Air Pollution, Housing Prices, and Costs of Sanctions: A Natural Experiment

Amirhossein Amini Behbahani*

Kaveh Nafari*

October 2017

Abstract

We analyze the causal impact of air pollution on the housing market as the result of a dramatic exogenous increase in air pollution levels in Tehran in 2010 in the aftermath of sanctions imposed on Iran. The sanctions, intended to pressure Iran to end uranium enrichment activities, targeted gasoline imports into the country. In response, Iran rapidly converted some petrochemical plants into refineries to produce gasoline, which was of much lower quality. This caused a quick and drastic increase in air pollution levels that varied significantly across individual neighborhoods. Using this natural experiment and unique administrative data on Tehran's housing market, we find that a 30 parts-per-billion increase in outdoor concentrations of nitrogen dioxide leads to a decrease in housing prices of approximately 3 percent to 6 percent. We find that lower levels of air pollution are associated with higher price-rent ratios, and higher levels of air pollution raise the odds that owners will rent their property rather than occupy it themselves. Our welfare analysis suggests that the deterioration of air quality in 2010 is associated with a reduction in aggregate housing values of \$11 billion to \$16 billion in Tehran alone. Also, this paper offers what we believe is a first examination of indirect costs that stem from international sanctions against Iran.

Keywords: Air Quality, Housing Market, Nitrogen Dioxide, Sanctions Against Iran

* University of Illinois at Urbana-Champaign, Department of Economics, 214 David Kinley Hall, 1407 West Gregory Drive, Urbana, IL 61801, USA. Email addresses: **aminibe2@illinois.edu**, **nafari2@illinois.edu**. The authors would like to thank Richard Akresh, David Albouy, Dan Bernhardt, Hadi Salehi Esfahani, Don Fullerton, Firuz Gahvari, Ben Marx, Daniel McMillen, Adam Osman, Elizabeth Powers, and Julain Reif for very constructive comments that greatly improve the paper.

1. Introduction

The association between air quality and housing values has been the subject of economic studies since the 1960's. Cross-sectional studies using hedonic price models suggest a negative relationship between air pollution indices and housing prices (e.g. Ridker 1967; Ridker et al 1967; Rosen 1974). However, cross-sectional hedonic models suffer from a number of econometric problems such as the omitted variable bias (e.g. Small 1975). This raises questions about the validity of the causal inference and the accuracy of traditional hedonic model-derived estimates of the marginal willingness to pay (MWTP) for air quality.

To address these problems, some studies (e.g. Chay et al 2005; Grainger 2013) have suggested using policy regulations as instrumental variables for changes in the level of air pollution. Chay and Greenstone's (2005) results show that the elasticity of housing values with respect to the level of total suspended particles (TSP) ranges between -0.2 and -0.35 and is larger than those found through cross-sectional studies. Their estimates are based on variations in pollution and housing prices over the course of 10 years from 1970 to 1980. Other studies also utilized IV methods to investigate the long-run association of air pollution and housing values between different regions/counties within a country (e.g. Bayer et al 2009; Isen et al 2017). However, in longer time horizons, the assumption that the housing supply is inelastic can be problematic as there may be variations in unobserved variables that correlate both with the pollution level and housing prices. Besides, households and businesses may find enough time to move to regions/counties that have better air quality. All of these can lead to biased estimates of individuals' marginal willingness to pay for the clear air. Finding a policy that induces a fast and heterogeneous increase in the level of air pollutants within a city can provide a framework that addresses these issues.

In this paper, we examine the casual impact of air pollution on housing prices by exploiting the exogenous and heterogeneous jump in nitrogen dioxide levels across Tehran, induced by unprecedented international sanctions that targeted Iran's gasoline imports and led the government to produce low-quality gasoline as a substitute. We utilize this unique natural experiment combined with a rich dataset that includes around 1 million housing transactions in owner-occupied and rental housing markets over the course of five years from 2009 to 2014. The dataset provides the opportunity to compare the households' responses between the two markets and across locations in the short run when supply is plausibly inelastic, allowing us to measure MWTP for air quality. We then examine the impact of air pollution on individuals' expectations of future housing prices and whether there is any evidence of substitution from the owner-occupied market to the rental market in highly polluted neighborhoods.

A second contribution of this paper is its assessment of the indirect environmental impact of the international sanctions on Iran in an effort to pressure it to suspend its uranium enrichment activities. In this respect, the present study is the first of its kind in this area. Following the imposition of sanctions on gasoline imports in 2010 and the increase in the supply of low-quality gasoline, air pollution rapidly increased in Iranian cities. The heterogeneous nature of this pollution jump within Tehran, which is an important factor in our identification strategy, mostly comes from the wind patterns, urban structure, and the differences in neighborhoods' elevation. Our study addresses the causality issue, exploiting heterogeneous severe increases in the levels of pollution in Tehran in the aftermath of sanctions. Since the effects of sanctions were unanticipated, we have no reason to believe that households sorted based on their preferences for the pollution before the spike.

One other distinctive feature of this particular pollution spike stems from its increase in the level of NO_2 as a prominent combustion-induced air pollutant while other studies have largely focused on pollutants that are mostly induced by industrial activities.

Our research design is based on sharp variation in the pollution indices across 1,700 neighborhoods, and comparing housing values within these neighborhoods over time. We employ daily readings of 39 monitors in Tehran to construct daily distance-weighted pollution indices for each neighborhood. For each transaction, we provide pollution indices that reflect the average level of air pollution over one week, one month, and three months before the transaction date in the respective neighborhood. Our model captures the effects of pollution on housing prices, rents, and price-rent ratio after adjusting for housing characteristics, time effects, and time-invariant neighborhoods effects.

Our findings demonstrate that 30 parts-per-billion (ppb) increase of outdoor concentration of nitrogen dioxide leads to a decrease in housing prices of 3.5 percent to 5.2 percent. Compared to Chay and Greenstone (2005), these estimates signify a lower elasticity of housing values with respect to the level of air pollution. Although these results are closer to the findings of most cross-sectional studies, one might consider that this paper's estimates are mainly derived by the housing market responses to an increase in the level of air pollution in a short-time horizon. We find similar adverse effects in the rental market, albeit the estimates are smaller in magnitude. Our welfare analysis indicates a $11 billion to $16 billion reduction in housing values in 2011 induced by the significant increase in the level of pollution due to gasoline sanctions. Moreover, an increase in the level of air pollution is associated with a decrease in the average price-rent ratio at the neighborhood level. This result may suggest that expectations for future prices make agents in the purchasing market more sensitive than the rental market to the deterioration of the level of air quality.

In addition to main findings, our results also reveal that if we restrict purchasing and rental observations to a shorter time period where supply is more inelastic, the coefficients of interest will be larger. Also, we examine how housing quality will interact with the impact of the pollution on housing prices. We find evidence on heterogeneity by size and floor, suggesting that the larger the housing unit becomes or if the unit's floor is above two, the weaker the impact of the air pollution on the housing value will be. The size and floor's impact is even stronger in the rental market. Further, to mitigate the impact of sellers' (who have currently occupied the housing unit) distaste for pollution, we run same baseline regressions on newly built housing units, where we still find significant and negative coefficients for the impact of pollution. Merging rental and purchasing data, we find that there is a substitution from the owner-occupied market to the rental market. Based on our estimates, the number of properties that are first sold and then offered for lease is significantly higher in more polluted neighborhoods. This pattern is consistent with our base results on the negative association between pollution indices and price-rent ratios. Finally, in section 5.4, we follow a semiparametric approach as an alternative to our fixed effect models. In this method, instead of neighborhoods' fixed effects, we include neighborhood location coordinates as nonparametric components to our model. In doing so, we control for any spatial omitted effect by including the location of each neighborhood in our model. Results from these semiparametric regressions support our baseline results when we use neighborhood's fixed effects.

The rest of the paper is organized as follows. Section 2 reviews related literature and the history of sanction. Section 3 discusses the data. Section 4 presents the empirical model, and section 5 outlines results and discussion followed by robustness checks. Section 6 concludes.

2. Literature Review and Background

2.1 Literature Review

Ridker and Henning (1967) undertake one of the first cross-sectional studies in the literature of the impact of air pollution on the housing prices. Their analysis of 167 neighborhoods in St. Louis shows that the sulfation level index of the air (SO2, SO3, H2S and H2SO4) explains 1.2 percent of the variation of the median property among different neighborhoods. Many other cross-sectional papers based on hedonic price models showed that a decrease in total suspended particles (TSP) results in an increase in property value. Smith and Huang (1995) provide a meta-analysis of many cross-sectional studies. A growing body of literature also uses the housing market to measure values of non-market amenities (e.g. Davis 2004).

