relabeling effect that causes perception changes revealing preferences and MWTP. Note that this effect is also only significant after the policy shock, with the coefficient of $PM_{2.5}$ × Section 3 being insignificant. Furthermore, the estimates of $PM_{2.5}$ × Post (β_5 in Equation 4) are also significantly negative, suggesting that homebuyers become more susceptible to $PM_{2.5}$ levels in general after the information shock.

[Table 2. Pollution and Housing Price: Section 2 *vs* 3]

On top of sales prices, we further examine the housing rental costs and report the OLS and IV estimates in Appendix Table A3. The rental responses are similar to the sales responses in

Table 2. Specifically, an extra day of $PM_{2.5}$ labeling change from "Normal" to "Bad" over the past 30 days lowers rental prices by around 0.27% ($30.5) per year and increases the MWTP for clean air measured by rental prices is around 0.0017% ($0.2). The percentage changes are smaller than those of the sales prices, but they are close in size. One potential interpretation of the slight differences is that air pollution is temporary to tenants, who then do not fully internalize the price of pollution into the rent. Tenants may also be more flexible than homeowners in relocation. In addition, declining housing values are bad for homeowners, but are good for renters, which is also consistent with the differential impacts.

As a robustness check, we also consider various types of fixed effects that are more flexible, such as tier-1 urban city by year, provincial-level division by year, day-of-the-week, week-of-month, and day-of-month fixed effects, to control for unobservable factors at different levels that may influence the home sales prices and rents. The main findings remain unchanged after including these fixed effects, as shown in Appendix Tables A4 and A5. Therefore, we will focus on the baseline model for the rest of the analyses.

4.2 Full Specification with All Sections

Following the Equation (5), we present the relabeling effects and perception changes of $PM_{2.5}$ on both home sales prices and rental costs, considering all sections using the full sample.

In Table 3, we first show pairwise comparisons between two adjacent sections in Columns (1) to (2). For example, Column (2) repeats the IV estimation from Equation (5), as reported in Table 2. Columns (1) compares the relabeled section, "Bad to Very Bad" Section 5, with the always "Bad" Section 4. Several key findings emerge from these results. First, the coefficient of Section 5 × Post in Column (1) is around -0.003, indicating that an additional day of $PM_{2.5}$ being relabeled from "Bad" to "Very Bad" over the past 30 days lowers home values by 0.303% ($961). Second, the coefficient of Section 5 is significantly negative, reflecting the labeling differences between Section 5 and Section 4 under the old AQS. Consistently, the coefficient on Section 5 is statistically insignificant in Column (1), which is consistent with the same label between Section 4 and Section 5 under the old AQS. The relabeling effect becomes significant only after the information shock. Third, an extra day of $PM_{2.5}$ relabeled from "Bad" to "Very Bad" over the past 30 days also increases the MWTP for a 1 μg/m3 reduction in $PM_{2.5}$ exposure by 0.0019% ($6), and this effect is significant only after the policy shock, with the coefficient of PM2.5 × Section 5 being insignificant. Finally, the significantly negative estimate of $PM_{2.5}$ × Post in Column (1) suggests that, after the information shock, homebuyers become increasingly responsive to $PM_{2.5}$ levels.

[Table 3. Pollution and Housing Costs: All Sections]

The results from our preferred full specification are shown in Column (4) of Table 3. We focus primarily on the coefficients of Section k and Section k × Post, which capture the (re)labeling effects for apartments in Sections 2 through 6, relative to Section 1. The estimates are displayed in the first 10 rows of Column (4). First, the coefficients of Sections 2 to 6 are all statistically significant and negative, with the absolute values increasing as higher pollution levels rise from Section 2 to Section 6. This result confirms the labeling effect under the old AQS, which lowers housing prices. The price decline is more pronounced as $PM_{2.5}$ is labeled worse, compared to the always "Good" section. This effect holds across the entire pollution distribution, even after accounting for the direct impacts of $PM_{2.5}$.

Second, the coefficients of Section k × Post are significant and negative only for Section 3 and Section 5, which correspond to the relabeled categories. The coefficients of Section 2 × Post, Section 4 × Post, and Section 6 × Post are all statistically insignificant. In fact, the sizes of the estimates are much smaller than the standard errors, suggesting a precisely estimated null effect. This is consistent with the fact that Sections 2, 4 and 6 experienced no label changes. Particularly, the magnitudes of the relabeling effects in Column (4) are similar to those in Columns (1) to (2). Compared with the always "Good" category, an additional day of $PM_{2.5}$ labeling change from "Normal" to "Bad", and from "Bad" to "Very Bad" over the past 30 days lowers housing values by approximately 0.32% ($1,015) and 0.23% ($717), respectively.

We also visualize the (re)labeling effect in Figure 4. In Panel (a), the blue and yellow bars show the labeling effect under the old standard for apartments in Sections 2 to 6, compared to housing units in Section 1. Accounting for the confidence intervals, the labeling effect is significantly negative for apartments in all sections. Appendix Figure A7 provides a conceptual illustration of this "labeling effect", represented by the dashed blue line. Note that the dashed blue line is a step function that shifts downward as air quality worsens, consistent with our empirical findings. Additionally, the significant relabeling effects are evident from the noticeable increase in the length of blue and orange bars for Sections 3 and 5 under the new standard, as shown in Panel (a) in Figure 4. This is further illustrated by the downward shift from the dashed blue line to the dashed yellow line in Appendix Figure A7. Overall, these results imply that relabeling the air quality under the new standard contributes to the decline of housing prices.

[Figure 4. Relabeling Effects and Perception Change of All Sections by Information Shock]

Next, we examine the impact of policy shock on perception changes. We focus on the coefficients of PM2.5 × Section *k* and PM2.5 × Section *k* × Post in Column (4) of Table 3, which capture changes in perception and MWTP. There are several key findings. First, we find an increase in MWTP for clean air not only in the relabeled categories (Sections 3 and 5, relative to Section 1) but also in non-relabeled sections (Sections 2, 4 and 6). Additionally, the estimate of PM2.5 × Post is significantly negative. These results suggest an overall higher risk perception under the new AQS.

Second, regarding economic significance, the increases in MWTP for a 1 $\mu g/m^3$ reduction in $PM_{2.5}$ due to an additional day of relabeling over the past 30 days from "Normal" to "Bad" (Section 3) or from "Bad" to "Very Bad" (Section 5) are 0.0023% ($7.3) or 0.0036% ($11.4) for home values, respectively. These values are slightly higher than those in Columns (1) and (2), where Sections 3 and 5 are compared to their adjacent sections.

Third, in most cases, the absolute values of the coefficients for PM2.5 × Section k × Post increase with *k*, suggesting that the perception changes due to the information shock are associated with the pollution label of apartments. Specifically, when an apartment is labeled with worse air quality, the increase in MWTP for clean air is greater.

Overall, the relabeling effect is over 100 times the size of the perception effect on the margin, revealing the salience of labeling and relabeling. Also, note that perception changes arise only after the policy shock, indicating that they are casually induced by the new standard. Panel (b) of Figure 4 visually represents these perception changes, showing a remarkable increase in the lengths of bars for all sections, relative to Section 1, after the policy shock.

We further report the results on housing rental prices in Columns (5) – (8) of Table 3. Compared with the always "Good" section, an additional day of $PM_{2.5}$ labeling change from "Normal" to "Bad" or from "Bad" to "Very Bad" over the past 30 days lowers rents by 0.22% ($24.8) or 0.17% ($19.2), per year, respectively. In categories with no relabeling, such as Sections 2, 4, and 6, we find insignificant differences in rents compared with the always "Good" Section 1 after the adjustment of AQS. As for the rental market, the MWTP for clean air due to one more day of the "Normal", "Normal to Bad", "Bad", "Bad to Very Bad", and "Very Bad" labels over the past 30 days, compared to the "Good" section, increases by 0.0008% ($0.09), 0.0026% ($0.29), 0.0024% ($0.27), 0.0029% ($0.33), 0.0023% ($0.26) for rental costs per year,

respectively. Again, the sales responses are slightly larger than the rental responses in general.

To compare the housing cost elasticity of air pollution with other studies, we report the estimated elasticities across all thresholds in Appendix Table A6. As shown in Columns (3) and (6), the sales price elasticity with respect to $PM_{2.5}$ is around -0.35 before the information shock and drops by 0.07 to -0.42 afterwards. The relabeling effects on the elasticities in the relabeled Section 3 and Section 5 are around -0.0002 and -0.0003, respectively, while the perception change effects in non-relabeled sections range from -0.0001 to -0.0004. The rent elasticity with respect to $PM_{2.5}$ is around -0.25 *ex-ante* and goes down by 0.03 to -0.25 *ex-post*, with relabeling effects and perception change effects between -0.0001 to -0.0003. These elasticities increase further with air pollution levels after the policy shock. The overall price elasticity is close to that in the United States estimated by Chay and Greenstone (2005).

4.3 Dynamics of Relabeling Effect and Perception Effect

Following the Equation (6), we explore the dynamics of relabeling effects and perception change using an event-study approach across all sections. The dynamic effects can also help to examine the parallel trend assumption. We are interested in the estimates of α_{kj} and λ_{kj}, representing the dynamic relabeling effects and perception changes within 30-day windows j over $[\underline{T}, \bar{T}]$ for each section k, relative to Section 1. We take j = -1 as the base category, which is the 30-day period before the initial hit by the policy shock. We consider j over [-12, 21], in other words, real estate transactions spanning from 12 months before the policy shock to 21 months after the policy shock. Observations extending beyond 12 months prior to the policy shock are grouped into the period at the left endpoint. If the estimates of α_{kj} and λ_{kj} for the period [-12, -2] are equal to zero, it would support the parallel trend assumption.

[Figure 5. Dynamics of Relabeling Effects and Perception Changes: All Sections]

The results are shown in Figure 5. Panels (a1) and (b1) show results of the relabeling effect for housing sales prices and rents, and Panels (a2) and (b2) show results regarding the overall perception changes. In sum, these results are consistent with our findings in Tables 2 and 3, confirming the parallel trend assumption across all four panels. Specifically, for apartments in other sections compared to those in Section 1, there are no significant differences between estimates of α_j and λ_j for j = -1 (the baseline) and j from -12 to -2 (the 12 months preceding the policy shock), supporting parallel trends. However, we see an immediate price drop right after the policy shock. For the relabeling effect, only apartments in relabeled Section 3 and

Section 5 witness a significant decrease in both housing and rental prices, with dynamic relabeling effects persisting for up to 21 months. For non-relabeled Sections 2, 4 and 6, no significant dynamic relabeling effects are observed.

Regarding perception changes, consistent with findings in Table 3, apartments in all sections are affected by the perception changes, only after the policy shock. Moreover, the magnitude of this effect grows as air quality worsens. Overall, the event-study estimates reveal parallel pre-trends before the information shock and immediate price declines ex-post, which persist up to 21 months till the end of the study period, validating the causal interpretation of the main results in Tables 2 and 3.

4.4 Heterogeneity

We explore potential heterogeneity of the relabeling effect across geography and floor level for both housing and rental markets, as well as types of rental contracts. As shown in Table 4, urban areas exhibit more pronounced relabeling effects and perception changes than rural areas, with apartments on lower floors being more impacted by the policy shock than those on higher floors. In general, the air quality in urban areas is poorer than that in rural areas, and residents living on lower floors and in cities are more exposed to air pollution, making them more sensitive to changes in AQS. For these residents, the new air quality standard may induce a larger shift in their risk perception and preference. Such heterogeneities provide corroborating evidence on the relabeling effect in our main analysis. Lastly, we also investigate the types of rental contracts and find no significant difference between apartments in the regular market and the Jeonse market.

[Table 4. Heterogeneity in Housing Sales and Rental Markets]

Lastly, we conduct a battery of robustness checks of our findings, including different controls, sampling methods, and matching methods. The results are remarkably consistent, as shown in the Appendix. Importantly, the lag length of policy shock could also influence the magnitude of relabeling effects and perception changes on housing costs. Following the Equation (6), we explore the estimated effects with the lag lengths of 10, 30, 90, 180, and 360 days, respectively. To ensure the comparability across lag lengths, all Section $k_{i,t-30:t}$ for 30-day period are now transferred to Section $k_{i,t-l:t}$, the count of Sections over the period *t-l*: *t*, where *l* denotes the lag length. Results in Appendix Table A7 show that all estimates of interest remain qualitatively similar to those in Table 3. However, as lag length increases, the impact

of additional relabeling days diminishes, aligning with the fact that the effect of a single day becomes diluted over a longer period.

5. Relabeling and Pollution

In addition to the direct and indirect effects of information relabeling, we further assess the potential benefits by examining whether air quality improves after the information shock. Given the same geocoded address for all apartments in a residential community, we examine the relabeling effects on subsequent pollution levels or emissions at the community-by-month level, if any, using the empirical strategy below:

$$ln\left(\text{Pollution}\right)_{ct} = \sum_{k=2}^{6} \beta_{kj} \text{Post}_{t-j} \times \text{Section}k_{c,t-j} + \sum_{k=2}^{6} \lambda_k \text{Section}k_{c,t-j} + X_{ct}\Theta + \eta_c + \lambda_{\text{Year/Month}} + \grave{o}_{ict}, \quad (7)$$

where Pollution_{ct} is the monthly average of pollution level ($PM_{2.5}$, PM_{10}, SO_2, CO, NO_2, and O_3) at the community *c* in month/year *t*. $\text{Section}k_{c,t-j}$ represents the number of days in which the daily average $PM_{2.5}$ lies in Section *k* at the community *c* in month/year *t-j*.[14] *j* represents the number of months before the month *t*. By default, we set it equal to 6 to examine 6-month lagged effects. Post_{t-j} equals one if the air quality standard adjustment occurs *j* months before the month/year *t*. β_{kj} denote the relabeling effects on the real pollution level *j* months later. $\text{Post}_{t-j} \times \text{Section}k_{c,t-j}$ and $\text{Section}k_{c,t-j}$ are instrumented by count of days of daily average wind directions at month-by-community level. To explore potential sensitivity in the results to the length of time window, we also examine the pollution effect dynamics of 1, 3, and 12 months after the policy shock, respectively.

[Table 5. Effects of (Re)labeling on 6-Month Lagged Pollution]

As shown in Table 5, we find significant declines in $PM_{2.5}$ levels 6 months after the information shock. Compared with the "Normal" or "Bad" section, $PM_{2.5}$ levels have dropped by around 0.042% or 0.056%, respectively, on average after 6 months due to an additional day in the relabeled group in a month, i.e., Section 3 for "Normal to Bad", or Section 5 for "Bad to Very Bad", whereas there are no significant changes in $PM_{2.5}$ levels in other sections. The results suggest that relabeling can lead to a negative and lagged impact on the actual $PM_{2.5}$

[14] The daily average $PM_{2.5}$ at the district level is measured by the simple average of $PM_{2.5}$ measures recorded by all monitors in a district.

level in the long run. We then conduct a back-of-the-envelope welfare analysis based on the average days in each section in a month, the estimated drop in $PM_{2.5}$, its marginal impact on housing sales price/rent, and number of housing units.[15] Overall, the total welfare gains due to pollution reduction from the relabeling effects are $892 million in total sales prices and $23 million in total annual rents. Specifically, given the average 1.2 days of Section 5 and 9.7 days of Section 3 in a month after the policy shock, we total the effects of (re)labelling on pollution reduction and multiply by the average $PM_{2.5}$ of 21.3 $\mu g/m^3$ to estimate the effect of relabeling to be 0.1 $\mu g/m^3$ reduction in $PM_{2.5}$ ([0.056%*1.2+0.042%*9.7]*21.3). For home sales market, we then multiply the drop in $PM_{2.5}$ by post-shock marginal impact on sales price, average sales price of an apartment, and the total number of housing units in South Korea, which yields to a total value of $892 million (0.1*[0.00208+0.000266)]*$317,114.2*11,989,000). For the housing rental market, we multiply the drop in $PM_{2.5}$ by post-shock marginal impact of relabeling on rent, annual rent, and the housing units for rental, which yields to a total value of $23 million (0.1*[0.00233+0.000237]*941*12*8,040,000).