Chay and Greenstone (2005) address the cross-sectional studies problems namely the causality issue and the heterogeneous taste for clean air by exploiting 1970 Clean Air Act Amendments (CAAA) as an instrumental variable. Grainger (2013) uses a similar instrumental variable method to compare the impact of the variation in the level of PM10 (particles with a diameter less than 10 micrometers) on rental versus owner-occupied housing values. He finds that only half of the increases in the housing value caused by improvement in air quality are reflected in the form of higher rents. Both studies are based on variations in pollution and housing prices at the county level over the course of 10 years. A growing body of literature also investigates the local impacts on the housing market of industrial activities with hazardous impacts or toxic pollutants (e.g. Davis 2011; Greenstone and Gallagher 2008; Currie, Davis, Greenstone and Walker 2015). Davis (2011) also finds that power plants have a smaller impact on local rent prices than on housing values.

A separate but related body of the literature analyzes the relationship between purchasing prices and rents in the housing market. Capozza and Seguin (1996) examine how price-rent ratios have predictive power for expected changes in future housing prices. Gyourko et al. (2013) discuss the correlation between the price-rent ratio and future expected prices. They show that a higher price-rent ratio implies that to obtain higher expected capital gains in the future, homeowners are willing to accept lower current yield in the form of rent.

There is also a body of the literature on the direct impact of sanctions on economic activities of the targeted country. Some articles (mostly not peer reviewed or in the literature of economics) discuss the economic impacts of recent Iranian Nuclear Sanctions. However, to the best of our knowledge, this is the first paper that measures the indirect impact of the mentioned sanctions, especially their environmental impact.

2.2 History of Sanctions

Following the development of the nuclear program in Iran, a series of international sanctions were imposed on the country's nuclear enrichment program. In 2006, the International Atomic Energy Agency (IAEA) reported Iran's suspicious activities and non-compliance with its agreements. Consequently, the United Nations Security Council Resolution 1737 against Iran nuclear program passed in December of the same year. The resolution demanded that Iran suspend all of its enrichment-related activities. As the dispute continued, a number of other resolutions were passed by the Security Council that mainly targeted Iranian economic activities.[1] The sanctions were not restricted to the Security Council Resolutions. The United States and the European Union imposed several other sanctions against Iran. Consequently, Iran's oil industry,

[1] Texts of UN resolutions 1696, 1737, 1747, 1803, 1835, 1929, 1984, 2049 are available at http://www.un.org/en/sc/documents/resolutions. After Iran Deal in July 2015 resolution of 2231 has been passed. It aimed to gradually lift UN sanctions against Iran.

banking sectors, and international trade activities faced the toughest sanctions in the country's history.

In July 2010, the U.S. Congress passed The Comprehensive Iran Sanctions, Accountability, and Divestment Act in order to extend the sanctions against Iran. It mainly targeted Iran's import of gasoline.[2] Although Iran was a major producer of oil, the country imported almost 40 percent of its gasoline and 11 percent of its diesel fuel at the time. In that year, as a preemptive action, Iran began rapidly increasing its fuel production capacity by converting petrochemical plants to gasoline production refineries in a two-year plan.[3]

2.2.1. Sub-Standard Gasoline and Air Pollution

Replacing imported gasoline with domestic refinery-produced gasoline resulted in a dramatic shock to the level of air pollution in Iran's large cities, especially the capital city of Tehran, starting in December 2010.[4] The air quality index of NO_2 increased almost 100 percent compared to its previous annual average. Since that time, many experts and even government officials have blamed the use of low-quality gasoline produced by domestic petrochemical refineries as the main cause of air pollution. Later, the Iranian oil minister admitted that the main source of the smog is sub-standard gasoline (The Guardian, 2014).

The main reasons for that the use of sub-standard gasoline leads to greater levels of air pollution are: 1) the low octane levels; 2) the higher level of benzene; and 3) the incomplete combustion. Internal combustion engines are one of the main sources of many major pollutants

[2] The text of the act is available at https://www.treasury.gov/resource-center/sanctions/Documents/hr2194.pdf.
[3] Masoud Mirkazemi Minister of Petroleum at the time announced that Iran's gasoline production increase action plan would secure the country against imminent sanctions on fuel imports, and would turn the nation from an importer to an exporter of gasoline.
[4] https://www.theguardian.com/world/2010/dec/09/iran-tehran-pollution-petrol-sanctions.

such as CO, NO_2, and O_3. According to Environmental Protection Agency (EPA), the most prominent source of nitrogen dioxide is emissions from cars and other road vehicles.

Daily data on pollution indices obtained from Tehran air quality monitors show the rapid increase in levels of both NO_2 and O_3. This supports the argument of those who blame the excessive presence of hydrocarbons such as benzene and imperfect combustion of refinery-produced gasoline as the main reason for post-2010 air pollution.

In this research, we use the level of nitrogen dioxide as an index for air pollution. Nitrogen dioxide is considered by many international standards as a major air pollution indicator. For instance, the U.S. EPA's National Ambient Air Quality Standard uses NO_2 as an indicator for a group of nitrogen oxides (NO_x). It is classified as one of the six common pollutants along with ground-level ozone, particulate matter (e.g. PM2.5 and PM10), carbon monoxide, lead, and sulphur dioxide.

2.2.2. Nitrogen Dioxide Health Effects

According to the U.S. EPA, high levels of NO_2 have major negative health effects. A short-term exposure of more than half an hour brings adverse respiratory effects on children and healthy adults (Chay and Greenstone 2003). Also, it exacerbates symptoms of those who have respiratory diseases such as asthma. Increased levels of this highly reactive gas are connected to increased visits to emergency rooms and hospitals for patients with respiratory issues (Shima and Adachi 2000). Nitrogen oxides also reacts with ammonia, moisture, and other compounds to form particles that can penetrate into sensitive lung tissue and cause emphysema, bronchitis and premature death.[5] Nitrogen oxides are also blamed for photochemical processes that lead to the formation of nitric acid (Cleveland 1979). Such acid causes adverse effects on the ecosystem.

The ground-level ozone that is created by NO_x can also cause shortness of breath, as well as throat and eye irritation. The excessive amount of ozone can be a serious problem for the environment. Plant scientists blame ozone for 90 percent of the damage to the vegetation in North America. As it can travel long distances, the urban-produced ground-level ozone can extend its negative effects onto rural and agricultural areas by reducing crop yields.[6]

Nitrogen dioxide is a gas that is visible because it absorbs short-wave length blue light. It has a reddish-brown color when warm, and is yellowish brown at cold temperatures (Shima and Motarki 2000). Nitrogen oxides together with ozone and other photochemical oxidants are key components responsible for the creation of smog. Therefore, a rise in the level of pollutants like NO_2 and O_3 will not only create easily identifiable negative health effects, but will also create smog, so that individuals easily can have a visible, negative way with which to observe and evaluate the air quality in a given neighborhood. This fact supports the notion that nitrogen dioxide provides a valid index both for the relevant level of pollution and for individual perception of the air quality.

3. Data

The Rahbar Informatics Services Company (RISC) provided the housing data. The air quality data described below come from the Tehran Air Quality Control Agency (TAQCA), which provides detailed data on concentrations of six major pollutants including nitrogen dioxide over

[5] https://www3.epa.gov/airquality/nitrogenoxides/index.html
[6] Pollution Prevention and Abatement Handbook, The World Bank Group, 1998, pp 223-225.

time for a network of monitors. Data on Universal Transverse Mercator (UTM) coordinates of Tehran's neighborhoods and air quality control (AQC) monitors are provided by the Iran Post Company. This section describes the data used in this study.

3.1. Housing data

As of 2009, Iranian law requires all housing transactions, including purchasing and rental transactions, to be registered online.[7] Typically, an owner sells or leases her property through real estate agencies. If the seller (owner) and buyer (renter) reach an agreement, the real estate agent will complete specific forms online and record needed information. The information recorded in the system includes personal information of the seller (owner) and the buyer (renter), price (rent), full address of the unit, size, age, ZIP Code, and date of contract. In the address, the floor number of the unit is also available.

The raw data include 348,645 rental and 735,436 purchasing observations during the years 2009 to 2014, covering the 22 different municipal districts of Tehran. In the final data, we remove transactions for which complete information is not available. All non-residential transactions are also excluded.[8] We also exclude observations where the district number does not match with the zip-code, possibly due to data-entering mistakes. Moreover, to rule out the effects of outliers, the rent and price per square meter are trimmed at the 1 percent and 99 percent levels. The final sample includes 296,613 rental and 690,226 purchasing observations from 2009 to 2014.

Table 1 illustrates the distribution of data across districts by representing each of the 22 districts, which contain several thousand rental and purchase observations, indicating that the data

[7] http://www.iranamlaak.ir/Files/TasvibNameh.aspx

[8] An apartment in this study is defined as a unit that is owned individually, which is very similar to the definition of a condo in the U.S. housing market.

are representative of all neighborhoods. Table 2 presents summary statistics for both rental and purchasing data. Data cover around 1,700 neighborhoods (i.e. five-digit zip-codes). The total number of neighborhoods in Tehran is around 2,700, including non-residential areas such as parks, university campuses, airports, and military zones. We drop zip codes that contain fewer than 10 residential transactions within five years of the data.

Later, to create a measure of price-rent ratio at the five-digit zip-code level, we calculate daily average rent and price per square meter for each five-digit zip-code in both rental and purchasing data, respectively, and merge the two data on the basis of five-digit zip-code, year, month, and day. Keeping high-quality matches using this method, the matched data yield 79,292 unique five-digit zip-code-day level observations.

3.2. Air Quality Data

The air quality data used in this study come from TAQCA, which collects hourly observations on concentration of six major pollutants (CO, SO_2, O_3, $PM2.5$, $PM10$, and NO_2) using 39 monitors across Tehran. Figure 1 shows that the locations of monitors are well spread throughout the city. To calculate the pollution level of each neighborhood, we employ UTM coordinates for each five-digit zip-code and the 39 air quality monitors. Note that, In Iran, 10-digit zip-codes locate an address precisely. A five-digit zip-code typically contains several blocks which can properly can properly determine the neighborhood boundaries.[9] Each five-digit zip-code may include a population of 5,000 residents, which is comparable to the population living in one census tract in large cities in the United States.

[9] A block is defined as the smallest area surrounded by four streets.

In order to construct the pollution indices, for each five-digit zip-code, we select the daily readings of the three closest monitors and calculate their inverse distance-weighted average.[10] Then we calculate the average of those daily indices for one week, one month, and three months before the time of each transaction. The logarithms of those averages are used as the value of the pollution-index variable in the model.[11]

4. Model

Figure 2 shows the average level of nitrogen dioxide in parts per billion (ppb) in Tehran since 2006. This figure demonstrates that before autumn of 2010, the average level of nitrogen dioxide density in the air of Tehran was around 30 ppb. A few months after the announcement of the start of new gasoline-production policy, Tehran's air quality monitors showed that the level of NO_2 increased almost to 90 ppb and then stabilized at around 60 ppb. That is an increase of almost 100 percent in the level of the NO_2 Index from the levels recorded before 2010.

The mentioned policy shock, which was caused by sanctions, provides a quasi-natural experiment to study the effect of air pollution on the housing market. First, the impact of this increase in the level of pollution seems to be independent of other factors that may have an impact on the housing market. As shown in Figure 2, the level of air pollution before the policy was adopted is almost stable, and a few months afterwards we observe an evident jump. Therefore, the air quality index of NO_2 does not seem to follow any specific trend or cycle related to macroeconomic factors. The sustained increase in pollution, along with implementation of new

[10] The distance-weighted average for each day includes monitors that were active on that day to account for the fact that some monitors may be added, repaired, or removed on a given day.
[11] We also construct another Pollution Index using the daily inverse distance-weighted average of all 39 monitors. The results are similar using either version of the Pollution Index.

sets of economic sanctions in 2011 and 2012, make it reasonable to assume that individuals living in Tehran would consider that the resulting poorer air quality would continue for the foreseeable future. Second, we observe a heterogeneous increase in the levels of pollution in different neighborhoods. As previously mentioned, our data come from 39 different monitors in different areas of Tehran. Not all neighborhoods and monitors show similar increases in the levels of pollution. Hence, the expectation is that the exogenous and heterogeneous increase in the levels of pollution has affected transaction values differently across neighborhoods. Figure 3 shows trends of the NO_2 index recorded from two separate monitors with roughly the same latitude.

Figure 4 demonstrates the heterogeneity of the pollution index we create to compare air quality across zip codes. This figure graphs the weekly pollution index for two days, one year before and one year after the time of the pollution spike in December 2010. The figure only includes zip codes that cover sales on both days. As figure 4 illustrates, the pollution index graph for one year before the shock is fairly flat across zip codes, with an average of 25 ppb. One year after the peak the heterogeneity of pollution index by zip code is evident with some zip codes still meeting the EPA standards for NO_2 concentration, while for some others, the pollution level is more than twice the standard level. Figure A1 also presents the monthly average of the pollution index across zip codes one year before and one year after the pollution spike peak in December 2010.

This paper suggests that in neighborhoods that experience less of an increase in the level of pollution, the relatively better air quality will be reflected in housing values in the form of higher real prices or rents. In fact, in the short run, where supply is reasonably inelastic, price adjustment fully captures the demand responses. Marginal willingness to pay for clean air is not necessarily equivalent in the purchasing and rental markets. In the purchasing market, individuals may consider the environmental amenities more than they do in the rental market. One explanation is that buyers take into account the long-run potential exposure to pollution. For instance, families may have concerns about the negative long-run impacts of such low air quality on their children's health.

To formally examine the association between air pollution and housing prices, we fit the following regression model:

$$\textit{Log of Price Per Square Meter}_{izt} = \beta_0 + \beta_1.\textit{Log of Pollution Index}_{zt} + \beta_2.\textit{Age}_{izt} + \beta_3.\textit{Size}_{izt} + \beta_4.\textit{Age}_{izt}^2 + \beta_5.\textit{Size}_{izt}^2 + \beta_6.\textit{Age}_{izt}\times\textit{Size}_{izt} + \textit{Floor Indicator}_{izt} + \textit{five-digit Zip-Code Fixed Effect}_z + \textit{Year Fixed Effects}_t + \textit{Seasonal Fixed Effect}_t + \varepsilon_{izt} \quad (1)$$

where i is the index of transaction, z represents the five-digit zip-code, and t indicates the date of the transaction. Equation (1) controls for seasonal and year fixed effects to account for seasonal patterns and macroeconomic variations that impact the overall housing market. It also includes five-digit zip-code fixed effects to capture all time-invariant determinants of housing prices in a neighborhood. We also report richer specifications that include district trends to allow for different over-time adjustment of housing prices in each district. There is a separate municipality in each district, which means public investment in infrastructure and local amenities can follow different trends across those districts. The inclusion of these regional trends does not affect our results.

To consider the impact of outliers, we utilize the logged value of housing prices, rents and pollution indices in our model. We try other specifications including linear and log-linear model, and we find economically and statistically significant results through these specifications, too. However, residuals distribution of the log-log specification look more normal compared to log-linear and linear models. In addition, log-log specification lead to a higher value of R-squared compared to log-linear specification. We also apply Box-Cox lambda transformation to our basic sets of regressions and find small lambda between 0.17-0.25. The null hypothesis of lambda is rejected for all economically sensible transformations of lambda equal to 0, 1 and -1. However, it does not make economic sense to insist on maximizing the log-likelihood score and use the best fitting transformation parameter of 0.17. Qualitatively, the number is closer to zero. Therefore, we use log-log transformation; though, it is worth underscoring that we also find significant results if we use other forms of specification.

This model follows a difference-in-difference strategy that relies on a comparison of housing transaction prices in less- and more-polluted neighborhoods. The constructed time-variant pollution-index variable captures the heterogeneous variation of pollution across neighborhoods. Therefore, our coefficient of interest in equation (1) is β_1. It reflects the impact of different levels of pollution across neighborhoods on housing transaction prices. As both the dependent and the explanatory variable are in logarithm form, the β_1 yields the price elasticity of the air pollution.

We also run the same regression in the rental market to compare the difference of the impact in this market with the impact in the purchasing market. In doing so, we use the logarithm of annual real rent per square meter for each transaction as the dependent variable. Moreover, we construct a panel data by merging the rental and purchasing data. We run panel regressions with the log of neighborhoods' averages of price-rent ratio as the dependent variable. In the next section, we present and discuss our results.

5. Results

5.1. Baseline Results

Table 3 presents the baseline results from eight regressions using equation (1). The dependent variable is a natural logarithm of real price per square meter and the parameter of interest is the log of the pollution index. These regressions are divided into four groups where we use different time periods before the transaction to calculate distance-weighted pollution index for each group. All regressions control for age, size, and floor of the housing unit, along with zip-code, year, and seasonal fixed effects. The even-numbered columns also include municipal region trends. The result of the baseline regression for the purchasing market is based on approximately 650,000 transactions over more than five years. Standard errors are adjusted for 1,710 clusters based on the notion of five-digit zip-codes. For all regressions in this section, the sample excludes observations within two months before and after the pollution spike (Dec 2010) to better capture the heterogeneity across zip codes. Results including those four months are available in Appendix Table B1 to B3.

As reported in Table 3, all coefficients of pollution indices are highly significant and negative. These results demonstrate the elasticity of (negative) 0.035 to 0.052 for house prices with respect to the NO_2 pollutant factor. In other words, a 30-unit increase in the NO_2 pollutant index (almost equal to the average increase in Tehran) will result in a decrease in housing values of 3 percent to 6 percent. From Table 3, we observe an increase in the impact as the time duration of the pollution index changes from one week in column (1) to three months in column (3). The 95 percent confidence intervals for columns (1) and (2) do not overlap with the 95 percent confidence interval in column (3). This pattern suggests that home buyers/ renters will demonstrate a greater degree of aversion to air pollution if the deterioration in the air quality is more persistent in a given neighborhood prior to the time of transaction.