We observe similar declines in PM_{10} levels, while other pollutants, including NO_2, CO, SO_2, and O_3, remain unchanged. The results are consistent with the fact that the primary sources of pollution in residential areas in South Korea include transportation and coal-fired power plants. Overall, the results in Table 5 reveal environmental benefits in the long run due to the regulatory effects of the new standards. Figure 6 summarizes the real pollution effects dynamics, taking 1, 3, 6, and 12 months as lag lengths, respectively. Similarly, we discover significant and negative relabeling effects only in $PM_{2.5}$ and PM_{10} levels more than 6 months later, not in them with shorter lag lengths or other pollutants with all lag lengths. Specifically, due to an additional day in a month for "Normal to Bad" and "Bad to Very Bad" categories, $PM_{2.5}$ levels have dropped by around 0.012% and 0.006% (0.022% and 0.016%), respectively, on average, after 1(3) month(s). After 12 months, the associated relabeling effects become 0.044% and 0.064%, respectively, close to the 6-month lagged effects.

[Figure 6. Lagged Relabeling Effects on Pollution Levels]

To explore mechanisms by which relabeling affects ambient pollution, we further collect additional data on two major sources of pollution emissions in South Korea levels:

[15] The statistics of housing stock and housing occupancy types are based on the 2020 Population and Housing Census, which is provided by Statistics of Bureau in South Korea. See: https://korea.kr/briefing/

transportation and power plants. Emission activities from transportation are proxied by the total number of vehicles passing through roads in each district. The Traffic Monitoring System (TMS) provides real-time traffic volume data across South Korea, collected through loop detectors, radar sensors, and automatic number plate recognition (ANPR) systems.[16] By integrating TMS data with search activity related to pollution, we investigate whether fluctuations in traffic volume align with changes in public concern about air pollution. Emission activities from power plants are measured by the total electricity generated at the province level. The Korea Power Exchange (KPX) Daily Fossil Fuel Power Generation Data records electricity generation from fossil-fuel power plants, categorized by region, fuel type, and daily power output (MWh).[17] The specification is as follows:

$$\ln(\text{Traffic or Power})_{dt} = \beta + \sum_{k=2}^{6} \beta_k \text{Section}k_{dt} + \sum_{k=2}^{6} \alpha_k \text{Section}k_{dt} \times \text{Post}_t + Z_{dt}\Gamma + \eta_d + \lambda_{\text{Year/Month}} + \varphi_{\text{Province/Year}} + \grave{o}_{dt}, \quad (8)$$

where $\ln(\text{Traffic or Power})_{dt}$ denotes the total number of cars that passed roads in district d or total electricity generated by power plants in each province in month/year t. Section k_{dt} represents the number of days in which the daily average $PM_{2.5}$ lies in Section k at the district d in month/year t. The vector of Z_{dt} includes local variables, such as total number of vehicles, unemployment rate, population, and climatic attributes.

Table 6 presents the empirical results on the mechanism analysis of (re)labeling effects on pollution. We find that both traffic volume and electricity generation are significantly lowered in the relabeled sections only after the information shock. In comparison, there is no significant impact in the non-relabeled sections, consistent with the previous findings showing that housing and rental prices do not change when there is no change in pollution labels or levels. The results suggest that power plant operation and transportation both play a role in pollution reduction in response to (re)labeling from the information shock. The responses may be driven by governmental policies or public pressure, which only applies to areas with more relabeling. Appendix Figure A8 shows the areas with pollution decline and increase in one year before and after the information shock. The significant declines in air pollution levels occur in the urban cities, Seoul and Busan, and some rural areas. In addition, we find the most relabeled days of Section 3 in some rural areas next to urban cities, while relabeled days of Section 5 happen the

[16] This dataset comprises information on vehicle flow, speed, and congestion levels, facilitating an analysis of temporal variations in road traffic patterns. See: https://www.road.re.kr/itms/

[17] This dataset excludes direct transactions with Korea Electric Power Corporation (KEPCO) and is based on transmission-end generation. See: https://www.data.go.kr/data/15069345/fileData.do?recommendDataYn=Y

most frequently in urban cities.

[Table 6. Mechanism of (Re)labeling Effects on Pollution]

6. Conclusion

This paper exploits a unique information shock to examine the effect of (re)labeling air pollution levels on the housing market in South Korea, a country with both high pollution and high income. The setting has a few novel and salient features: an exogenous and pure information shock changing some of the $PM_{2.5}$ labels only, and high-frequency housing sales and rental data. We bring information (re)labeling to hedonic modeling and use quasi-experimental estimation to show that (re)labeling pollution levels both shifts and rotates the Hedonic Price Schedule locally and globally. Specifically, relabeling pollution significantly lowers housing sales and rental prices in the relabeled sections. In addition, the information shock also increases risk perception and MWTP for clean air in each section. The effects are both immediate and persistent, with slightly larger sizes for the sales market than the rental market. The effects are also larger on lower floors in urban areas, consistent with the perception of pollution risks. Lastly, relabeling can further improve air quality in the long run through emission reduction, which brings significant welfare gains in the housing market.

Our findings shed light on information design and behaviors, as well as environmental evaluation and policies. Incorporating the relabeling effect has important welfare implications for hedonic pricing models and cost-benefit analysis. The losses in housing values may not be marginal compared with the benefits from pollution reduction in the longer run. The results provide useful insights into air quality standards and environmental information provision. More research can be done on sorting to fully capture the welfare impacts of relabeling if wage and migration data are available, which is beyond the scope of this paper.

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Figures and Tables

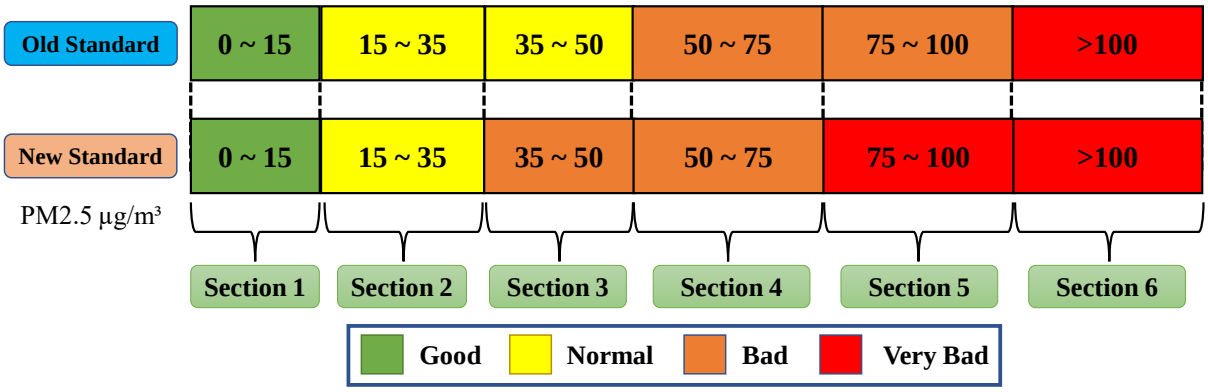
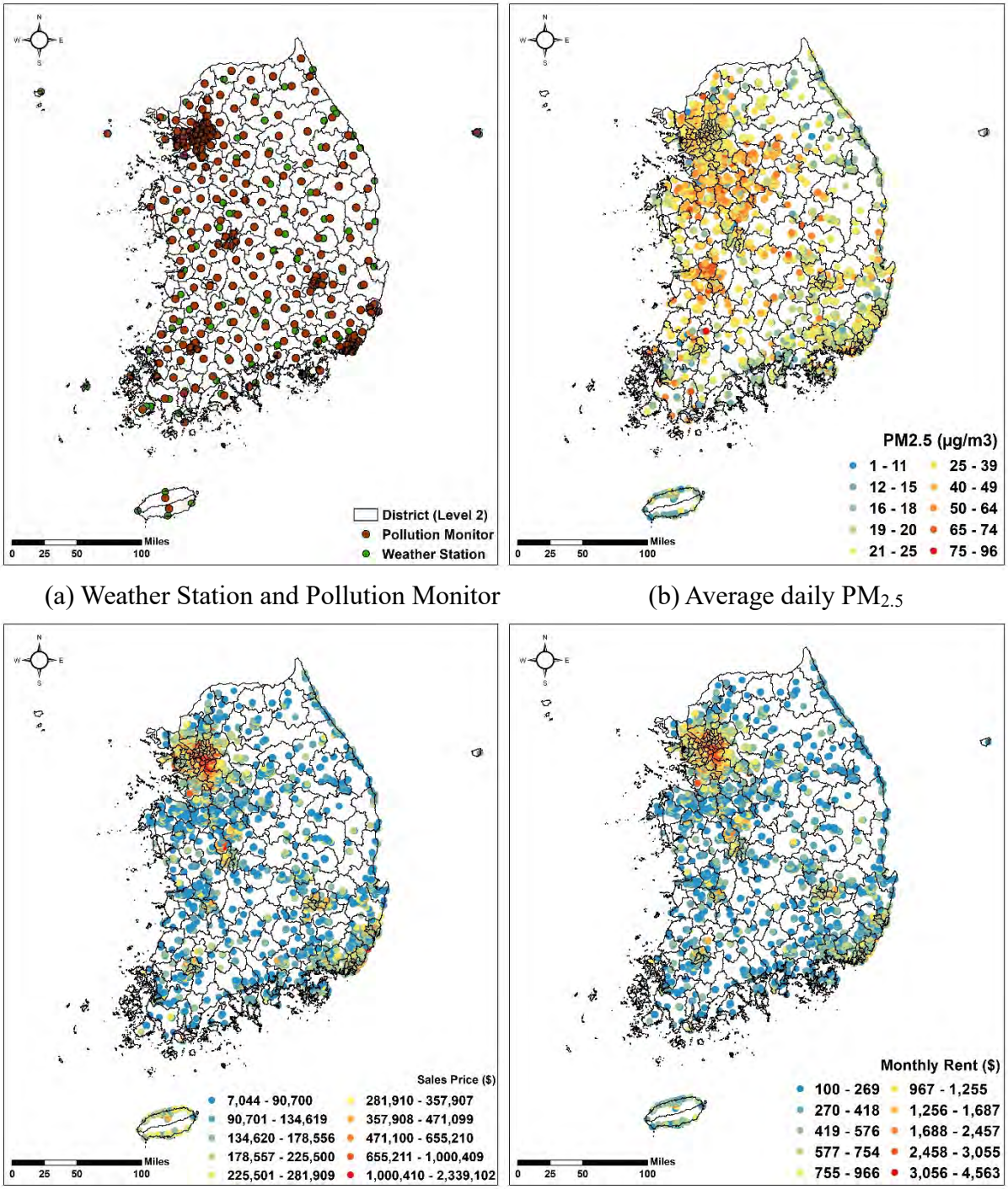


Figure 1. Old vs New AQS of $PM_{2.5}$ in South Korea

Notes: This figure plots the old and new Air Quality Standards (AQS) of $PM_{2.5}$ (particulate matter with a diameter smaller than 2.5 micrometers) in South Korea. The new AQS took effect on March 27, 2018, after which daily $PM_{2.5}$ levels between 35-50 µg/m^3 and between 75-100 µg/m^3 are relabeled from "Normal" to "Bad" and from "Bad" to "Very Bad", respectively.



(a) Weather Station and Pollution Monitor (b) Average daily $PM_{2.5}$

(c) Average Sales Price (d) Average Monthly Rent

Figure 2. Geographical Variations in Average $PM_{2.5}$ and Housing Costs

Notes: This figure plots (a) the distribution of weather station and pollution monitor at the district level, (b) the average daily $PM_{2.5}$ levels, (c) the average housing sales price, and (d) the average monthly rent at the community level in South Korea. The sample period spans from January 2015 to December 2019.

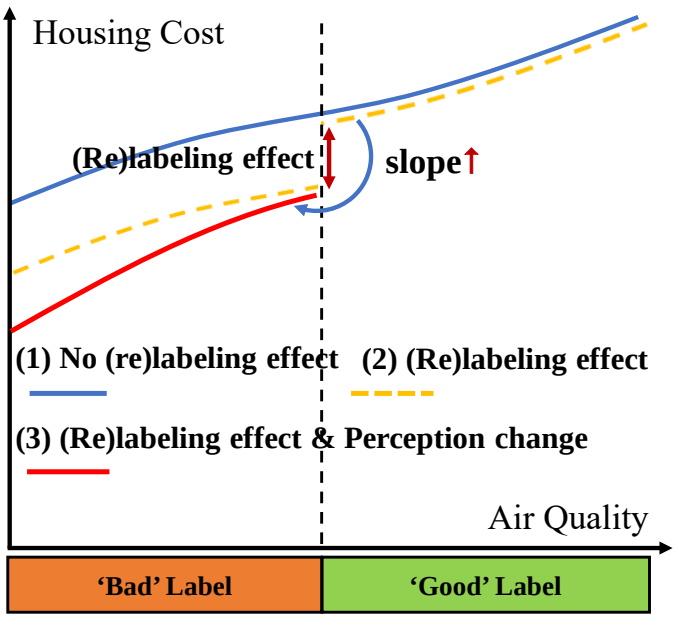
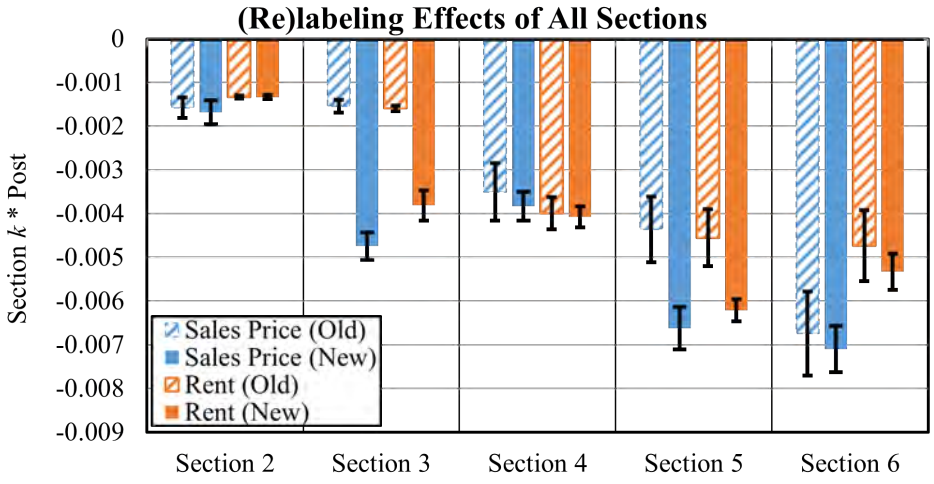
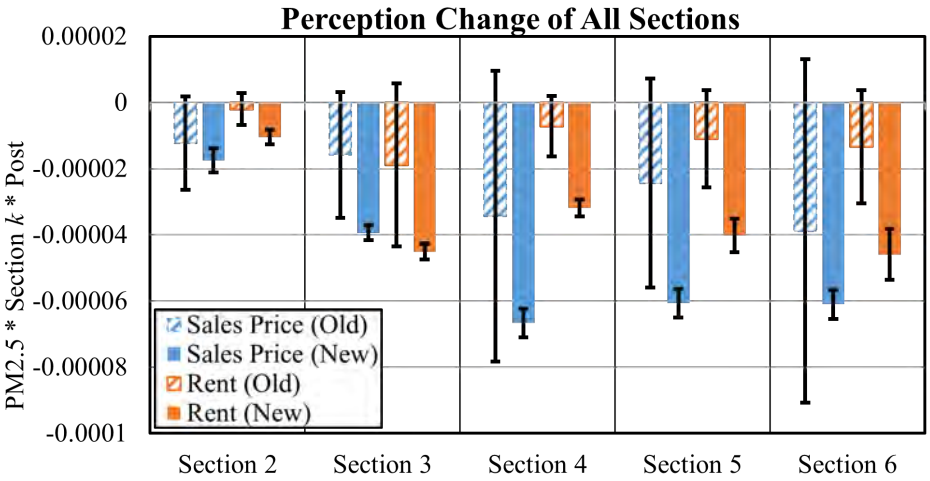


Figure 3. A Conceptual Representation of (Re)Labeling Effect and Perception Effect

Notes: This figure illustrates (re)labeling effects and perception change on housing costs, depending on air quality and label. The blue line describes how housing costs change with air quality and associated labels in the absence of (re)labeling effect. The yellow dashed line depicts the (re)labeling effect. The red line shows the composition of (re)labeling effect and the perception change, which steepens the slope of the original yellow line.