Table 4 presents results of regressions based on equation (1), using the log of real rental prices as the dependent variable. The coefficients are smaller in magnitude compared to the results for the purchasing market in Table 3. One explanation for this difference in impact between the purchasing and rental markets might be due to long-term concerns in buying versus renting a property. In other words, buyers demonstrate larger willingness to pay for the clean air as they probably plan to stay longer in that property than tenants. Moreover, one might consider that buying a property is a form of investment. Hence, the expectation of future prices might play an important role in decision making about purchasing a house. Next, we explore this possibility.

In Table 5, we construct panel data using daily average prices and rents in both the purchasing and rental markets for each five-digit zip-code. The dependent variable is the ratio of the daily five-digit zip-code average price to rent. Here, as in the previous analyses, the variable of interest is the pollution index. Following the baseline regression, we control for average age, size, and other features for each zip code. The panel regression also controls for both time and five-digit zip-code fixed effects.

The estimates from Table 5 show that a 1 percent increase in the level of air pollution is associated with a 0.019 percent to 0.028 percent decrease in the price-rent ratio. Controlling for localized trends (presented in the even-numbered columns) does not change the results. Our estimates suggest that in more-polluted neighborhoods, individuals might expect lower increases in the housing prices over the long run compared to relatively cleaner neighborhoods. This is consistent with the findings of Capozza and Seguin (1996) and Gyourko et al. (2013) that show higher price-rent ratios in housing markets are associated with higher expected capital gains.

5.2. Alternative Specifications and Robustness Checks

In the short run, housing supply is relatively inelastic, thus, the full welfare effects of pollution are exclusively captured by adjustment in prices (rents). On the other hand, over the long run, some of the welfare effects can be captured by quantity adjustment as supply becomes more elastic. To attenuate the effects of quantity responses, Tables 6 and 7 present results from equation 1 that restrict purchasing and rental observations to within 20 months of the pollution spike that took place in December 2010.[12] Our estimates for the pollution indices in the short run for both the rental and owner-occupied markets are larger, but consistent with the base results. Over the shorter period of time with arguably more inelastic supply, house price capitalization explains the full welfare effect so that the point estimates are larger.[13]

Taking advantage of observable characteristics of properties in our data, we also examine how variation in quality of houses can affect our baseline estimates. The housing characteristics we explore are size, floor and age of properties. Table 8 presents the results of this investigation for the owner-occupied market. Regression models are based on the augmented versions of equation (1), which include an additional term for the interaction of the pollution indices with each of the above characteristics. We then estimate another regression model that includes all interaction terms. The parameter estimates associated with *Pollution Index*×*Property Age* across different specifications are almost all insignificant, indicating that there is no evidence of heterogeneity by property age. On the other hand, we find evidence on heterogeneity by property size and floor. Columns (2), (6), and (10), which include an interaction of Pollution Index with size, imply that a 100-square-meter increase in the size of a property reduces the effects of

[12] Our data start from March 2009, 20 months before December 2010.
[13] The 95 percent confidence interval for the *one-week* and *one-month pollution index* in Table 6 do not overlap those associated with the counterpart estimates in Table 3.

pollution on housing prices by half. A possible explanation for this result is that larger properties arguably have better quality and higher level of additions, appliances, and other amenities. From a buyer's perspective, these amenities may mitigate the adverse effects of air pollution on the desirability of a given property. Also, we include a floor dummy variable equal to one if the unit's floor is three or above. Columns (3), (7), and (11) show that coefficients of interactions between the pollution index and floor fixed effect is positive, meaning that the impact of pollution on housing prices is smaller for units located at higher floors. There can be different explanations for this result. One may argue that older buyers tend to buy units in lower floors, and they are expected to have higher distaste for air pollution or as altitude and wind leads to less exposure to the pollution at higher floors. We may add that buildings with more than two floors may have better quality in terms of appliances, and again these substitutes may mitigate the adverse air pollution impacts.

Table 9 presents respective estimates for the rental market. Similar to estimates in Table 8, we find evidence for heterogeneity with respect to size and floor. Point estimates for the interaction of size and pollution, or floor fixed effect and pollution are larger in the rental market. Moreover, the coefficient estimates of the pollution index in Table 9 are significantly smaller than their counterparts in Table 8, which coincides with our explanation for the baseline results. Under the assumption that the size or floor are reasonable proxy for quality of housing, it is possible that, at the time of a given transaction, renters, as opposed to buyers, consider the quality of housing to be more substitutable with air quality. This is to say, renters behave more like short-term consumers of housing, while buyers behave more like long-term investors.

One might expect that in highly polluted neighborhoods sellers with an extreme aversion to air pollution are willing to sell their properties at discounted value to move out sooner. In that case, the price response to the pollution may be partially driven by sellers' aversion to pollution. To alleviate this concern, we rerun the specification (1), focusing only on new construction. The advantage of this approach is that a seller of a newly constructed property is plausibly indifferent to the air pollution levels in the neighborhood of the given property as he or she most likely does not reside there.

Table 10 reports the pollution index estimates for a subsample of new construction in the purchasing market. Point estimates are smaller in magnitude compared to estimates in Table 3, ranging from 0.031 to 0.045. This result suggests that sellers' views regarding air pollution might have weak influence on our estimates of local responses to the air pollution. However, the 95 percent confidence intervals of estimates for the sample of new construction overlap those associated with the estimates for the full sample.

Thus far, all the evidence on the effects of air pollution on housing prices and rents use the distance-weighted average for pollution indices. Here we explore an alternative estimation that uses non-distance weighted emissions of nitrogen dioxide for the pollution indices. In particular, we construct a one-mile radius circle around each monitor and assign the average of daily readings of nitrogen dioxide concentrations from a given monitor to the housing transactions that lie within the given circle. Note that if a housing transaction is close to more than one monitor, the pollution index is the average of readings from all close monitors.

Table 11 shows the results for the alternative estimations. The regression models are based on equation (1) and include year, seasonal, and five-digit zip-code fixed effects. The estimates indicate that a 100 percent increase in the level of outdoor nitrogen dioxide is associated with a 1.8 to 3.1 percent reduction in housing values. Despite the fact that we drop roughly 80 percent of our observations, all estimates are still strongly significant, albeit smaller in magnitude than the baseline results. Table B.3 presents the results for half-mile circles to check for the sensitivity of these results to the choice of distance. We find that our results are robust to the choice of distance. Using similar specifications for the rental market leads to insignificant coefficients as only 12 percent to 16 percent of rental observations survive.

5.3. Effects of Pollution on Buyers' Decisions on Property Usage

In this section, we present evidence indicating that the pollution may change the usage of purchased properties from owner occupied to non-owner occupied. In fact, buyers of owner-occupied properties in highly polluted areas can avoid pollution by turning them to rental properties. Moreover, based on our findings of the negative correlation between the price-rent ratio and the level of pollution, conditional on a property's price, the current yield (rent) on housing investment is more likely to be higher in more-polluted neighborhoods. Therefore, the prediction is that the number of properties that are first sold, and then offered for lease will be significantly higher in more polluted neighborhoods.

To check for the validity of this prediction, we merge the purchasing data with the rental data on the basis of 10-digit zip code, floor-level, size and district to determine which properties appear in both datasets. We tag the properties among these for which the sales date is before the rent date. There are 55,532 properties that buyers have offered for lease. We refer to these properties as "bought and rent" properties. We formally investigate the impact of air pollution on the probability of the substitution of a property from being owner occupied to being rented using the following logit regression:

$$Y_{it} = \beta_0 + \beta_1.Log\ of\ Pollution\ Index_{zt} + \beta_2.Age_{izt} + \beta_3.Size_{izt} + \beta4.Age_{izt}^2 + \beta_5.Size_{izt}^2 + \beta_6.Age \times Size + Floor\ Indicator + five\text{-}digit\ Zip\text{-}Code\ Fixed\ Effect + Year\ Fixed\ Effects + Seasonal\ Fixed\ Effect + \varepsilon \quad (2)$$

where Y_{it} is an indicator equal to one if a property is "bought and rent" and zero otherwise, and t is the date of the transaction. The independent variables are the same as those in equation (1). Table 12 reports the results. As predicted, we find that the probability of switching the usage of a property from owner occupied to non-owner occupied is significantly higher in more-polluted neighborhoods. A 100 percent increase in the concentration of outdoor nitrogen dioxide is associated with an increase of approximately 10 percent in the odds of renting a purchased property.

5.4. Spatial Analysis Using Locations and Semiparametric Approach

In our base model, we use fixed effects for neighborhoods as controls for locations. These fixed effects aim to control for any omitted time-invariant variables that may correlate with error terms. One concern with the fixed effect approach is that, omitted variables may vary smoothly over space. McMillen (2010) argues that in this case a semiparametric approach can be utilized to control for spatial trends and be an alternative to a fixed effect approach and other spatial models such as spatial lag models. In this approach, the semiparametric regression takes the form of $Y=X\beta+f(la,lo)+u$ where latitude or longitude of housing locations are controlled nonparametrically. As a result, without any restrictions on the function of coordinates, we control for any omitted spatial effect. In this section, we run different regressions similar to our baseline model, but this time, instead of five-digit zip-code fixed effects we try to control for other spatial variables in our model and lastly run a semiparametric regression. Here, we used the UTM coordinates instead of latitude and longitude to be consistent with our other regressions' results. We found similar results when using latitude and longitude instead of UTM, X and Y coordinates.