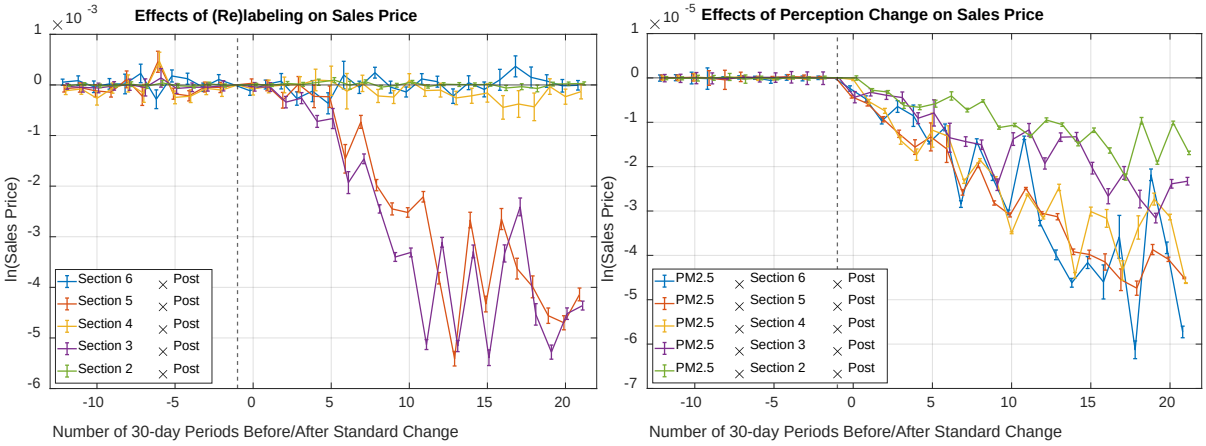
Panel (a): (Re)labeling Effects of All Sections: Section k × Post



Panel (b): Perception Change of All Sections: $PM_{2.5}$ × Section k × Post

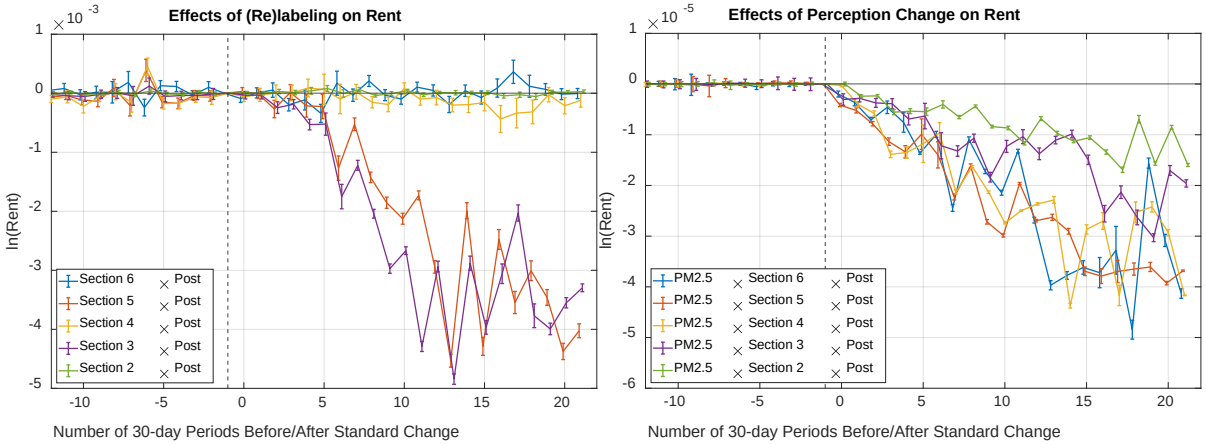
Figure 4. Relabeling Effects and Perception Change of All Sections by Information Shock

Notes: This figure shows the relabeling effects and perception change of all sections in panels (a) and (b). The estimated coefficients are from columns (4) and (8) in Table 3. The confidence intervals of coefficients under the new AQS are calculated as linear combinations of coefficients. The dashed blue, solid blue, dashed orange, and solid orange bars represent the effects on housing sales price under the old AQS, housing sales price under the new AQS, rent under the old AQS and rent under the new AQS, respectively.



(a1) Section k × Post (a2) $PM_{2.5}$ × Section k × Post

Panel (a) Dynamic Coefficients for Sales Price: All Sections

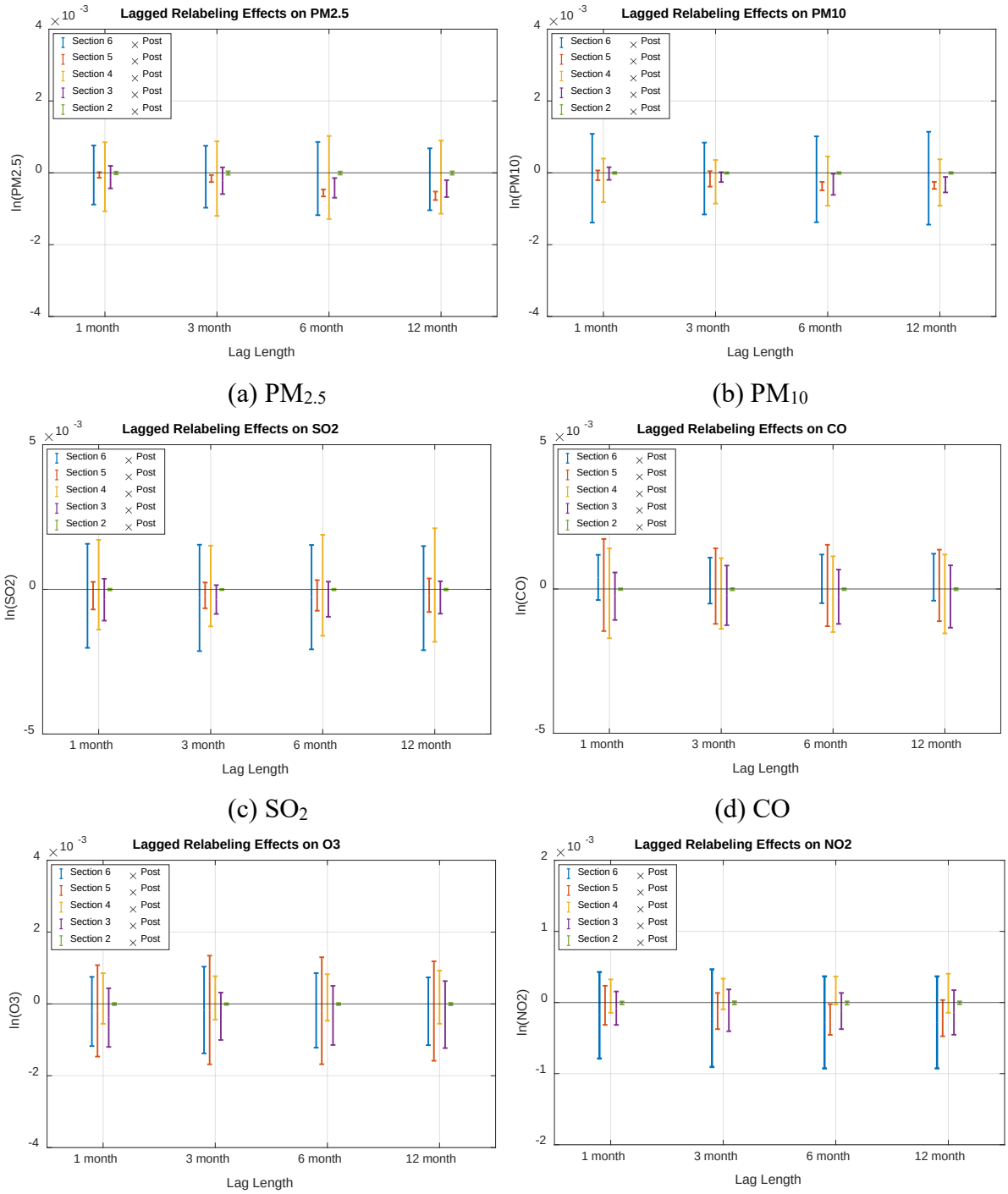


(b1) Section k × Post (b2) $PM_{2.5}$ × Section k × Post

Panel (b) Dynamic Coefficients for Rents: All Sections

Figure 5. Dynamics of Relabeling Effects and Perception Changes: All Sections

Notes: This figure plots the results of dynamic labeling effects and perception changes with an event study approach following the model specification (6). Panels (a1) and (b1) show results of the relabeling effect on housing sales prices and rents. Panels (a2) and (b2) show results regarding the overall perception changes. 12 months before and 21 months after the policy shock are considered. We group all observations more than 12 periods earlier than the policy shock into the period at the left endpoint. The reference period is the 30-day period before the initial hit by the policy shock.



(a) $PM_{2.5}$ (b) PM_{10}

(c) SO_2 (d) CO

(e) O_3 (f) NO_2

Figure 6. Lagged Relabeling Effects on Pollution Levels

Notes: This figure plots the results of dynamic relabeling effects of the information shock on 1, 3, 6, and 12-month lagged pollution and emission levels at the community-by-month level. All regressions are estimated using wind directions as instruments following the model specification (7). Control variables include district and climate attributes, as well as community and year-by-month fixed effects. The robust standard errors are clustered at the district level. *** $p<0.01$, ** $p<0.05$, * $p<0.1$

Table 1. Summary Statistics

Variable	*N*	Mean	SD	Min	Max
(A) Housing sales at transaction level					
Price ($)	4,370,904	317,114.21	292,046.62	4,000	1.20e+7
Area (square meter)	4,370,904	75.2251	26.3534	9.26	424.32
Floor	4,370,904	9.0261	6.2856	1	83
Age of apt sold (year)	4,370,904	16.8219	9.3558	0	60
(B) Rental contracts at transaction level					
Monthly rent ($)	4,423,468	941.4223	706.9158	100	158,000
Age of apt rented (year)	4,423,468	13.6217	10.4495	0	60
Area (square meter)	4,423,468	70.0456	25.8957	7.5701	359.91
Floor	4,423,468	9.3427	6.5208	1	83
Rental type (Regular vs Jeonse)[1]	4,423,468	0.3610	0.4796	0	1
(C) Air pollution at daily-monitor level					
$PM_{2.5}$ ($\mu g/m^3$)	856,812	21.5357	14.4486	.02	282
SO2 (PPM: parts per million)	1,029,504	0.0037	0.0021	0.0020	0.1226
CO (PPM: parts per million)	1,027,070	0.4635	0.1943	0.0030	3.8708
O3 (PPM: parts per million)	1,032,559	0.0289	0.0137	0.0010	0.1302
NO2 (PPM: parts per million)	1,037,487	0.0194	0.0130	0.0010	0.1692
PM_{10} ($\mu g/m^3$)	1,024,553	40.8599	27.7153	0.0120	926.8750
(D) Weather at day-station level					
Wind direction (Degree)[2]	314,858	206.0361	106.7554	0	360
Wind speed (meter/second)	314,858	2.5058	1.6507	0	28.8
Precipitation (mm)	314,858	3.9029	22.1461	0	1,600
Temperature (Degree Celsius)	314,858	13.3233	9.7876	-44.3	51.8751
Dew point (Degree Celsius)	314,858	7.1524	11.4137	-44.4	29.3029
(E) Attributes at month-district level					
Number of cars	18,901	101,033.8	97,503.46	0	619,854
Car density	18,901	0.4711	0.1488	0	2.7626
Population	18,901	271,215.40	373,702.11	0	2,405,256
Municipal area (square meter)	18,901	4.39e+8	3.82e+8	2,825,782	1.82e+9
Student faculty ratio	18,901	11.2921	2.9240	3.9173	17.3448

Notes: The table shows the summary statistics of variables in housing sales transactions, rental contracts, air pollution and weather at the daily level, and community attributes over 2015/01-2019/12. [1] Rental type is a dummy variable that equals one if a rental contract is regular and zero if a rental contract is signed in the Jeonse rental market. [2] We measure the daily average directions of all recorded winds at the day-station level.

Table 2. Pollution and Housing Price: Section 2 *vs* 3

	Dependent variable: ln(sales price)											
	Panel A: OLS						Panel B: IV					
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)
Section 3 × Post	-0.01972	0.00534	0.00162	0.00008	0.00013	0.00017*	-0.92321**	-0.32562***	-0.20523***	-0.00318***	-0.00319***	-0.00320***
	(0.02592)	(0.00593)	(0.00196)	(0.00012)	(0.00011)	(0.00009)	(0.36231)	(0.06472)	(0.01391)	(0.00003)	(0.00003)	(0.00003)
Section 3	-0.00156	0.00428	-0.00012	0.000004	-0.00003	-0.00065	0.00437	-0.00072	-0.00211	-0.00023	-0.00023	-0.00022
	(0.01631)	(0.00345)	(0.00123)	(0.000092)	(0.00008)	(0.00064)	(0.02072)	(0.00680)	(0.00780)	(0.00018)	(0.00019)	(0.00018)
Post	0.56921	0.24521*	-0.01031	0.00962***	0.00926***	0.00817***	0.04962***	0.02202***	0.01212***	0.01171***	0.01172***	0.01172***
	(0.55721)	(0.12511)	(0.04132)	(0.00262)	(0.00249)	(0.00203)	(0.00909)	(0.00167)	(0.00034)	(0.00002)	(0.00001)	(0.00001)
PM2.5	-0.00188	0.00211	-0.00286***	0.000004	-0.00004	-0.00006	0.07542***	-0.00104***	-0.00213***	-0.00202***	-0.00201***	-0.00221***
	(0.01471)	(0.00307)	(0.00105)	(0.000083)	(0.00007)	(0.00005)	(0.02681)	(0.00004)	(0.00911)	(0.00003)	(0.00003)	(0.00003)
PM2.5 × Post	-0.02281	-0.00843	0.00091	0.00007	0.00011	0.00013	-0.22423***	-0.00180***	-0.00326***	-0.00033***	-0.00032***	-0.00033***
	(0.02292)	(0.00512)	(0.00169)	(0.00012)	(0.00010)	(0.00008)	(0.04601)	(0.00008)	(0.00022)	(0.00005)	(0.00005)	(0.00005)
PM2.5 × Section 3	0.00008	-0.000168	0.000003	-0.0000002	0.000001	0.000003	-0.02862***	-0.00034	-0.00048	-0.00001	-0.00001	-0.00001
	(0.00066)	(0.000141)	(0.000050)	(0.0000031)	(0.000003)	(0.000003)	(0.00891)	(0.00026)	(0.00036)	(0.00004)	(0.00009)	(0.00004)
PM2.5 × Section 3 × Post	0.00085	0.000213	-0.00006	-0.000003	-0.000005	-0.000006*	-0.06701***	-0.000067***	-0.00012***	-0.000022***	-0.000023***	-0.000022***
	(0.00107)	(0.000243)	(0.00008)	(0.000004)	(0.000004)	(0.000004)	(0.01872)	(0.000003)	(0.00002)	(0.000001)	(0.000001)	(0.000001)
Constant	10.0221***	10.1202***	10.0812***	10.0857***	10.0339***	10.0165***	11.1912***	11.6321***	9.8741***	9.7493***	9.7517***	9.7425***
	(0.3621)	(0.0806)	(0.0272)	(0.0023)	(0.0023)	(0.0019)	(0.4281)	(0.0752)	(0.0147)	(0.0543)	(0.0483)	(0.0541)
N	368,815	365,483	365,483	365,483	365,483	365,483	368,815	365,483	365,483	365,483	365,483	365,483
R-squared	0.5351	0.7262	0.7226	0.7298	0.7329	0.7575	0.5401	0.7757	0.7795	0.7894	0.7954	0.8032
Community FE		Y	Y	Y	Y	Y		Y	Y	Y	Y	Y
Year by Month FE			Y	Y	Y	Y			Y	Y	Y	Y
Housing Attributes				Y	Y	Y				Y	Y	Y
District Attributes				Y	Y	Y				Y	Y	Y
Climate Attributes				Y	Y	Y				Y	Y	Y
Province by Year FE					Y	Y					Y	Y
Day-of-Month FE						Y						Y