To start, we construct panels of data based on our purchasing and rental datasets by taking the median of all observable variables for each day in each neighborhood.[14] Table 13 presents this section's spatial analysis results for both the purchasing market, and Table 14 includes results for the rental market.

First, we start with parametric models while adding controls that vary spatially across neighborhoods. On both tables, in columns (1), (3) and (5) we run a panel regression controlling for each neighborhood's median of control variables in equation (1). We add a neighborhood's distance from the city center, its square and the respective elevation value to our set of controls.

Next, we run a semiparametric model. Instead of fixed effects or spatial variables, we include neighborhoods' geographic coordinates as nonparametric components of our model. To run our analysis, we utilize McSpatial R-package. The Semip command in this package implements Robinson's (1988) semi-parametric estimator to estimate our model while controlling for both UTM coordinates nonparametrically.[15] In this method, we first run the nonparametric regression of the dependent variable Y on coordinates and nonparametric regressions of X on coordinates using locally weighted regression methods. Second, we run the OLS regression of residuals of the two sets of nonparametric estimates, omitting the intercept. The resulting coefficients of the residuals regression will yield our estimates of β. Based on the mentioned method, results in

---

[14] In our data, we do not have the coordinates of each transaction/address but rather the five-digit-zipcode neighborhood. Therefore, we construct a panel data and used each neighborhood's distance from city center, elevation and finally location coordinated as control variables.

[15] We used Euclidean distance method while other distance methods or using latitude or longitude led to similar results.

Columns (2), (4) and (6) of Tables 13 and 14 present the coefficient of interest for our pollution index. Results show that the impact of pollution on housing prices are robust and significant. The semi-parametric models' estimate for elasticity of housing values with respect to the level of air pollution is between -0.04 to -0.06, which support our fixed effect models' estimates on Tables 3. Our Table 14's results for rental market based on the semiparametric approach is stronger compared to those results from the fixed effect model or panel regression but still the impact is smaller compared to pollution effects in purchasing market.

5.5. Costs of the Sanctions

All of our analyses show that air pollution has a causal effect on housing prices and rents in Tehran. The deterioration of the air quality in Tehran and the subsequent consequences that linked to higher levels of pollution can be considered to be indirect impacts of the sanctions. In this section, we use the results from Table 3 to analyze the extent to which the cost of the sanctions is associated with the adverse effect of pollution on the housing market.

The above hedonic approach leads to an estimation of average marginal willingness to pay (MWTP) for a one-unit improvement in the pollution index. However, to measure the welfare consequences of the sanction-induced non-marginal increase in air pollution, we need to identify the MWTP function (Chay and Greenstone, 2005). Therefore, we calculate the willingness to pay (WTP) for pollution under the assumption of linear and homogeneous preferences, which means constant MWTP. Under these strong assumptions, we provide our simple welfare analysis here.

As mentioned before, Tehran's residents experienced an average of 30 units increase of nitrogen dioxide index in the year following the implementation of the gasoline sanction (2011), with the capitalization rate of 3.5 percent to 5.2 percent declines in their property values. Since the nominal price per square meter in 2011 was 20 million Rials ($1,300 in 2011 dollars), this means a reduction per square meter of housing of approximately 700 to 1055 thousands Rials ($48 to $72 in 2011 dollars).[16] The National Population and Housing Census (NPHC) data from the Iran Statistics Center show that in 2011 about 2.6 million residential units were in Tehran, with a total accumulative size of approximately 228 million square meters. These numbers imply that the dramatic increase in air pollution due to sanctions is associated with a loss in the housing market of approximately $11 billion to $16 billion. The estimated costs will be larger if we were to include all other cities, especially large metropolitan regions of Iran.

6. Conclusions

This paper exploits a natural experiment to examine the economic value of air quality and infer indirect costs of international sanctions. The exogenous and heterogeneous increase in the level of NO_2 combined with rich data on individual housing transactions provide a set-up that mitigates econometric concerns. One contribution of this research is that with this unique structure, we examine agents' responses to the variation in the levels of the air quality in both purchasing and rental markets within one city in the short run.

We show that air quality has a considerable impact on housing values. In fact, the dramatic increase in the level of air pollution in Tehran in 2010 is associated with an average decrease in housing prices of 3.5 percent to 5.2 percent. We also find significant reduction in rental prices, though the magnitudes are smaller. The panel analysis also reveals that more-polluted neighborhoods are associated with lower price-rent ratios, which implies the impact of air pollution

[16] IRR-USD exchange change rate is approximately 15,000 for 2011.

on expectations of future capital gains. This study also provides evidence on marginal substitution between two markets. We find that the increase in the level of air pollution raises the odds of renting a purchased property.

This paper is also the first to use a hedonic approach to study one aspect of the indirect and environmental costs of sanctions against Iran. Based on a simple cost analysis, this incidence is responsible for the loss of $11 billion to $16 billion (in 2011 dollars) in the housing market in Tehran alone. These sorts of sanctions and restrictions remain common throughout the world, and, thus, our paper can provide a better perspective of total welfare consequences of these policies.

Our finding of different responses from rental and owner-occupant properties might be of interest for future studies that attempt to separate effects of policies on housing consumption and investments. Another extension of this paper is to look at the impacts of sanction-induced increases in air pollution on human health, such as child birth-weight and mortality of children and the elderly.

References

Auffhammer, Maximilian, Antonio Bento, and Scott Lowe. 2009. "Measuring the Effects of the Clean Air Act Amendments on Ambient PM10 Concentrations: The Critical Importance of a Spatially Disaggregated Analysis." *Journal of Environmental Economics and Management* 58(1): 15-26.

Bayer, Patrick, Nathaniel Keohane and Christopher Timmins. 2009. "Migration and Hedonic Valuation: The Case of Air Quality." *Journal of Environmental Economics and Management*, 58(1): 1-14.

Capozza, Dennis R., and Paul J. Seguin. 2009. "Expectations, efficiency, and euphoria in the housing market." *Journal of Urban Economics,* 26(3): 369-386.

Chay, Kenneth Y., and Michael Greenstone. 2003. "The Impact of Air Pollution on Infant Mortality: Evidence from Geographic Variation in Pollution Shocks Induced by a Recession." *Quarterly Journal of Economics* 118(8): 1121 – 1167.

Chay, Kenneth Y., and Michael Greenstone. 2005. "Does Air Quality Matter? Evidence from the Housing Market." *Journal of Political Economy,* 113(11): 376 – 423.

Cleveland, William S., and T. E. Graedel. 1979. "Photochemical Air Pollution in the Northeast United States." *Science* 204(June): 1273 – 1278.

Currie, Janet, Lucas Davis, Michael Greenstone, and Reed Walker. 2015. "Environmental Health Risks and Housing Values: Evidence from 1,600 Toxic Plant Openings and Closings." *American Economic Review,* 105(2): 678-709.

Davis, Lucas W. 2004. "The Effect of Health Risk on Housing Values: Evidence from a Cancer Cluster." *American Economic Review* 94(5): 1693 – 1704.

Davis, Lucas W. 2008. "The Effect of Driving Restrictions on Air Quality in Mexico City." *Journal of Political Economy,* 116(1): 38 – 81.

Davis, Lucas W. 2011. "The Effect of Power Plants on Local Housing Values and Rents." *Review of Economics and Statistics,* 93(4): 1391 - 1402.

Grainger, Corbett A. 2013. “The Distributional Effects of Pollution Regulations: Do Renters Fully Pay for Cleaner Air?” *Journal of Public Economics,* 96(9): 840 – 852.

Greenstone, Michael, and Justin Gallagher. 2008. “Does Hazardous Waste Matter? Evidence from the Housing Market and the Superfund Program.” *The Quarterly Journal of Economics,* 123(3): 951-1003.

Gyourko, Joseph, Christopher Mayer, and Todd Sinai. 2013. "Superstar cities." *American Economic Journal: Economic Policy*, 5(4): 167-199.

Isen, Adam, Maya Rossin-Slater, and W. Reed Walker. 2017. "Every breath you take—Every dollar you’ll make: The long-term consequences of the Clean Air Act of 1970." *Journal of Political Economy,* 125(3): 848-902.

McMillen, Daniel P. 2010. “Issues in spatial data analysis.” *Journal of Regional Science*, 50(1): 119-141.

McMillen, Daniel P. 2013. “McSpatial: Nonparametric spatial data analysis.” R package version, 2.

Ridker, Ronald G. 1967. “Economic costs of air pollution”. New York: Praeger.

Ridker, Ronald G., and John A. Henning. 1967. “The Determinants of Residential Property Values with Special Reference to Air Pollution.” *Review of Economics and Statistics,* 49(5): 246- 257.