Notes: This table presents the relabeling effects and perception change of $PM_{2.5}$ on both home sales prices over the past 30 days, considering only Section 2 *vs* 3, following the model specification (4). The data spans from 2015/01 to 2019/12. The air pollution near an apartment is measured by the closest monitor. Observations with the previous 30-day period across the policy shock are dropped. Housing, district, climate attributes, and other pollutants, as well as community, year-by-month, province-by-year, and day-of-month fixed effects are controlled for. The instrument variables are frequencies of wind in eight directions recorded in one day. The standard errors are clustered at the district level. *** $p<0.01$, ** $p<0.05$, * $p<0.1$

Table 3. Pollution and Housing Costs: All Sections

Dependent variable:	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
	ln(sales price)				ln(rent)			
	4 *vs* 5	2 *vs* 3	All Sections	All Sections	4 *vs* 5	2 *vs* 3	All Sections	All Sections
Section 6 × Post			-0.00029	-0.00035			-0.00062	-0.00059
			(0.00052)	(0.00057)			(0.00059)	(0.00058)
Section 6			-0.00675***	-0.00674***			-0.00470***	-0.00473***
			(0.00043)	(0.00049)			(0.00042)	(0.00041)
Section 5 × Post	-0.00303***		-0.00238***	-0.00226***	-0.00250***		-0.00165**	-0.00166**
	(0.00031)		(0.00049)	(0.00051)	(0.00001)		(0.00066)	(0.00066)
Section 5	-0.00023		-0.00431***	-0.00436***	-0.00012		-0.00455***	-0.00455***
	(0.00054)		(0.00036)	(0.00038)	(0.00083)		(0.00033)	(0.00033)
Section 4 × Post			-0.00028	-0.00032			-0.00008	-0.00008
			(0.00023)	(0.00025)			(0.00009)	(0.00009)
Section 4			-0.00357***	-0.00350***			-0.00400***	-0.00399***
			(0.00032)	(0.00033)			(0.00019)	(0.00018)
Section 3 × Post		-0.00320***	-0.00318***	-0.00320***		-0.00274***	-0.00222***	-0.00222***
		(0.00003)	(0.00010)	(0.00010)		(0.00027)	(0.00003)	(0.00003)
Section 3		-0.00022	-0.00154***	-0.00154***		-0.00012	-0.00159***	-0.00159***
		(0.00018)	(0.00007)	(0.00007)		(0.00026)	(0.00003)	(0.00003)
Section 2 × Post			-0.000006	-0.000007			-0.000001	-0.000001
			(0.000056)	(0.000078)			(0.000002)	(0.000002)
Section 2			-0.00155***	-0.00157***			-0.00134***	-0.00133***
			(0.00010)	(0.00012)			(0.00002)	(0.00002)
Post	0.013121***	0.011722***	0.01221***	0.01221***	0.01313***	-0.03171***	0.01202***	0.01202***
	(0.000005)	(0.000005)	(0.00001)	(0.00001)	(0.00002)	(0.00001)	(0.00001)	(0.00001)
PM2.5	-0.00162***	-0.00221***	-0.00209***	-0.00208***	-0.00124***	-0.00143***	-0.00233***	-0.00233***
	(0.00007)	(0.00003)	(0.00002)	(0.00002)	(6.88e-7)	(0.00020)	(0.00003)	(0.00003)
PM2.5 × Post	-0.00024***	-0.00033***	-0.00026***	-0.00026***	-0.00016***	-0.00045***	-0.00023***	-0.00023***
	(0.00004)	(0.00005)	(0.00008)	(0.00008)	(3.03e-6)	(0.00013)	(0.00001)	(0.00001)
PM2.5 × Section 6 × Post			-0.000029***	-0.000022***			-0.000019**	-0.000023***
			(0.000001)	(0.000004)			(0.000008)	(0.000008)
PM2.5 × Section 6			-0.000030	-0.000029			-0.000013	-0.000013
			(0.000022)	(0.000021)			(0.000008)	(0.000008)
PM2.5 × Section 5 × Post	-0.000019***		-0.000032***	-0.000036***	-0.00001***		-0.000026***	-0.000029***
	(0.000006)		(0.000002)	(0.000004)	(2.99e-06)		(0.000007)	(0.000007)
PM2.5 × Section 5	-0.0000009		-0.00002	-0.00002	-0.00012		-0.00001	-0.00001
	(0.0000008)		(0.00002)	(0.00002)	(0.00339)		(0.00002)	(0.00002)
PM2.5 × Section 4 × Post			-0.000034***	-0.000032***			-0.000024***	-0.000024***
			(0.000001)	(0.000001)			(0.000001)	(0.000001)
PM2.5 × Section 4			-0.00003	-0.00003			-0.00001	-0.000007
			(0.00003)	(0.00002)			(0.00001)	(0.000004)
PM2.5 × Section 3 × Post		-0.000022***	-0.000022***	-0.000023***		-0.000017***	-0.000026***	-0.000026***
		(0.000001)	(0.000001)	(0.000003)		(0.000002)	(0.000001)	(0.000001)
PM2.5 × Section 3		-0.00001	-0.00001	-0.00001		-0.00004	-0.00001	-0.00001
		(0.00004)	(0.00002)	(0.00001)		(0.00005)	(0.00005)	(0.00001)
PM2.5 × Section 2 × Post			-0.000005	-0.000005***			-0.000008***	-0.000008***
			(0.000003)	(0.000001)			(0.000001)	(0.000001)
PM2.5 × Section 2			-0.00001	-0.00001			-0.000002	-0.000002
			(0.00002)	(0.00001)			(0.000002)	(0.000002)
N	46,104	365,483	4,370,904	4,370,904	38,386	408,051	4,423,468	4,423,468
R-squared	0.6042	0.8033	0.8741	0.8903	0.7042	0.8093	0.8744	0.8872
Community FE	Y	Y	Y	Y	Y	Y	Y	Y
Year by Month FE	Y	Y	Y	Y	Y	Y	Y	Y
Housing Attributes	Y	Y	Y	Y	Y	Y	Y	Y
District Attributes	Y	Y	Y	Y	Y	Y	Y	Y
Climate Attributes	Y	Y	Y	Y	Y	Y	Y	Y
Province by Year FE				Y				Y
Day-of-Month FE				Y				Y

Notes: This table presents the relabeling effects and perception changes of $PM_{2.5}$ on housing sales prices and rents, considering all sections in the full sample. Housing, district, climate attributes, and other pollutants, as well as community, year-by-month, province-by-year, and day-of-month fixed effects are controlled for. The IVs are frequencies of wind directions. The standards errors are clustered at the district level. *** $p<0.01$, ** $p<0.05$, * $p<0.1$

Table 4. Heterogeneity in Housing Sales and Rental Markets

Dependent variable	ln(sales price)				ln(rent)					
	Urban *vs* Rural		High *vs* Low		Urban *vs* Rural		Rent Type		High *vs* Low	
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
	Urban	Rural	High	Low	Urban	Rural	Regular	Jeonse	High	Low
Section 6 × Post	-0.00077	-0.00037	0.00035	-0.00086	-0.00013	-0.00326**	-0.00271	-0.00122	-0.00410**	-0.00054
	(0.00069)	(0.00095)	(0.00073)	(0.00083)	(0.00181)	(0.00159)	(0.00216)	(0.00147)	(0.00164)	(0.00193)
Section 6	-0.00613***	-0.00665***	-0.00623***	-0.00711***	-0.00546***	-0.00731***	-0.00664***	-0.00630***	-0.00803***	-0.00488***
	(0.00070)	(0.00074)	(0.00077)	(0.00069)	(0.00127)	(0.00110)	(0.00150)	(0.00098)	(0.00113)	(0.00133)
Section 5 × Post	-0.00276***	-0.00230***	-0.00216***	-0.00240***	-0.00226***	-0.00198***	-0.00573**	-0.00309*	-0.00171	-0.00256
	(0.00069)	(0.00087)	(0.00077)	(0.00077)	(0.00051)	(0.00045)	(0.00247)	(0.00172)	(0.00190)	(0.00225)
Section 5	-0.00458***	-0.00395***	-0.00523***	-0.00369***	-0.00420***	-0.00253***	-0.00252**	-0.00381***	-0.00181*	-0.00480***
	(0.00048)	(0.00063)	(0.00049)	(0.00055)	(0.00099)	(0.00089)	(0.00122)	(0.00083)	(0.00093)	(0.00112)
Section 4 × Post	-0.00023	0.00008	-0.00082**	0.00007	-0.00011	0.00029	0.00035	-0.00007	0.00055*	-0.00030
	(0.00030)	(0.00048)	(0.00036)	(0.00034)	(0.00028)	(0.00030)	(0.00036)	(0.00025)	(0.00030)	(0.00031)
Section 4	-0.00362***	-0.00392***	-0.00316***	-0.00378***	-0.00380***	-0.00282***	-0.00313***	-0.00340***	-0.00251***	-0.00402***
	(0.00041)	(0.00059)	(0.00050)	(0.00047)	(0.00056)	(0.00052)	(0.00068)	(0.00047)	(0.00053)	(0.00061)
Section 3 × Post	-0.00352***	-0.00314***	-0.00307***	-0.00329***	-0.00241***	-0.00223***	-0.00223***	-0.00222***	-0.00212***	-0.00242***
	(0.00015)	(0.00015)	(0.00014)	(0.00013)	(0.00001)	(0.00001)	(0.00001)	(0.00001)	(0.00001)	(0.00001)
Section 3	-0.00153***	-0.00151***	-0.00169***	-0.00141***	-0.00160***	-0.00145***	-0.00146***	-0.00156***	-0.00136***	-0.00166***
	(0.00009)	(0.00012)	(0.00010)	(0.00011)	(0.00009)	(0.00009)	(0.00012)	(0.00008)	(0.00010)	(0.00010)
Section 2 × Post	-0.000005	-0.000006	-0.000008	-0.000008	-0.000002	-0.000003	-0.000003	-0.000004	-0.000002	-0.000004
	(0.000012)	(0.000012)	(0.000012)	(0.000010)	(0.000008)	(0.000007)	(0.000009)	(0.000006)	(0.000006)	(0.000006)
Section 2	-0.00162***	-0.00151***	-0.00140***	-0.00171***	-0.00020***	-0.00010*	-0.00011	-0.00016***	-0.00004	-0.00025***
	(0.00013)	(0.00021)	(0.00016)	(0.00017)	(0.00006)	(0.00006)	(0.000075)	(0.00004)	(0.00005)	(0.00006)
Post	0.01223***	0.01223***	0.01222***	0.01222***	0.01201***	0.01202***	0.01207***	0.01201***	0.01201***	0.01202***
	(0.00001)	(0.00001)	(0.00001)	(0.00001)	(0.00001)	(0.00001)	(0.00001)	(0.00001)	(0.00001)	(0.00001)
PM2.5	-0.00205***	-0.00211***	-0.00201***	-0.00205***	-0.00274***	-0.00231***	-0.00247***	-0.00239***	-0.00258***	-0.00297***
	(0.00003)	(0.00003)	(0.00003)	(0.00003)	(0.00010)	(0.00010)	(0.00013)	(0.00008)	(0.00010)	(0.00011)
PM2.5 × Post	-0.00025**	-0.00023*	-0.00021***	-0.00031***	-0.00022***	-0.00019***	-0.00020***	-0.00021***	-0.00018***	-0.00024***
	(0.00011)	(0.00013)	(0.00007)	(0.00009)	(0.00002)	(0.00002)	(0.00002)	(0.00001)	(0.00001)	(0.00002)
PM2.5 × Section 6 × Post	-0.000025***	-0.000021***	-0.000021***	-0.000046***	-0.000031***	-0.000036***	-0.000069**	-0.00004**	-0.00009***	-0.00001
	(0.000003)	(0.000002)	(0.000003)	(0.000002)	(0.000007)	(0.000004)	(0.000032)	(0.00002)	(0.00002)	(0.00002)
PM2.5 × Section 6	-0.00005	-0.00003	-0.00006	-0.00002	-0.000001	-0.00003	-0.00002	-0.00001	-0.00002	-0.00001
	(0.00004)	(0.00002)	(0.00006)	(0.00005)	(0.000026)	(0.00002)	(0.00003)	(0.00002)	(0.00002)	(0.00002)
PM2.5 × Section 5 × Post	-0.000040***	-0.000038***	-0.00005***	-0.00003***	-0.000026***	-0.000014***	-0.000015***	-0.000017***	-0.000026***	-0.000035***
	(0.000007)	(0.000018)	(0.00001)	(0.00001)	(0.000004)	(0.000002)	(0.000005)	(0.000003)	(0.000002)	(0.000002)
PM2.5 × Section 5	-0.00002	-0.00002	-0.00002	-0.00003	-0.000004	-0.00001	-0.00002	-0.000005	-0.00002	-0.00002
	(0.00008)	(0.00003)	(0.00008)	(0.00004)	(0.000008)	(0.00002)	(0.00003)	(0.000006)	(0.00002)	(0.00003)
PM2.5 × Section 4 × Post	-0.000036***	-0.000032***	-0.000004***	-0.000007***	-0.000023***	-0.000025***	-0.000026***	-0.000022***	-0.000029***	-0.000019***
	(0.000001)	(0.000001)	(0.000001)	(0.000001)	(0.000003)	(0.000003)	(0.000003)	(0.000002)	(0.000003)	(0.000003)
PM2.5 × Section 4	-0.00003	-0.00002	-0.00003***	-0.000031***	-0.000002	-0.000005	-0.000004	-0.000005	-0.000008	-0.000002
	(0.00002)	(0.00002)	(0.00001)	(0.000009)	(0.000003)	(0.000003)	(0.000004)	(0.000004)	(0.000006)	(0.000003)
PM2.5 × Section 3 × Post	-0.000012***	-0.000003***	-0.000003***	-0.000011***	-0.000026***	-0.000026***	-0.000026***	-0.000026***	-0.000026***	-0.000026***
	(0.000002)	(0.000001)	(0.000001)	(0.000002)	(0.000001)	(0.000001)	(0.000001)	(0.000001)	(0.000001)	(0.000001)
PM2.5 × Section 3	-0.00001	-0.00001	-0.00001	-0.00001	-0.00001	-0.00001	-0.00001	-0.00001	-0.00001	-0.00001
	(0.00002)	(0.00002)	(0.00002)	(0.00002)	(0.00001)	(0.00001)	(0.00001)	(0.00001)	(0.00001)	(0.00001)
PM2.5 × Section 2 × Post	-0.000003***	-0.000009**	-0.000004***	-0.000007***	-0.000009***	-0.000008***	-0.0000004***	-0.0000011***	-0.0000008***	-0.0000010***
	(0.000001)	(0.000004)	(0.000001)	(0.000001)	(0.000001)	(0.000002)	(0.0000001)	(0.0000002)	(0.0000002)	(0.0000002)
PM2.5 × Section 2	-0.00001	-0.00001	-0.00001	-0.00001	-0.000002	-0.000002	-0.000001	-0.000001	-0.000003	-0.000003
	(0.00002)	(0.00002)	(0.00002)	(0.00002)	(0.000002)	(0.000002)	(0.000003)	(0.000002)	(0.000002)	(0.000003)
Constant	10.3512***	9.8652***	10.1421***	10.0721***	4.6081***	4.2736***	4.3975***	4.4614***	4.4372***	4.4391***
	(0.0004)	(0.0006)	(0.0005)	(0.0005)	(0.0013)	(0.0013)	(0.0017)	(0.0012)	(0.0013)	(0.0015)
N	2,152,472	2,218,432	2,046,919	2,323,985	2,177,836	2,245,632	1,596,997	2,826,471	2,156,943	2,266,525
R-squared	0.7652	0.7633	0.7684	0.7982	0.8574	0.8343	0.8346	0.8565	0.8128	0.8121
Community FE	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
Year by Month FE	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
Housing Attributes	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
District Attributes	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
Climate Attributes	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
Province by Year FE	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
Day-of-Month FE	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y

Notes: This table presents the results of the heterogeneity analysis. Apartments in sales markets are grouped by the following categories: (1) urban vs rural housing market, and (2) apartments with high (≥8) and low (<8) floors, while apartments in rental markets are grouped by the following categories: (1) urban vs rural housing market; (2) regular rental *vs* Jeonse market; (3) apartments with high (≥8) and low (<8) floors. All regressions are estimated using wind directions as instruments. Control variables include housing, district, climate attributes, and other pollutants, as well as community, and year-by-month fixed effects. The standard errors are clustered at the district level. *** p<0.01, ** p<0.05, * p<0.1

Table 5. Effects of (Re)labeling on Pollution After 6 Months

Dependent variable:	(1)	(2)	(3)	(4)	(5)	(5)
ln(Pollution)	$PM_{2.5}$	PM_{10}	SO_2	CO	NO_2	O_3
Section 6 × Post	-0.00016	-0.00018	-0.00027	0.00035	-0.00028	-0.00018
	(0.00052)	(0.00061)	(0.00092)	(0.00043)	(0.00033)	(0.00053)
Section 6	-0.00017	-0.00013	-0.00016	-0.00012	0.00017	0.00011
	(0.00029)	(0.00072)	(0.00074)	(0.00057)	(0.00069)	(0.00032)
Section 5 × Post	-0.00056***	-0.00037***	-0.00021	0.00012	-0.00024	-0.00019
	(0.00005)	(0.00006)	(0.00027)	(0.00072)	(0.00017)	(0.00076)
Section 5	-0.00036	-0.00045	0.00039	-0.00052	0.00035	-0.00039
	(0.00033)	(0.00043)	(0.00060)	(0.00049)	(0.00058)	(0.00051)
Section 4 × Post	-0.00013	-0.00023*	0.00014	-0.00018	0.00017*	0.00018
	(0.00059)	(0.00035)	(0.00089)	(0.00067)	(0.00010)	(0.00033)
Section 4	-0.00005	-0.00003	-0.00002	-0.00002	-0.00003	-0.00006
	(0.00037)	(0.00017)	(0.00092)	(0.00500)	(0.00471)	(0.00121)
Section 3 × Post	-0.00042***	-0.00032**	-0.00034	-0.00027	-0.00012	-0.00032
	(0.00014)	(0.00015)	(0.00031)	(0.00048)	(0.00013)	(0.00042)
Section 3	-0.00014	-0.00015	-0.00021	-0.00019	-0.00021	-0.00014
	(0.00071)	(0.00096)	(0.00223)	(0.00126)	(0.00022)	(0.00011)
Section 2 × Post	-0.000007	-0.000005	-0.000006	-0.000008	-0.000007	-0.000004
	(0.000022)	(0.000013)	(0.000014)	(0.000017)	(0.000012)	(0.000015)
Section 2	-0.00001	-0.00001	-0.000005	-0.000004	-0.000007	-0.00001
	(0.00002)	(0.00003)	(0.00002)	(0.00004)	(0.00004)	(0.00005)
N	720,341	720,341	720,341	720,341	720,341	720,341
R-squared	0.6925	0.8555	0.8633	0.8621	0.8912	0.8121
Community FE	Y	Y	Y	Y	Y	Y
Year by Month FE	Y	Y	Y	Y	Y	Y
District Attributes	Y	Y	Y	Y	Y	Y
Climate Attributes	Y	Y	Y	Y	Y	Y

Notes: This table presents the results of (re)labeling effects of the information shock on 6-month lagged pollution levels or emissions at the community-by-month level. All regressions are estimated using wind directions as instruments following the model specification (7). Control variables include district and climate attributes, as well as community and year-by-month fixed effects. The standard errors are clustered at the district level. *** $p<0.01$, ** $p<0.05$, * $p<0.1$

Table 6. Mechanism of (Re)labeling Effects on Pollution

Dependent variable:	(1)	(2)
ln(Traffic or Electricity)	Traffic	Electricity
Section 6 × Post	-0.00004	0.00003
	(0.00027)	(0.00005)
Section 6	-0.00071***	-0.00044***
	(0.00004)	(0.00005)
Section 5 × Post	-0.00019***	-0.00013***
	(0.00006)	(0.00001)
Section 5	-0.00039***	-0.00031***
	(0.00002)	(0.00001)
Section 4 × Post	0.00008*	-0.000005*
	(0.00004)	(0.000003)
Section 4	-0.00043***	-0.00031***
	(0.00001)	(0.00001)
Section 3 × Post	-0.00035***	-0.00010***
	(0.00002)	(0.00001)
Section 3	-0.00015***	-0.00026***
	(0.00001)	(0.00001)
Section 2 × Post	-0.00002*	-0.0000003
	(0.00001)	(0.0000002)
Section 2	-0.00013***	-0.00014***
	(0.00001)	(0.00001)
Constant	11.7821***	0.000007
	(0.0150)	(0.000010)
N	30,032	408
R-squared	0.8902	0.3983
District Attributes	Y	Y
Climate Attributes	Y	Y
District FE	Y	
Year by Month FE	Y	Y
Province by Year FE	Y	Y

Notes: This table presents the results of mechanisms of pollution effects via traffic volume, i.e., total number of cars passing roads in each district in Column (1) and electricity generated by power plants in each province in Column (2). Local attributes, including total number of cars, unemployment rate, population, climatic attributes, and other pollutants, are controlled for. All regressions are estimated using wind directions as instrumental variables. The robust standards errors are clustered at the district (province) level. *** $p<0.01$, ** $p<0.05$, * $p<0.1$.

Appendix

Appendix A. A Detailed Introduction to the Environmental Policy

South Korea has established and operated environmental standards to protect human health and maintain a pleasant living environment. The country's standards for dust began in 1983 with the setting of Total Suspended Particles (TSP), and in 1993, standards for particulate matter smaller than 10 micrometers (PM_{10}) were introduced. Initially, an annual average of 150 μg/m³ and a daily average exceeding 300 μg/m³ were considered poor. The standards based on total suspended particles were abolished in 2001. The initial standards for PM_{10} dictated that an annual average above 80 and a daily average exceeding 150 would be considered poor, which over time became subject to stricter criteria. Eight years later, in 2001, the annual standard was strengthened from 80 to 70, and in 2007, the annual average was further reduced to 50, with the daily average set at 100. Subsequently, in 2011, new environmental standards for fine particulate matter, or $PM_{2.5}$, were added, with levels exceeding an annual average of 25 and a daily average of 50 classified as poor.

The establishment of particulate matter (PM) standards in South Korea follows the recommendations set by WHO in 2005, which has divided its particulate matter environmental standards into four stages: the guideline values, and interim targets 1, 2, and 3. The guideline values set the standards for particulate matter at an annual mean of 20 μg/m³ and a daily mean of 50 μg/m³, while for fine particulate matter ($PM_{2.5}$), the standards are an annual mean of 10 μg/m³ and a daily mean of 25 μg/m³. The next level, interim target 3, corresponds to a PM_{10} annual mean of 30 μg/m³ and a daily mean of 75 μg/m³, and for $PM_{2.5}$, an annual mean of 15 μg/m³ and a daily mean of 37.5 μg/m³. For interim target 2, PM_{10} levels are set at an annual mean of 50 μg/m³ and a daily mean of 100 μg/m³, while $PM_{2.5}$levels are set at an annual mean of 25 μg/m³ and a daily mean of 50 μg/m³. Interim target 1 corresponds to a PM_{10} annual mean of 70 μg/m³ and a daily mean of 150 μg/m³, and for $PM_{2.5}$, an annual mean of 35 μg/m³ and a daily mean of 75 μg/m³. Many countries establish their national environmental standards based on these criteria, and the levels of particulate matter and fine particulate matter in South Korea also correspond to interim target 2.

However, the environmental standards for fine particulate matter ($PM_{2.5}$) in South Korea were considered to be lower than those of other countries. This became clear when comparing standards with other developed countries; for example, the United States Environmental Protection Agency (EPA) set the 24-hour environmental standard for $PM_{2.5}$ at 35 μg/m³ in 2006, corresponding to interim target 1 of the WHO guidelines, which is a higher standard than that

of South Korea (WHO, 2006). Similarly, Japan set its 24-hour environmental standard for $PM_{2.5}$ at 35 $\mu g/m^3$, maintaining stricter levels compared to South Korea (Korean Ministry of Environment). Furthermore, other developed countries have set their environmental standards even stricter than interim target 1; Canada and Australia have set their daily average $PM_{2.5}$ environmental standards at 27 $\mu g/m^3$ and 25 $\mu g/m^3$, respectively, showing a difference that is nearly double that of South Korea. This led to voices within South Korea advocating for the need to adjust the $PM_{2.5}$ environmental standards to align with those of other developed countries, recognizing the current standards as lagging. Consequently, the Ministry of Environment aligned South Korea's standards with those of developed countries and made changes to the existing forecast standards on March 27, 2018.

Appendix B. Additional Figures

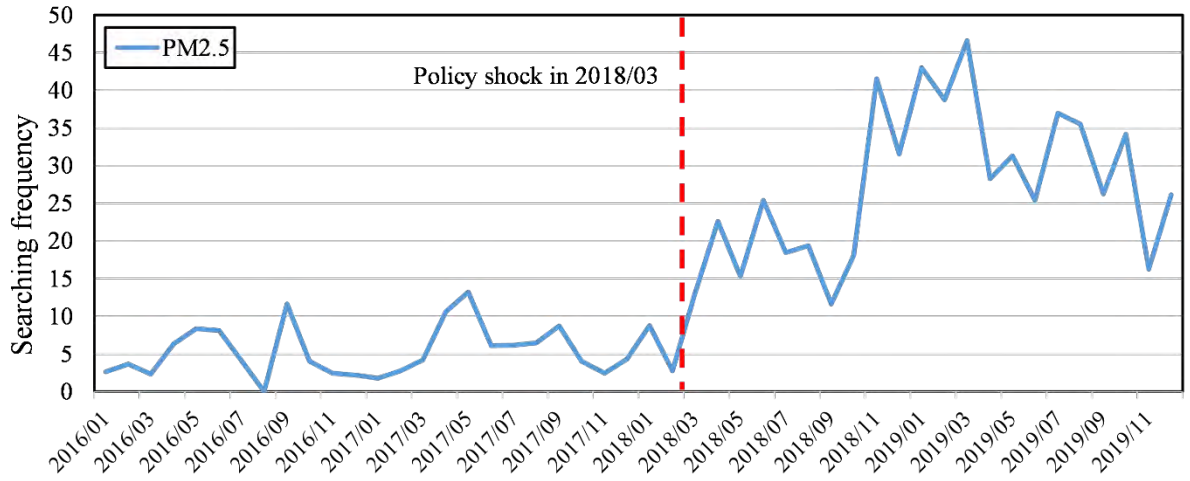


Figure A1. Monthly Google Search Frequency of $PM_{2.5}$

Notes: This figure plots the time series data on monthly Google search index for the keyword of "$PM_{2.5}$". The monthly data originally ranges over 0-100 and later is deseasonalized by month to explore a clear pattern. It covers the entire South Korea from January 2016 to December 2019.

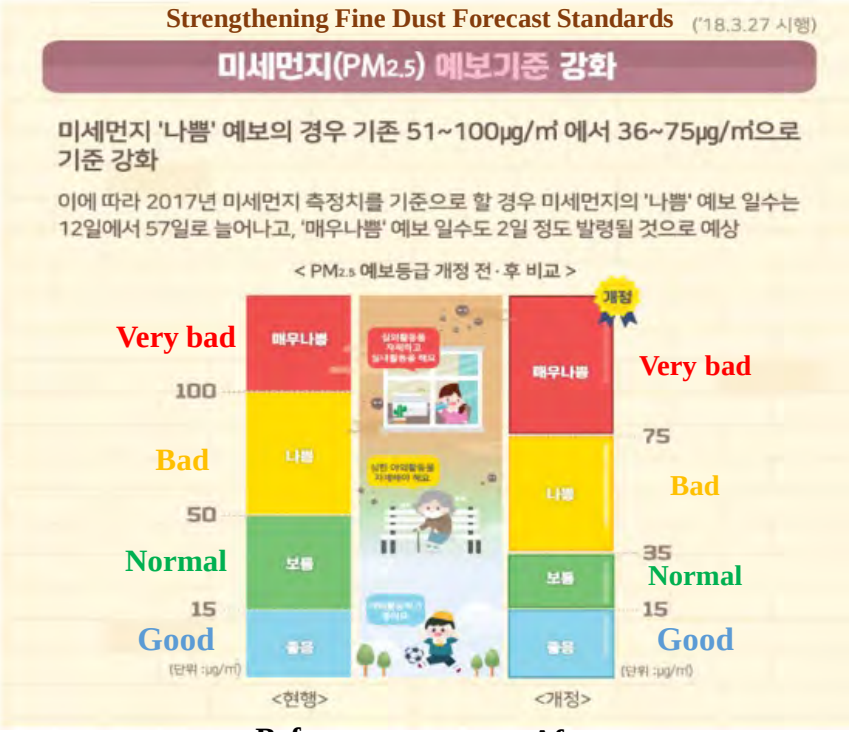
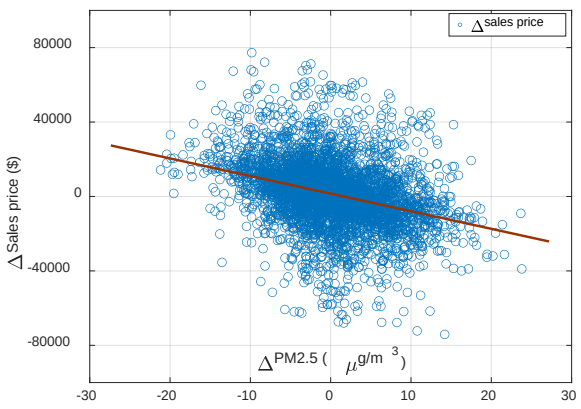
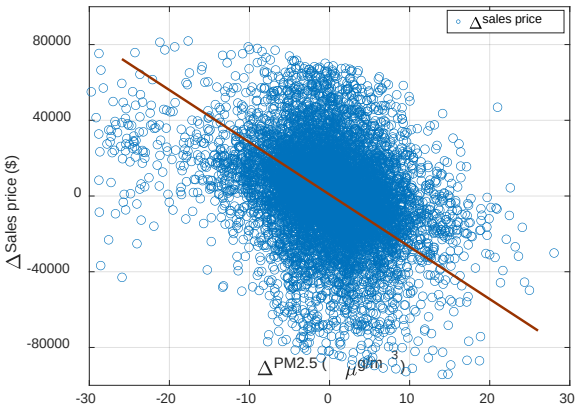


Figure A2. Change in Enforcement Ordinance for Air Quality Standard on March 27, 2018

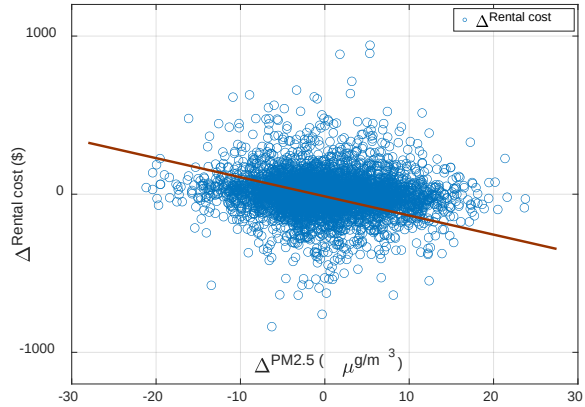
Notes: This figure plots the old and new Air Quality Standards (AQS) of $PM_{2.5}$ (particulate matter with a diameter smaller than 2.5 micrometers) in South Korea. The new AQS took effect on March 27, 2018, after which daily $PM_{2.5}$ levels between 35-50 $\mu g/m^3$ and between 75-100 $\mu g/m^3$ are relabeled from "Normal" to "Bad" and from "Bad" to "Very Bad", respectively.