Rosen, Sherwin. 1974. “Hedonic prices and implicit markets: product differentiation in pure competition”. *Journal of political economy,* 82(1): 34-55.

Robinson, Paul M. 1988. "Root-N-Consistent Semiparametric Regression," *Econometrica: Journal of the Econometric Society,* 931-954.

Small, Kenneth A. (1975). “Air pollution and property values: further comment”. *The Review of Economics and Statistics*, 57(February): 105-107.

Smith, Kerry V., and Ju-Chin Huang. 1995. “Can Markets Value Air Quality? A Meta-Analysis of Hedonic Property Value Models.” *The Journal of Political Economy,* 103(1): 209-227.

Shima, M., and Motoaki Adachi. 2000. "Effect of Outdoor and Indoor Nitrogen Dioxide on Respiratory Symptoms in Schoolchildren." *International Journal of Epidemiology*, 29(2): 862-870.

U.S. EPA. "Altitude as a Factor in Air Pollution." U.S. Environmental Protection Agency, Washington, D.C., EPA/600/9-78/015 (NTIS PB285645), 1978.

Figures

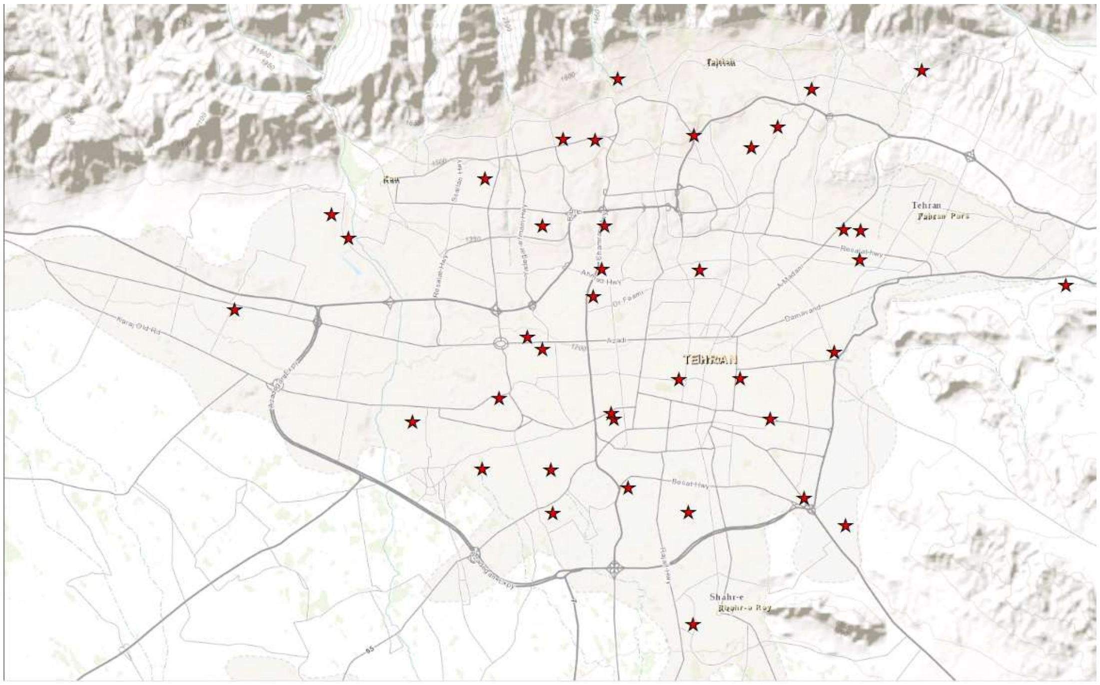

Figure 1: Distribution of Monitors across Tehran

Notes: This figure illustrates the location of 39 monitors across Tehran.

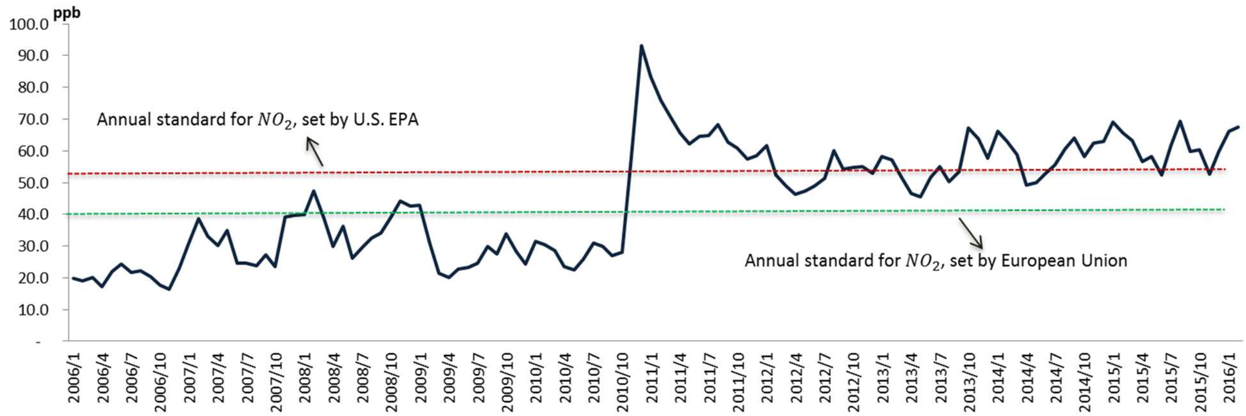

Figure 2: Concentration of Nitrogen Dioxide (NO_2) in Tehran

Notes: This figure shows the average quarterly level of NO_2 measured in parts per billion based on daily readings of Tehran Air Quality monitors for years 2006 to 2016. The Comprehensive Iran Sanctions, Accountability, and Divestment Act was passed by U.S. Congress in July 2010 to restrict Iran's import of gasoline. The red dashed line shows the annual standard for NO_2 set by U.S. EPA. The green dashed line shows the annual standard for NO_2 set by the European Union.

Figure 3: Concentration of Nitrogen Dioxide across Tehran

Notes: This figure shows the heterogeneous variations in level of nitrogen dioxide between two districts in Tehran for years 2009 to 2014. Tehran is divided into 22 municipal regions. District 4, illustrated by the solid line, is located at the west side of Tehran. District 22, illustrated by the dashed line, is located at the east side of Tehran. Both districts are considered to be resided by urban middle-class residents.

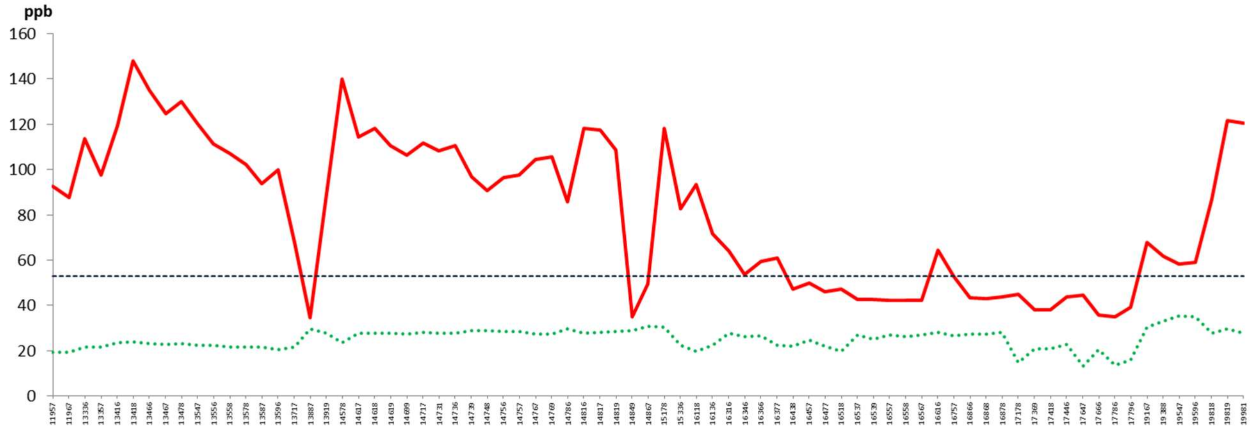

Figure 4: The Level of Pollution Index across Neighborhoods

Notes: This figure shows the heterogeneous variations in level of distance-weighted pollution index across five-digit zip codes for two days; one year before (12/15/2009) and after (12/15/2011) the peak of the sanction-induced pollution jump. The figure includes zip code that contain sales record for both days. Dashed line shows the annual standard for NO_2 set by U.S. EPA.

Tables

Table 1: Distribution of Properties across Districts

District	Owner-Occupant Market	Rental-Housing Market
1	24,607	11,591
2	57,938	34,299
3	27,459	14,980
4	73,681	29,136
5	93,777	43,552
6	25,737	15,803
7	37,509	19,522
8	42,408	18,248
9	13,168	5,459
10	40,754	17,782
11	32,217	12,191
12	21,263	8,641
13	24,467	10,470
14	42,618	15,338
15	37,494	11,614
16	14,632	4,660
17	16,931	3,508
18	24,522	6,462
19	9,439	2,704
20	10,747	3,212
21	13,430	4,140
22	5,428	3,301
Total	690,226	296,613

Notes: This table shows the number of housing transactions in each district for years 2009 -2014. Column (2) presents number of purchasing transactions. Column (3) presents number of rental transactions.