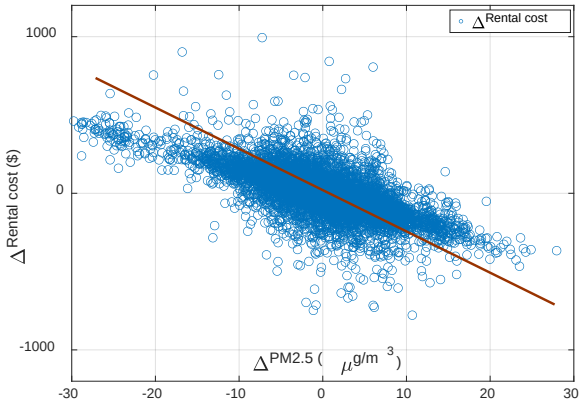
(a) $PM_{2.5}$ vs Sales Price in Old Standard



(b) $PM_{2.5}$ vs Sales Price in New Standard



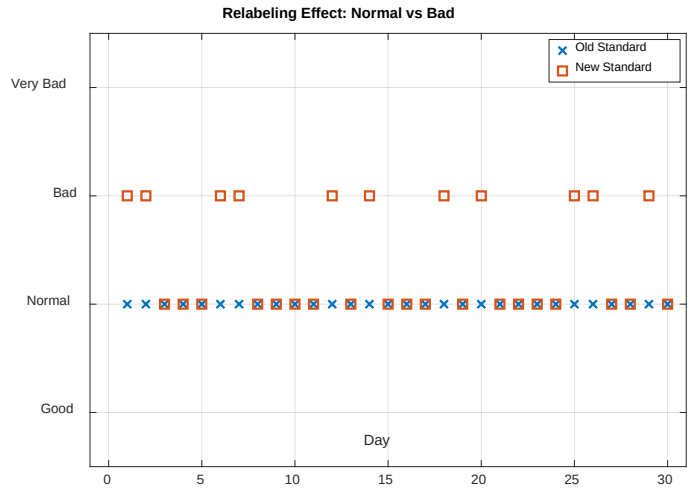
(c) $PM_{2.5}$ vs Rental Cost in Old Standard



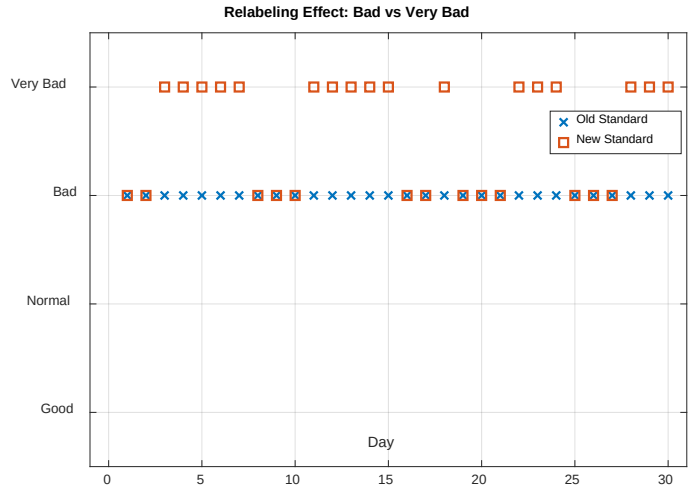
(d) $PM_{2.5}$ vs Rental Cost in New Standard

Figure A3. Correlation between Housing Costs and $PM_{2.5}$ Levels under Old and New AQS

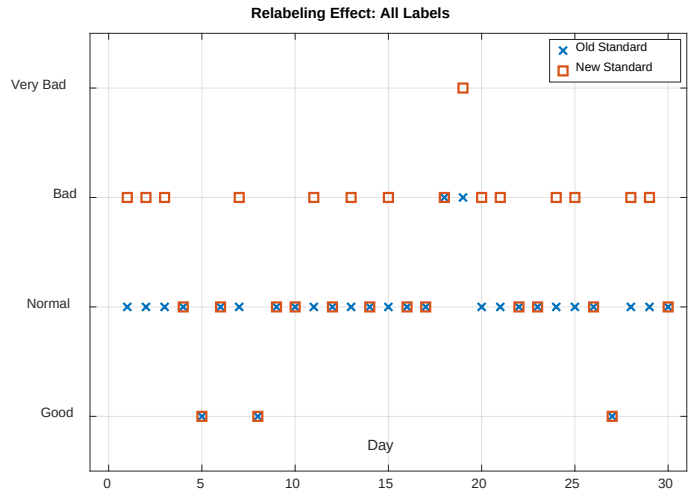
Notes: This figure plots the correlation between housing costs and $PM_{2.5}$ levels under old and new standards. Panels (a) and (b) show correlations between the changes in $PM_{2.5}$ and the changes in sales prices under old and new AQS. Panels (c) and (d) show correlation between the changes in $PM_{2.5}$ and the changes in rental cost under old and new AQS. The red lines are generated as fitted values by running a simple OLS regression.



(a) Normal vs Bad: Iksan in Jeollabuk-do Province in April 2018



(b) Bad vs Very Bad: Yangju in Gyeonggi Province in November 2018



(c) All Labels: Gyeongju in Gyeongsangbuk-do Province in April 2018

Figure A4. Graphical Representation of Relabeling Changes

Notes: This figure plots the relabeling changes in some representative months with switching days from "Normal" to "Bad" in Panel (a), from "Bad" to "Very Bad" in Panel (b), and both in Panel (c).

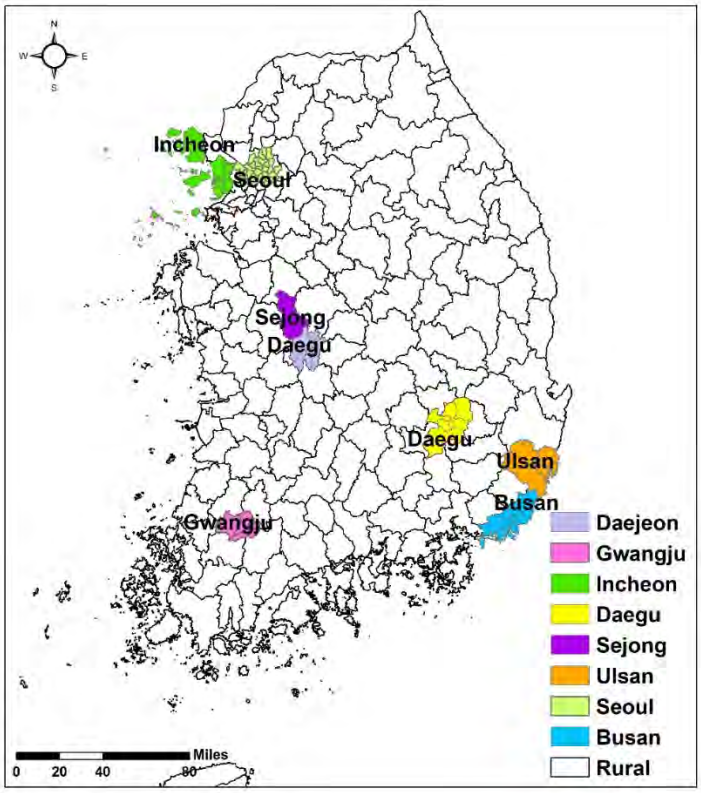


Figure A5. Urban and Rural Areas

Notes: This figure plots the urban and rural areas in South Korea. All areas in white are rural areas. Urban areas include Daejoen, Gwangju, Incheon, Daegu, Sejong, Ulsan, Seoul, and Busan.

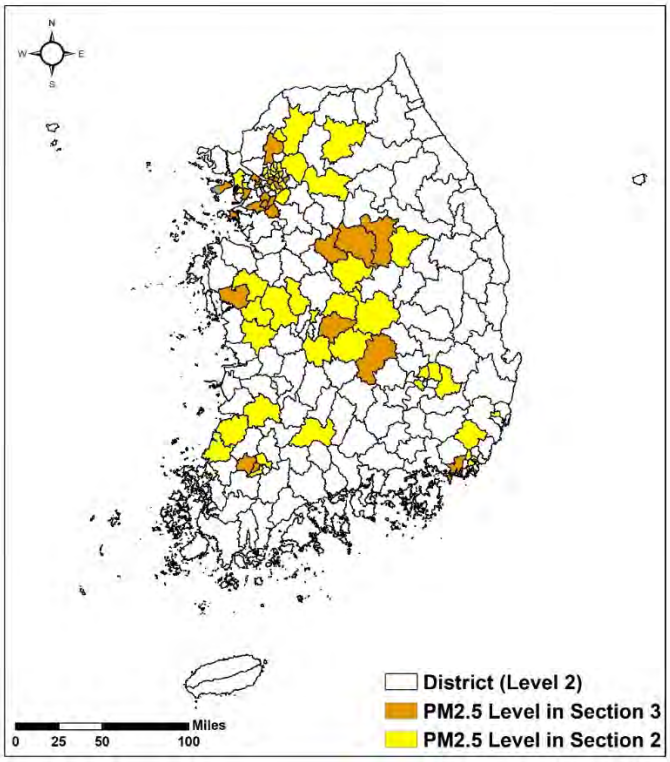


Figure A6. Districts of $PM_{2.5}$ Levels in Section 2 vs 3

Notes: This figure presents geographical units at district level of $PM_{2.5}$ levels that are always in Section 2 or 3. We see that there are only a proportion of districts that are included in our more restrictive identification of treatment and control housing units.

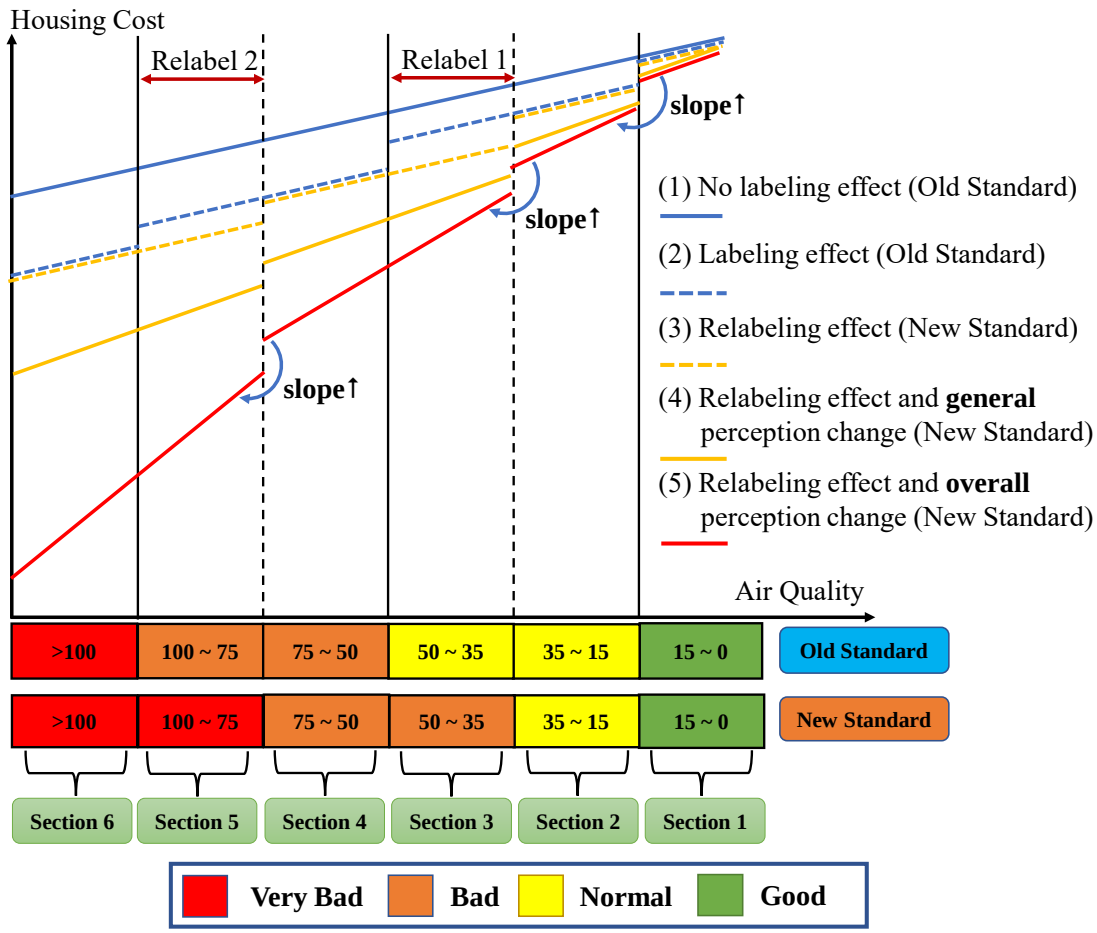
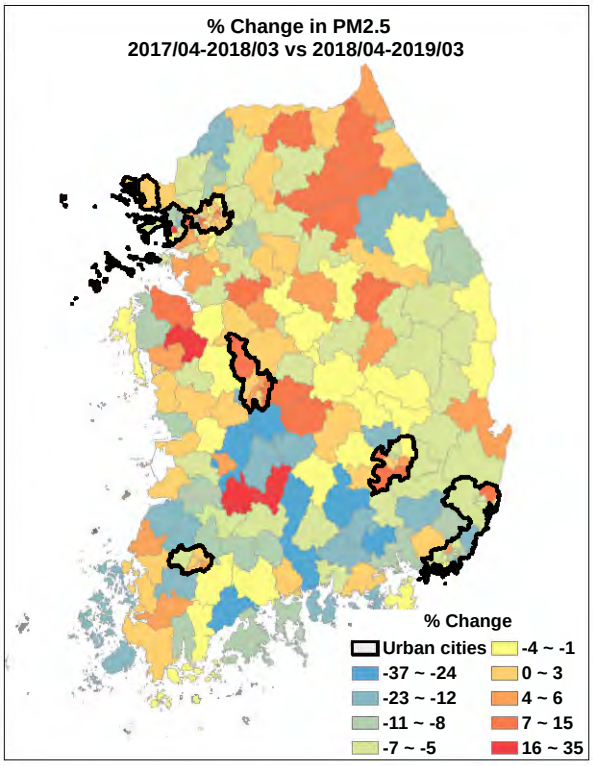
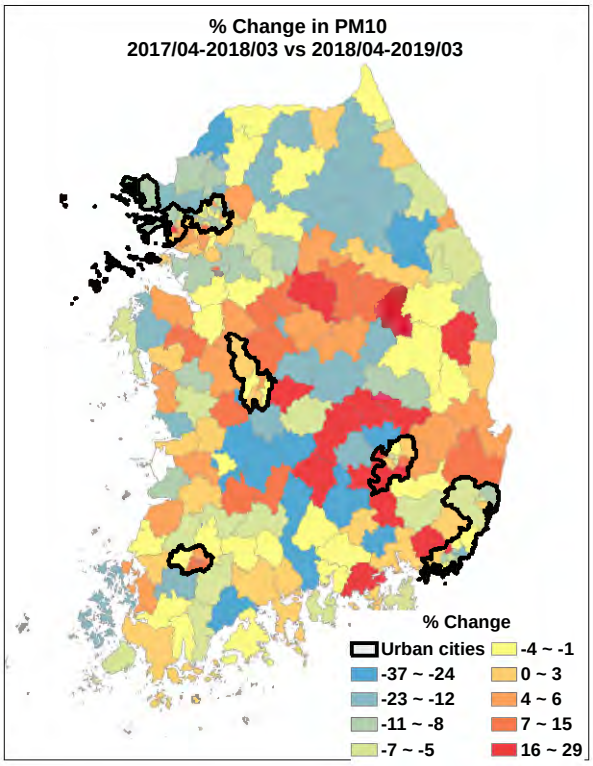


Figure A7. A Conceptual Illustration of Relabeling Effects and Perception Change

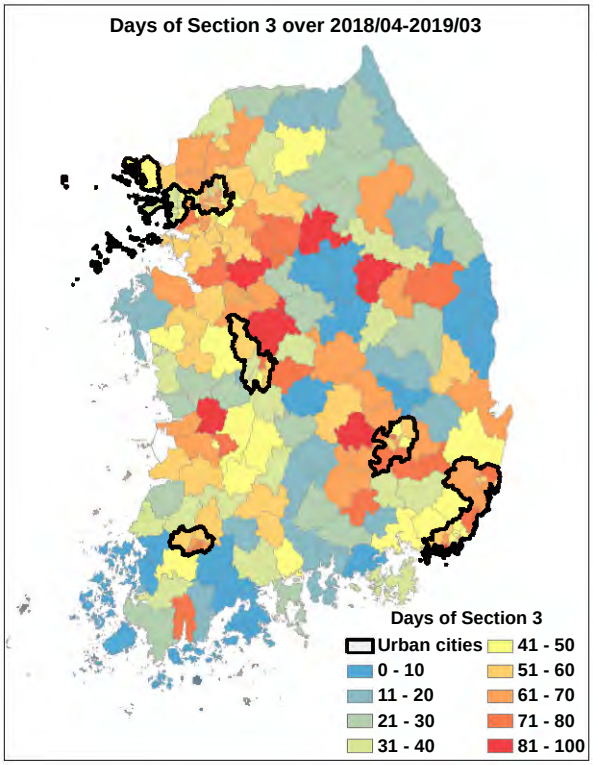
Notes: This figure illustrates the labeling effect under the old AQS, relabeling effect and the composition of relabeling effect and perception change under the new AQS. The new AQS took effect on March 27, 2018, after which daily $PM_{2.5}$ levels between 35-50 $\mu g/m^3$ and between 75-100 $\mu g/m^3$ are relabeled from "Normal" to "Bad" and from "Bad" to "Very Bad", respectively. The blue solid line shows how housing costs change with air quality, and associated labels with no labeling effect. The blue dashed line shows the case when labeling effect exists under the old AQS. The yellow dashed line shows the relabeling effect under the new AQS. The solid yellow and red lines show the composition of relabeling effect and perception change under the new AQS.