Table 2: Summary Statistics

Variables	Owner-Occupant Market	Rental-Housing Market
Mean Price per Square Meter (000 Rials)	43,654	
Mean Rent per Square Meter (000 Rials)		3,130
Median Size (Square Meter)	72	71
Median Age (Year)	5	9
Number of Neighborhoods (5-digit zip codes)	1,710	1,699
Total Observations	690,217	296,613

Notes: This Table presents the summary statistics for sample of residential properties transactions for years 2009 to 2014. Rent and price values are deflated to reflect year 2015 prices using the Statistical Centre of Iran Housing Price Index. Each five-digit zip code in the sample represents one neighborhood.

Table 3: The Impact of Air Pollution on Housing Prices

	1 Week		1 Month		3 Months	
	(1)	(2)	(3)	(4)	(5)	(6)
Pollution Index	-0.0349***	-0.0349***	-0.0416***	-0.0416***	-0.0520***	-0.0520***
	(0.00191)	(0.00191)	(0.00219)	(0.00219)	(0.00241)	(0.00240)
Year Fixed Effects	X	X	X	X	X	X
5-Digit Zip-code Fixed Effects	X	X	X	X	X	X
Seasonal Fixed Effects	X	X	X	X	X	X
District Trends		X		X		X
Observations	648,776	648,776	648,606	648,606	647,000	647,000
R-squared	0.619	0.620	0.619	0.620	0.620	0.621

Notes: This table presents the impact of air pollution on housing prices for purchased transactions from years 2009 to 2014. Observations within 2 months after and before the pollution spike (Dec 2010) are excluded. All regressions are based on equation (1). The dependent variable is log of real price per-square meter. Pollution index is the daily inverse distance weighted-average of the readings of three closest monitors' measures of NO_2 for each zipcode. For columns (1) and (2), the Pollution Index is average of those daily pollution indices for one week before the time of each transaction. For columns (3) and (4), the Pollution Index is average of those daily pollution indices for one month before the time of each transaction. For columns (5) and (6), the Pollution Index is average of those daily pollution indices for three months before the time of each transaction. All specifications include five-digit zip-code, year, and seasonal fixed effects. The even-numbered columns also include municipal district trend effects. Standard errors in all columns are clustered by five-digit zip-code and stars indicate statistical significance level. * = 10 percent level, ** = 5 percent level. *** = 1 percent level.

Table 4: The Impact of Air Pollution on Rental Prices

	1 Week		1 Month		3 Months	
	(1)	(2)	(3)	(4)	(5)	(6)
Pollution Index	-0.00685**	-0.00676**	-0.00895***	-0.00886***	-0.0136***	-0.0134***
	(0.00271)	(0.00270)	(0.00312)	(0.00311)	(0.00354)	(0.00353)
Year Fixed Effects	X	X	X	X	X	X
5-Digit Zip-code Fixed Effects	X	X	X	X	X	X
Seasonal Fixed Effects	X	X	X	X	X	X
District Trends		X		X		X
Observations	293,605	293,605	293,432	293,432	292,355	292,355
R-squared	0.408	0.411	0.408	0.411	0.408	0.411

Notes: This table presents the impact of air pollution on rental prices for rental transactions from years 2009 to 2014. Observations within 2 months after and before the pollution spike (Dec 2010) are excluded. All regressions are based on equation (1). The dependent variable is log of total annual real rent per-square-meter. Pollution index is the daily inverse distance weighted-average of the readings of three closest monitors' measures of $\boldsymbol{NO_2}$ for each zipcode. For columns (1) and (2), the Pollution Index is average of those daily pollution indices for one week before the time of each transaction. For columns (3) and (4), the Pollution Index is average of those daily pollution indices for one month before the time of each transaction. For columns (5) and (6), the Pollution Index is average of those daily pollution indices for three months before the time of each transaction. All specifications include five-digit zip-code, year, and seasonal fixed effects. The even-numbered columns also include municipal district trend effects. Standard errors in all columns are clustered by five-digit zip-code and stars indicate statistical significance level. * = 10 percent level, ** = 5 percent level. *** = 1 percent level.

Table 5: The Impact of Air Pollution on Price-Rent Ratio

	1 Week		1 Month		3 Months	
	(1)	(2)	(3)	(4)	(5)	(6)
Pollution Index	-0.0194***	-0.0192***	-0.0235***	-0.0233***	-0.0282***	-0.0282***
	(0.00557)	(0.00556)	(0.00649)	(0.00647)	(0.00732)	(0.00730)
Year Fixed Effects	X	X	X	X	X	X
5-Digit Zip-code Fixed Effects	X	X	X	X	X	X
Seasonal Fixed Effects	X	X	X	X	X	X
District Trends		X		X		X
Observations	78,365	78,365	78,362	78,362	78,329	78,329
R-squared	0.156	0.158	0.156	0.158	0.156	0.158

Notes: This table presents the impact of air pollution on price-rent ratio from years 2009 to 2014. All regressions are based on equation (1). Observations within 2 months after and before the pollution spike (Dec 2010) are excluded. The dependent variable is zip code-day average price divided by average rent. Pollution index is the daily inverse distance weighted-average of the readings of three closest monitors' measures of NO_2 for each zipcode. For columns (1) and (2), the Pollution Index is average of those daily pollution indices for one week before the time of each transaction. For columns (3) and (4), the Pollution Index is average of those daily pollution indices for one month before the time of each transaction. For columns (5) and (6), the Pollution Index is average of those daily pollution indices for three months before the time of each transaction. All specifications include five-digit zip-code, year, and seasonal fixed effects. The even-numbered columns also include municipal district trend effects. Standard errors in all columns are clustered by five-digit zip-code and stars indicate statistical significance level. * = 10 percent level, ** = 5 percent level. *** = 1 percent level.

Table 6: The Impact of Air Pollution on Housing Prices within 20 Months of the Pollution Spike

	1 Week		1 Month		3 Months	
	(1)	(2)	(3)	(4)	(5)	(6)
Pollution Index	-0.0477***	-0.0478***	-0.0531***	-0.0531***	-0.0573***	-0.0574***
	(0.00218)	(0.00217)	(0.00240)	(0.00238)	(0.00249)	(0.00247)
Year Fixed Effects	X	X	X	X	X	X
5-Digit Zip-code Fixed Effects	X	X	X	X	X	X
Seasonal Fixed Effects	X	X	X	X	X	X
District Trends		X		X		X
Observations	353,645	353,645	353,475	353,475	351,869	351,869
R-squared	0.653	0.654	0.653	0.654	0.654	0.655

Notes: This table presents the impact of air pollution on housing prices for purchased transactions from years 2009 to 2011. Observations within 2 months after and before the pollution spike (Dec 2010) are excluded. All regressions are based on equation (1). The dependent variable is log of real price per-square meter. Pollution index is the daily inverse distance weighted-average of the readings of three closest monitors' measures of $\boldsymbol{NO_2}$ for each zipcode. For columns (1) and (2), the Pollution Index is average of those daily pollution indices for one week before the time of each transaction. For columns (3) and (4), the Pollution Index is average of those daily pollution indices for one month before the time of each transaction. For columns (5) and (6), the Pollution Index is average of those daily pollution indices for three months before the time of each transaction. All specifications include five-digit zip-code, year, and seasonal fixed effects. The even-numbered columns also include municipal district trend effects. Standard errors in all columns are clustered by five-digit zip-code and stars indicate statistical significance level. * = 10 percent level, ** = 5 percent level. *** = 1 percent level.

Table 7: The Impact of Air Pollution on Rental Prices 20 Months of the Pollution Spike

	1 Week		1 Month		3 Months	
	(1)	(2)	(3)	(4)	(5)	(6)
Pollution Index	-0.0113**	-0.0113**	-0.0167***	-0.0168***	-0.0212***	-0.0212***
	(0.00451)	(0.00449)	(0.00515)	(0.00512)	(0.00571)	(0.00568)
Year Fixed Effects	X	X	X	X	X	X
5-Digit Zip-code Fixed Effects	X	X	X	X	X	X
Seasonal Fixed Effects	X	X	X	X	X	X
District Trends		X		X		X
Observations	96,542	96,542	96,369	96,369	95,292	95,292
R-squared	0.418	0.420	0.419	0.420	0.420	0.421

Notes: This table presents the impact of air pollution on rental prices for rental transactions from years 2009 to 2014. Observations within 2 months after and before the pollution spike (Dec 2010) are excluded. All regressions are based on equation (1). The dependent variable is log of total annual real rent per-square-meter. Pollution index is the daily inverse distance weighted-average of the readings of three closest monitors' measures of $\boldsymbol{NO_2}$ for each zipcode. For columns (1) and (2), the Pollution Index is average of those daily pollution indices for one week before the time of each transaction. For columns (3) and (4), the Pollution Index is average of those daily pollution indices for one month before the time of each transaction. For columns (5) and (6), the Pollution Index is average of those daily pollution indices for three months before the time of each transaction. All specifications include five-digit zip-code, year, and seasonal fixed effects. The even-numbered columns also include municipal district trend effects. Standard errors in all columns are clustered by five-digit zip-code and stars indicate statistical significance level. * = 10 percent level, ** = 5 percent level. *** = 1 percent level.