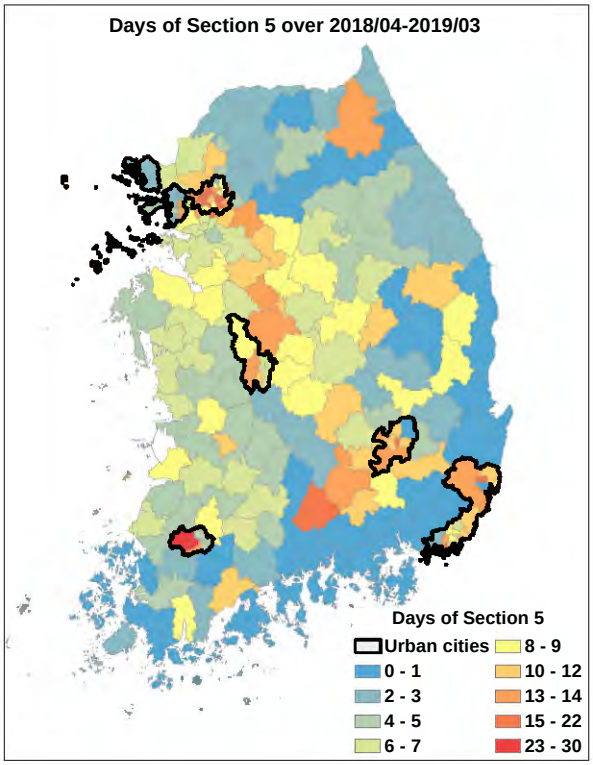
(a) Change in $PM_{2.5}$



(b) Change in PM_{10}



(c) Relabeled Days of Section 3



(d) Relabeled Days of Section 5

Figure A8. Changes in Pollution Levels and Count of Relabeled Days at the District Level

Notes: The panels show the percentage change of pollution levels and relabeled days at the district level for $PM_{2.5}$ and PM_{10}, respectively. We consider the comparisons between one year before and after the policy shock, i.e., 2017/04-2018/03 *vs* 2018/04-2019/03. Panels (c) and (d) present the relabeled days of Section 3 and 5, respectively, over a one-year period of 2018/04-2019/03.

Appendix C. Additional Tables

Table A1. Correlation Test of $PM_{2.5}$ Level and Housing Cost

	Old standard	New standard
	△Home sales price	△Home sales price
Lagged △$PM_{2.5}$	-0.34220**	-0.45811***
	(-1.993)	(-4.343)
N	4,023	7,298
	△Home rental price	△Home rental price
Lagged △$PM_{2.5}$	-0.19012*	-0.25812***
	(-1.973)	(-3.132)
N	4,132	7,391

Notes: This table presents correlations between monthly changes in lagged $PM_{2.5}$ and monthly changes in home sales/rental prices at the district level, under old and new air quality standards over 2015/01-2019/12. The robust *t* statistics are reported in parentheses. ***, **, and * indicate significance levels at 1%, 5%, and 10%, respectively.

Table A2. First-Stage of Wind Direction IV

	Dependent variable: $PM_{2.5}$					
Wind Direction	(1)	(2)	(3)	(4)	(5)	(6)
North	-0.0053	0.1272	0.1182*	-0.0337	0.0477	0.0468
	(0.1312)	(0.0866)	(0.0656)	(0.0635)	(0.0558)	(0.0557)
East	-0.7382***	0.0083	-0.2672***	-0.1102*	0.0121	0.0123
	(0.1133)	(0.0892)	(0.0638)	(0.0618)	(0.0513)	(0.0514)
West	-0.9394***	-0.0124	-0.4122***	-0.1631*	-0.0523	-0.0490
	(0.1682)	(0.1252)	(0.0792)	(0.0865)	(0.0625)	(0.0629)
South	-0.1832	0.2842***	-0.1351*	-0.1182	-0.1683***	-0.1692***
	(0.2021)	(0.1012)	(0.0754)	(0.0730)	(0.0544)	(0.0544)
Northeast	-0.3852***	0.02992	0.1911**	0.1172	0.1673**	0.1671**
	(0.1202)	(0.0837)	(0.0969)	(0.0847)	(0.0717)	(0.0719)
Southwest	-0.0061	0.2102*	-0.1222*	-0.1153*	-0.2032***	-0.2032***
	(0.1492)	(0.1071)	(0.0715)	(0.0663)	(0.0542)	(0.0545)
Southeast	-0.0204	0.1782**	-0.1472***	0.0194	-0.1382***	-0.1392***
	(0.1161)	(0.0761)	(0.0561)	(0.0593)	(0.0474)	(0.0475)
N	4,370,921	4,370,921	4,370,921	4,370,921	4,370,921	4,370,921
R-squared	0.8922	0.8313	0.8752	0.8773	0.8321	0.8292
F-statistic	23.98	20.09	21.34	22.89	22.12	24.98
District Attributes		Y	Y	Y	Y	Y
Other pollutants		Y	Y	Y	Y	Y
Weather		Y	Y	Y	Y	Y
District FE			Y	Y	Y	Y
Year by Month FE				Y	Y	Y
Province by year					Y	Y
Day-of-month						Y

Notes: This table presents the first-stage results of wind direction IVs on $PM_{2.5}$ using day-by-monitor data of air pollution over 2015/01-2019/12. Air pollution is measured by the closest monitor. District and climate attributes as well as other pollutants are controlled for. Fixed effects include provincial-level division by year, day-of-month, district, and year-by-month fixed effects. The instrument variables are frequencies of the dominant wind direction recorded daily in eight directions, taking Northwest wind direction as reference group. The robust standard errors are clustered at the district level. *** $p<0.01$, ** $p<0.05$, * $p<0.1$

Table A3. Pollution and Rental Price: Section 2 *vs* 3

	Dependent variable: ln(rent)											
	Panel A: OLS						Panel B: IV					
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)
Section 3 × Post	-0.01311	-0.00528	-0.01622	-0.00768	-0.00023	-0.00063	-0.00534***	-0.00132***	-0.00427***	-0.00274***	-0.00280***	-0.00274***
	(0.01496)	(0.0129)	(0.01211)	(0.01025)	(0.00281)	(0.00117)	(0.00162)	(0.00012)	(0.00042)	(0.00027)	(0.00033)	(0.00027)
Section 3	0.02792***	0.02224***	0.01598**	0.01901***	0.00481**	0.00495***	-0.00082	-0.00082	0.00010	-0.00012	-0.00019	-0.00012
	(0.01051)	(0.00818)	(0.00696)	(0.00611)	(0.00205)	(0.00071)	(0.00125)	(0.00113)	(0.00092)	(0.00026)	(0.00029)	(0.00026)
Post	0.01803	-0.04082	0.07216	0.12223*	0.02442	0.01172***	-0.01561***	-0.07271***	-0.05362***	-0.04271***	-0.03581***	-0.03171***
	(0.11334)	(0.09891)	(0.08746)	(0.07101)	(0.02061)	(0.00011)	(0.00028)	(0.02212)	(0.00408)	(0.00253)	(0.00366)	(0.00007)
PM2.5	0.00776***	0.00628***	0.00148	0.00402**	0.00150***	0.00134***	-0.00818***	-0.00833***	-0.00171*	-0.00145***	-0.00125***	-0.00143***
	(0.00266)	(0.00204)	(0.00157)	(0.00158)	(0.00038)	(0.00016)	(0.00269)	(0.00206)	(0.00089)	(0.00020)	(0.00022)	(0.00020)
PM2.5 × Post	-0.00358	-0.00094	-0.00485	-0.00552**	-0.00272***	-0.00022	-0.05682***	-0.05601***	-0.00375*	-0.00043***	-0.00094***	-0.00045***
	(0.00398)	(0.00332)	(0.00299)	(0.00228)	(0.00069)	(0.00294)	(0.00831)	(0.00610)	(0.00201)	(0.00013)	(0.00014)	(0.00013)
PM2.5 × Section 3	-0.00115***	-0.00098***	-0.00067***	-0.00071***	-0.00019***	-0.00004***	0.00211	0.00229	-0.00182**	-0.00004	0.00005	-0.00004
	(0.00033)	(0.00024)	(0.00020)	(0.00017)	(0.00004)	(0.00001)	(0.00305)	(0.00234)	(0.00076)	(0.00005)	(0.00018)	(0.00005)
PM2.5 × Section 3 × Post	0.00056	0.00030	0.00074**	0.00035	0.00010	0.00029	0.05432***	0.05282***	0.00380*	-0.000015***	-0.000014***	-0.000017***
	(0.00047)	(0.00038)	(0.00036)	(0.00028)	(0.00007)	(0.00036)	(0.01131)	(0.00848)	(0.00229)	(0.000003)	(0.000002)	(0.000002)
Constant	9.6152***	9.6391***	9.6488***	9.6484***	9.6416***	9.6427***	9.4662***	9.8142***	9.7095***	9.7095***	9.7433***	9.7373***
	(0.0301)	(0.0227)	(0.0257)	(0.0257)	(0.0262)	(0.0260)	(0.1462)	(0.0680)	(0.1162)	(0.1162)	(0.0960)	(0.0961)
N	408,884	408,051	408,051	408,051	408,051	408,051	408,884	408,051	408,051	408,051	408,051	408,051
R-squared	0.5355	0.7267	0.7227	0.7295	0.7323	0.7575	0.5402	0.7755	0.7893	0.7924	0.7973	0.8092
Community FE		Y	Y	Y	Y	Y		Y	Y	Y	Y	Y
Year by Month FE			Y	Y	Y	Y			Y	Y	Y	Y
Housing Attributes				Y	Y	Y				Y	Y	Y
District Attributes				Y	Y	Y				Y	Y	Y
Climate Attributes				Y	Y	Y				Y	Y	Y
Province by Year FE					Y	Y					Y	Y
Day-of-Month FE						Y						Y

Notes: This table presents the relabeling effects and perception change of $PM_{2.5}$ on rental prices over the past 30 days, considering only Section 2 *vs* 3, following the model specification (4). The data spans from 2015/01 to 2019/12. The air pollution near an apartment is measured by the closest monitor. Observations with the previous 30-day period across the policy shock are dropped. Housing, district, climate attributes, and other pollutants, as well as community, year-by-month, province-by-year, and day-of-month fixed effects are controlled for. The instrument variables are frequencies of wind in eight directions recorded in one day. The robust standards errors are clustered at the district level. *** $p<0.01$, ** $p<0.05$, * $p<0.1$

Table A4. Housing Sales Prices with Alternative Fixed Effects: Section 2 *vs* 3

	Dependent variable: ln(sales price)						
	(1)	(2)	(3)	(4)	(5)	(6)	(7)
Section 3 × Post	-0.00318***	-0.00319***	-0.00319***	-0.00318***	-0.00318***	-0.00318***	-0.00320***
	(0.00003)	(0.00003)	(0.00003)	(0.00003)	(0.00003)	(0.00003)	(0.00003)
Section 3	-0.00023	-0.00023	-0.00023	-0.00022	-0.00024	-0.00029	-0.00022
	(0.00018)	(0.00029)	(0.00019)	(0.00023)	(0.00024)	(0.00027)	(0.00018)
Post	0.01171***	0.01173***	0.01172***	0.01171***	0.01175***	0.01174***	0.01172***
	(0.00002)	(0.00001)	(0.00001)	(0.00001)	(0.00001)	(0.00001)	(0.00001)
PM2.5	-0.00202***	-0.00201***	-0.00201***	-0.00202***	-0.00202***	-0.00202***	-0.00221***
	(0.00003)	(0.00004)	(0.00003)	(0.00003)	(0.00003)	(0.00004)	(0.00003)
PM2.5 × Post	-0.00033***	-0.00033***	-0.00032***	-0.00032***	-0.00032***	-0.00032***	-0.00033***
	(0.00005)	(0.00005)	(0.00005)	(0.00005)	(0.00005)	(0.00005)	(0.00005)
PM2.5 × Section 3	-0.00001	-0.00001	-0.00001	-0.00001	-0.00001	-0.00001	-0.00001
	(0.00004)	(0.00002)	(0.00009)	(0.00002)	(0.00002)	(0.00002)	(0.00004)
PM2.5 × Section 3 × Post	-0.000022***	-0.000023***	-0.000023***	-0.000024***	-0.000024***	-0.000024***	-0.000022***
	(0.000001)	(0.000001)	(0.000001)	(0.000001)	(0.000001)	(0.000001)	(0.000001)
Constant	9.7493***	9.8233***	9.7517***	9.8231***	9.8233***	9.8239***	9.7425***
	(0.0543)	(0.0481)	(0.0483)	(0.054)	(0.0539)	(0.0559)	(0.0541)
N	365,483	365,483	365,483	365,483	365,483	365,483	365,483
R-squared	0.7894	0.7934	0.7954	0.7975	0.7937	0.7996	0.8032
Housing Attributes	Y	Y	Y	Y	Y	Y	Y
District Attributes	Y	Y	Y	Y	Y	Y	Y
Climate Attributes	Y	Y	Y	Y	Y	Y	Y
Other Pollutants	Y	Y	Y	Y	Y	Y	Y
Community FE	Y	Y	Y	Y	Y	Y	Y
Year by Month FE	Y	Y	Y	Y	Y	Y	Y
Urban by year		Y					
Province by year			Y				Y
Day-of-week				Y			
Week-of-month					Y		
Day-of-month						Y	Y

Notes: This table presents the relabeling effects and perception change of $PM_{2.5}$ on housing sales prices over the past 30 days, considering only Section 2 *vs* 3, following Equation (4). Control variables include housing, district, and climate attributes as well as other pollutants. Multiple types of fixed effects are added, including tier-1 urban city by year, provincial-level division by year, day-of-the-week, week-of-month, and day-of-month fixed effects, on top of the community and year-by-month fixed effects. The instrument variables are frequency of wind directions. The robust standard errors are clustered at the district level. *** $p<0.01$, ** $p<0.05$, * $p<0.1$

Table A5. Housing Rental Prices with Alternative Fixed Effects: Section 2 *vs* 3

	Dependent variable: log(rent)						
	(1)	(2)	(3)	(4)	(5)	(6)	(7)
Section 3 × Post	-0.00274***	-0.00274***	-0.00280***	-0.00274***	-0.00274***	-0.00274***	-0.00274***
	(0.00027)	(0.000272)	(0.00033)	(0.000271)	(0.000271)	(0.000272)	(0.00027)
Section 3	-0.00012	-0.00012	-0.00019	-0.00012	-0.00012	-0.00012	-0.00012
	(0.00026)	(0.00023)	(0.00029)	(0.00021)	(0.00021)	(0.00024)	(0.00026)
Post	-0.04271***	0.01172***	-0.03581***	0.01172***	0.01161***	0.01162***	-0.03171***
	(0.00253)	(0.00021)	(0.00366)	(0.00015)	(0.00029)	(0.00035)	(0.00007)
PM2.5	-0.00145***	-0.00145***	-0.00125***	-0.00145***	-0.00145***	-0.00145***	-0.00143***
	(0.00020)	(0.00020)	(0.00022)	(0.00020)	(0.00020)	(0.00020)	(0.00020)
PM2.5 × Post	-0.00043***	-0.00045***	-0.00094***	-0.00045***	-0.00045***	-0.00044***	-0.00045***
	(0.00013)	(0.00013)	(0.00014)	(0.00013)	(0.00013)	(0.00013)	(0.00013)
PM2.5 × Section 3	-0.00004	-0.00004	0.00005	-0.00004	-0.00004	-0.00004	-0.00004
	(0.00005)	(0.00003)	(0.00018)	(0.00004)	(0.00004)	(0.00004)	(0.00005)
PM2.5 × Section 3 × Post	-0.000015***	-0.000017***	-0.000014***	-0.000017***	-0.000017***	-0.000017***	-0.000017***
	(0.000003)	(0.000006)	(0.000002)	(0.000006)	(0.000006)	(0.000006)	(0.000002)
Constant	9.7095***	9.2101***	9.7433***	9.2103***	9.2102***	9.2101***	9.7373***
	(0.1162)	(0.0030)	(0.0960)	(0.0030)	(0.0030)	(0.0030)	(0.0961)
N	408,051	408,884	408,051	408,884	408,884	408,884	408,051
R-squared	0.7924	0.7932	0.7973	0.7972	0.7933	0.7994	0.8092
Housing Attributes	Y	Y	Y	Y	Y	Y	Y
District Attributes	Y	Y	Y	Y	Y	Y	Y
Climate Attributes	Y	Y	Y	Y	Y	Y	Y
Other Pollutants	Y	Y	Y	Y	Y	Y	Y
Community FE	Y	Y	Y	Y	Y	Y	Y
Year by Month FE	Y	Y	Y	Y	Y	Y	Y
Urban by year		Y					
Province by year			Y				Y
Day-of-week				Y			
Week-of-month					Y		
Day-of-month						Y	Y

Notes: This table presents the relabeling effects and perception change of $PM_{2.5}$ on housing rental costs over the past 30 days, considering only Section 2 *vs* 3, following Equation (4). Control variables include housing, district, and climate attributes as well as other pollutants. Multiple types of fixed effects are added, including tier-1 urban city by year, provincial-level division by year, day-of-the-week, week-of-month, and day-of-month fixed effects, on top of the community and year-by-month fixed effects. The instrument variables are frequencies of wind directions. The robust standard errors are clustered at the district level. *** $p<0.01$, ** $p<0.05$, * $p<0.1$

Table A6. Price Elasticity of Pollution Level across All Thresholds

	Dependent variable: ln(sales price)			Dependent variable: ln(rent)		
	(1)	(2)	(3)	(4)	(5)	(6)
ln(PM2.5)	-0.3432***	-0.3473***	-0.3472***	-0.2942***	-0.2472***	-0.2473***
	(0.0232)	(0.0168)	(0.0167)	(0.0819)	(0.0021)	(0.0189)
ln(PM2.5) × Post	-0.0622***	-0.0698***	-0.0698***	-0.8274***	-0.0349***	-0.0342***
	(0.0023)	(0.0003)	(0.0001)	(0.0127)	(0.0022)	(0.0002)
ln(PM2.5) × Section 6 × Post	-0.00032***	-0.00037***	-0.00038***	-0.00024**	-0.00032***	-0.00031***
	(0.00004)	(0.00003)	(0.00003)	(0.00012)	(0.00011)	(0.00010)
ln(PM2.5) × Section 6	-0.00003	-0.00002	-0.00001	-0.03363	-0.00033***	-0.00033***
	(0.00006)	(0.00003)	(0.00004)	(0.02641)	(0.00001)	(0.00001)
ln(PM2.5) × Section 5 × Post	-0.00028***	-0.00030***	-0.00030***	-0.00617**	-0.00023	-0.00020
	(0.00004)	(0.00001)	(0.00001)	(0.02513)	(0.00056)	(0.00056)
ln(PM2.5) × Section 5	-0.00002	-0.00003***	-0.00004***	-0.01375	-0.00010	-0.00010
	(0.00056)	(0.00001)	(0.00001)	(0.01549)	(0.00036)	(0.00036)
ln(PM2.5) × Section 4 × Post	-0.00023***	-0.00028***	-0.00028***	-0.03195	-0.00028***	-0.00028***
	(0.00002)	(0.00001)	(0.00001)	(0.00441)	(0.00010)	(0.00010)
ln(PM2.5) × Section 4	-0.00001	-0.00001	-0.00001	-0.01357***	-0.00021***	-0.00021***
	(0.00007)	(0.00001)	(0.00002)	(0.00408)	(0.00007)	(0.00007)
ln(PM2.5) × Section 3 × Post	-0.00022***	-0.00024***	-0.00024***	-0.00187	-0.00024***	-0.00024***
	(0.00002)	(0.00001)	(0.00001)	(0.00172)	(0.00001)	(0.00001)
ln(PM2.5) × Section 3	-0.00001	-0.00001***	-0.00001***	-0.00257	-0.00010***	-0.00010***
	(0.00002)	(6.60e-08)	(6.61e-08)	(0.03812)	(0.00001)	(0.00001)
ln(PM2.5) × Section 2 × Post	-0.00007***	-0.00007***	-0.00007***	-0.00003	-0.000012***	-0.000012***
	(0.00001)	(0.00001)	(0.00001)	(0.00004)	(0.000001)	(0.000001)
ln(PM2.5) × Section 2	-0.00001	-0.00001***	-0.00001***	-0.000051***	-0.000017**	-0.000018**
	(0.00004)	(3.14e-08)	(3.13e-08)	(0.000003)	(0.000008)	(0.000008)
N	4,370,904	4,370,904	4,370,904	4,423,468	4,423,468	4,423,468
R-squared	0.9452	0.9783	0.9825	0.7624	0.7825	0.7976
Housing Attributes	Y	Y	Y	Y	Y	Y
District Attributes	Y	Y	Y	Y	Y	Y
Climate Attributes	Y	Y	Y	Y	Y	Y
Other Pollutants	Y	Y	Y	Y	Y	Y
Community FE		Y	Y		Y	Y
Year by Month FE		Y	Y		Y	Y
Province by Year FE			Y			Y
Day-of-month FE			Y			Y

Notes: This table presents the relabeling effects and perception change of ln(PM2.5) on both home sales prices and rental costs over the past 30 days, considering all Sections in the full sample. Air pollution is measured by the closest monitor. Observations with the previous 30-day period across the policy shock are dropped. Control variables include housing, district, climate attributes and other pollutants, as well as provincial-level division by year, day-of-month, community, and year-by-month fixed effects. The instrument variables are frequencies of wind from eight directions. The robust standards errors are clustered at the district level. *** $p<0.01$, ** $p<0.05$, * $p<0.1$

Table A7. (Re)labeling Effects by Lag Length

	Dependent variable: ln(sales price)					Dependent variable: ln(rent)				
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
Lag length (days)	10	30	90	180	360	10	30	90	180	360
Section 6 × Post	-0.00081	-0.00035	-0.00061	-0.00052	-0.00032	-0.00061	-0.00059	-0.00041	-0.00037	-0.00022
	(0.00211)	(0.00057)	(0.00122)	(0.00319)	(0.00348)	(0.00124)	(0.00058)	(0.00133)	(0.00156)	(0.00153)
Section 6	-0.00712***	-0.00674***	-0.00521***	-0.00502***	-0.00450***	-0.00622***	-0.00473***	-0.00456***	-0.00412***	-0.00381**
	(0.00121)	(0.00049)	(0.00152)	(0.00132)	(0.00122)	(0.00183)	(0.00041)	(0.00121)	(0.00121)	(0.00191)
Section 5 × Post	-0.00317***	-0.00226***	-0.00201***	-0.00192***	-0.00177***	-0.00251***	-0.00166**	-0.00232***	-0.00221***	-0.00202***
	(0.00022)	(0.00051)	(0.00042)	(0.00020)	(0.00032)	(0.00063)	(0.00066)	(0.00023)	(0.00022)	(0.00024)
Section 5	-0.00452***	-0.00436***	-0.00410***	-0.00384***	-0.00312***	-0.00456***	-0.00455***	-0.00419***	-0.00401***	-0.00362***
	(0.00021)	(0.00038)	(0.00021)	(0.00052)	(0.00028)	(0.00018)	(0.00033)	(0.00016)	(0.00018)	(0.00017)
Section 4 × Post	-0.00035	-0.00032	-0.00032	-0.00031	-0.00033	-0.00003	-0.00008	-0.00002	-0.00002	-0.00002
	(0.00134)	(0.00025)	(0.00212)	(0.00222)	(0.00211)	(0.00031)	(0.00009)	(0.00034)	(0.00034)	(0.00032)
Section 4	-0.00452***	-0.00350***	-0.00382***	-0.00379***	-0.00361***	-0.00382***	-0.00399***	-0.00362***	-0.00357***	-0.00321***
	(0.00016)	(0.00033)	(0.00016)	(0.00017)	(0.00014)	(0.00012)	(0.00018)	(0.00019)	(0.00029)	(0.00030)
Section 3 × Post	-0.00421***	-0.00320***	-0.00293***	-0.00234***	-0.00204***	-0.00245***	-0.00222***	-0.00205***	-0.00200***	-0.00178***
	(0.00022)	(0.00010)	(0.00034)	(0.00022)	(0.00020)	(0.00012)	(0.00003)	(0.00012)	(0.00012)	(0.00011)
Section 3	-0.00173***	-0.00154***	-0.00143***	-0.00162***	-0.00143***	-0.00162***	-0.00159***	-0.00153***	-0.00155***	-0.00153***
	(0.00012)	(0.00007)	(0.00021)	(0.00017)	(0.00012)	(0.00012)	(0.00003)	(0.00017)	(0.00016)	(0.00012)
Section 2 × Post	-0.00011	-0.000007	-0.00010	-0.00011	-0.00010	-0.00005	-0.000001	-0.00003	-0.00004	-0.00004
	(0.00021)	(0.000078)	(0.00026)	(0.00021)	(0.00021)	(0.00021)	(0.000002)	(0.00024)	(0.00024)	(0.00025)
Section 2	-0.00162**	-0.00157***	-0.00152**	-0.00132**	-0.00122**	-0.00132***	-0.00133***	-0.00111***	-0.00102***	-0.00104***
	(0.00052)	(0.00012)	(0.00043)	(0.00052)	(0.00045)	(0.00045)	(0.00002)	(0.00026)	(0.00022)	(0.00225)
Post	0.01211***	0.01221***	0.01222***	0.01224***	0.01293***	0.01121***	0.01202***	0.01132***	0.01129***	0.01131***
	(0.00014)	(0.00001)	(0.00074)	(0.00174)	(0.00142)	(0.00232)	(0.00001)	(0.00212)	(0.00212)	(0.00225)

(Continued) Table A7. (Re)labeling Effects by Lag Length

	Dependent variable: ln(sales price)					Dependent variable: ln(rent)				
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
Lag Length (Days)	10	30	90	180	360	10	30	90	180	360
PM2.5	-0.00173***	-0.00208***	-0.00141***	-0.00132***	-0.00124***	-0.00164***	0.01202***	-0.00212***	-0.00202***	-0.00122***
	(0.00121)	(0.00002)	(0.00023)	(0.00023)	(0.00016)	(0.00031)	(0.00001)	(0.00022)	(0.00021)	(0.00012)
PM20.5 × Post	-0.00022***	-0.00026***	-0.00025***	-0.00022***	-0.00025***	-0.00023***	-0.00233***	-0.00022***	-0.00023***	-0.00021***
	(0.00002)	(0.00008)	(0.00002)	(0.00002)	(0.00004)	(0.00002)	(0.00003)	(0.00002)	(0.00002)	(0.00002)
PM20.5 × Section 6 × Post	-0.000039***	-0.000022***	-0.000032***	-0.000031***	-0.000029***	-0.000029***	-0.00023***	-0.000024***	-0.000022***	-0.000021***
	(0.000002)	(0.000004)	(0.000003)	(0.000003)	(0.000003)	(0.000002)	(0.00001)	(0.000002)	(0.000002)	(0.000002)
PM20.5 × Section 6	-0.000003	-0.00003	-0.000002	-0.000003	-0.000002	-0.000003	-0.000022***	-0.000003	-0.000003	-0.000003
	(0.000004)	(0.00002)	(0.000005)	(0.000002)	(0.000005)	(0.000012)	(0.000008)	(0.000012)	(0.000012)	(0.000011)
PM20.5 × Section 5 × Post	-0.000022***	-0.000036***	-0.000031***	-0.000030***	-0.000028***	-0.000024***	-0.000013	-0.000023***	-0.000021***	-0.000020***
	(0.000005)	(0.000004)	(0.000004)	(0.000004)	(0.000003)	(0.000003)	(0.000008)	(0.000003)	(0.000002)	(0.000001)
PM20.5 × Section 5	-0.000003	-0.00002	-0.000002	-0.000002	-0.000002	-0.000003	-0.000029***	-0.000002	-0.000002	-0.000002
	(0.000052)	(0.00002)	(0.000052)	(0.000041)	(0.000032)	(0.000026)	(0.000007)	(0.000002)	(0.000006)	(0.000003)
PM20.5 × Section 4 × Post	-0.000031***	-0.000032***	-0.000026***	-0.000028***	-0.000027***	-0.000025***	-0.00001	-0.000024***	-0.000022***	-0.000020***
	(0.000003)	(0.000001)	(0.000003)	(0.000002)	(0.000002)	(0.000002)	(0.00002)	(0.000002)	(0.000002)	(0.000002)
PM20.5 × Section 4	-0.000001	-0.00003	-0.000001	-0.000001	-0.000001	-0.000001	-0.000024***	-0.000001	-0.000001	-0.000001
	(0.000007)	(0.00002)	(0.000005)	(0.000006)	(0.000005)	(0.000010)	(0.000001)	(0.000010)	(0.000010)	(0.000011)
PM20.5 × Section 3 × Post	-0.000025***	-0.000023***	-0.000023***	-0.000022***	-0.000021***	-0.000027***	-0.000007	-0.000025***	-0.000024***	-0.000021***
	(0.000002)	(0.000003)	(0.000002)	(0.000002)	(0.000002)	(0.000001)	(0.000004)	(0.000001)	(0.000001)	(0.000001)
PM20.5 × Section 3	-0.000001	-0.00001	-0.000001	-0.000001	-0.000001	-0.000001	-0.000026***	-0.000001	-0.000001	-0.000001
	(0.000003)	(0.00001)	(0.000003)	(0.000003)	(0.000003)	(0.000004)	(0.000001)	(0.000004)	(0.000004)	(0.000003)
PM20.5 × Section 2 × Post	-0.000007***	-0.000005***	-0.000007***	-0.000007***	-0.000006***	-0.000009***	-0.00001	-0.000009***	-0.000008***	-0.000008***
	(0.000001)	(0.000001)	(0.000001)	(0.000001)	(0.000001)	(0.000002)	(0.00001)	(0.000002)	(0.000002)	(0.000002)
PM20.5 × Section 2	-0.00001	-0.00001	-0.00001	-0.00001	-0.00001	-0.00001	-0.00008***	-0.00001	-0.00001	-0.00001
	(0.00005)	(0.00001)	(0.00004)	(0.00005)	(0.00004)	(0.00002)	(0.00001)	(0.00002)	(0.00002)	(0.00002)
N	4,370,904	4,370,904	4,370,904	4,370,904	4,370,904	4,423,468	4,423,468	4,423,468	4,423,468	4,423,468
R-squared	0.9752	0.8903	0.9732	0.9741	0.9792	0.8913	0.8872	0.8921	0.8927	0.8951
Housing Attributes	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
District Attributes	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
Climate Attributes	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
Other Pollutants	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
Community FE	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
Year by Month FE	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
Province by Year FE	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
Day-of-month FE	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y

Notes: This table presents the results of heterogeneity analysis by lag length. The model specifications consider all Sections for the lag length of 10, 30, 90, 180, and 360 days, respectively. To make the coefficients of various lag lengths comparable, all variables of Sections for a 30-day period are now transferred to the count of Sections over each period given the lag length. The pollution levels are also averaged over the same period. All regressions are estimated using as instruments the frequencies of wind in 8 directions. Control variables include housing, district, climate attributes, other pollutants, as well as community and year-by-month fixed effects. The robust standards errors are clustered at the district level. *** $p<0.01$, ** $p<0.05$, * $p<0.1$