Table 8: Responses to Air Pollution by Size, Age and Floor (Owner-occupied Market)

	1 Week				1 Month				3 Months			
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)
Pollution Index	-0.0369***	-0.0717***	-0.0387***	-0.0713***	-0.0434***	-0.0814***	-0.0454***	-0.0807***	-0.0530***	-0.0915***	-.0566***	-0.0912***
	(0.00217)	(0.00459)	(0.00208)	(0.00455)	(0.00248)	(0.00498)	(0.00233)	(0.00492)	(0.00273)	(0.00524)	(0.00250)	(0.00518)
Pollution Index ×Property Age	0.000268*			-.0000419	0.000241			-0.000109	0.000133			-0.00022
	(0.000160)			(0.000166)	(0.000166)			(0.000173)	(0.000173)			(0.000179)
Pollution Index ×Property Size		0.000467***		0.000423***		0.000506***		0.000465***		0.000500***		0.000467***
		(5.59e-05)		(5.65e-05)		(6.00e-05)		(6.04e-05)		(6.14e-05)		(6.15e-05)
Pollution Index ×Property Floor Index			0.009387***	0.008124***			0.009677***	0.008130***			0.010252***	0.00856***
			(0.00189)	(0.00185)			(0.00199)	(0.00196)			(0.00207)	(0.00203)
Year Fixed Effects	X	X	X	X	X	X	X	X	X	X	X	X
5-Digit Zip-code Fixed Effects	X	X	X	X	X	X	X	X	X	X	X	X
Seasonal Fixed Effects	X	X	X	X	X	X	X	X	X	X	X	X
Observations	648,776	648,776	614,060	614,060	648,606	648,606	613,971	613,971	647,000	647,000	613,150	613150
R-squared	0.619	0.619	0.623	0.623	0.619	0.620	0.623	0.623	0.620	0.620	0.623	0.624

Notes: This table presents the impact of air pollution on housing prices for purchased transactions from years 2009 to 2014. Observations within 2 months after and before the pollution spike (Dec 2010) are excluded. Columns (1), (5) and (9) report estimates from a version of equation (1) that includes interaction of pollution index and property age. Columns (2), (6) and (10) report estimates from a version of equation (1) that includes interaction of pollution index and size. Columns (3), (7) and (11) report estimates from a version of equation (1) that includes interaction of pollution index and floor dummy that is equal to one if the transaction's floor is higher than two. Columns (4),(8) and (12) report estimates that include all interaction terms. The dependent variable is log of real price per-square meter. Pollution index is the daily inverse distance weighted-average of the readings of three closest monitors' measures of $\boldsymbol{NO_2}$ for each zipcode. For columns (1), (2), (3) and (4) the Pollution Index is average of those daily pollution indices for one week before the time of each transaction. For columns (5), (6), (7) and (8), the Pollution Index is average of those daily pollution indices for one month before the time of each transaction. For columns (9), (10), (11) and (12), the Pollution Index is the average of those daily pollution indices for three months before the time of each transaction. All specifications include five-digit zip-code, year, and seasonal fixed effects. Standard errors in all columns are clustered by five-digit zip-code and stars indicate statistical significance level. * = 10 percent level, ** = 5 percent level. *** = 1 percent level.

Table 9: Responses to Air Pollution by Size, Age and Floor (Rental Market)

	1 Week				1 Month				3 Months			
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)
Pollution Index	-0.00804*	-0.0546***	-0.0119***	-0.0544***	-0.0113**	-0.0612***	-0.0131***	-0.0607***	-0.0197***	-0.0609***	-0.0174***	-0.0655***
	(0.00417)	(0.00663)	(0.00331)	(0.00752)	(0.00458)	(0.00717)	(0.003717)	(0.00809)	(0.00520)	(0.00786)	(0.00418)	(0.00890)
Pollution Index ×Property Age	0.000107			0.000200	0.000211			0.000300	0.000549*			0.000658*
	(0.000271)			(0.000295)	(0.000289)			(0.000315)	(0.000320)			(0.000346)
Pollution Index ×Property Size		0.000616***		0.000517***		0.000675***		0.000568***		0.000609***		0.000517***
		(7.82e-05)		(8.22e-05)		(8.32e-05)		(8.79e-05)		(8.93e-05)		(9.51e-05)
Pollution Index ×Property Floor Index			0.017113***	0.0172***			0.016774***	0.0172***			0.015757***	0.0173***
			(0.004132)	(0.00416)			(0..004419)	(0.00444)			(0.004732)	(0.00475)
Year Fixed Effects	X	X	X	X	X	X	X	X	X	X	X	X
5-Digit Zip-code Fixed Effects	X	X	X	X	X	X	X	X	X	X	X	X
Seasonal Fixed Effects	X	X	X	X	X	X	X	X	X	X	X	X
Observations	293,605	293,605	274885	274,885	293,432	293,432	274788	274,788	292,355	292,355	274217	274,217
R-squared	0.408	0.408	0.410	0.411	0.408	0.408	0.4105	0.411	0.408	0.409	0.411	0.411

Notes: This table presents the impact of air pollution on housing prices for rental transactions from years 2009 to 2014. Observations within 2 months after and before the pollution spike (Dec 2010) are excluded. Columns (1), (5) and (9) report estimates from a version of equation (1) that includes interaction of pollution index and property age. Columns (2), (6) and (10) report estimates from a version of equation (1) that includes interaction of pollution index and size. Columns (3), (7) and (11) report estimates from a version of equation (1) that includes interaction of pollution index and floor dummy that is equal to one if the transaction's floor is higher than two. Columns (4),(8) and (12) report estimates that include all interaction terms. The dependent variable is log of real rent per-square meter. Pollution index is the daily inverse distance weighted-average of the readings of three closest monitors' measures of $\boldsymbol{NO_2}$ for each zipcode. For columns (1), (2), (3) and (4) the Pollution Index is average of those daily pollution indices for one week before the time of each transaction. For columns (5), (6), (7) and (8), the Pollution Index is average of those daily pollution indices for one month before the time of each transaction. For columns (9), (10), (11) and (12), the Pollution Index is the average of those daily pollution indices for three months before the time of each transaction. All specifications include five-digit zip-code, year, and seasonal fixed effects. Standard errors in all columns are clustered by five-digit zip-code and stars indicate statistical significance level. * = 10 percent level, ** = 5 percent level. *** = 1 percent level.

Table 10: The Impact of Air Pollution on Housing Prices (New Constructions)

	1 Week		1 Month		3 Months	
	(1)	(2)	(3)	(4)	(5)	(6)
Pollution Index	-0.0308***	-0.0307***	-0.0356***	-0.0355***	-0.0452***	-0.0451***
	(0.00364)	(0.00363)	(0.00412)	(0.00412)	(0.00429)	(0.00428)
Year Fixed Effects	X	X	X	X	X	X
5-Digit Zip-code Fixed Effects	X	X	X	X	X	X
Seasonal Fixed Effects	X	X	X	X	X	X
District Trends		X		X		X
Observations	116,051	116,051	116,017	116,017	115,783	115,783
R-squared	0.656	0.656	0.656	0.656	0.656	0.657

Notes: This table presents the impact of air pollution on housing prices for new construction transactions from years 2009 to 2014. Observations within 2 months after and before the pollution spike (Dec 2010) are excluded. All regressions are based on equation (1). The dependent variable is log of real price per-square meter. Pollution index is the daily inverse distance weighted-average of the readings of three closest monitors' measures of $\boldsymbol{NO_2}$ for each zipcode. For columns (1) and (2), the Pollution Index is average of those daily pollution indices for one week before the time of each transaction. For columns (3) and (4), the Pollution Index is average of those daily pollution indices for one month before the time of each transaction. For columns (5) and (6), the Pollution Index is average of those daily pollution indices for three months before the time of each transaction. All specifications include five-digit zip-code, year, and seasonal fixed effects. The even-numbered columns also include municipal trend effects. Standard errors in all columns are clustered by five-digit zip-code and stars indicate statistical significance level. * = 10 percent level, ** = 5 percent level. *** = 1 percent level.

Table 11: The Impact of Air Pollution on Housing Prices Using Alternative Pollution Index

	1 Week		1 Month		3 Months	
	(1)	(2)	(3)	(4)	(5)	(6)
Pollution Index	-0.0178***	-0.0178***	-0.0231***	-0.0230***	-0.0314***	-0.0313***
	(0.00366)	(0.00366)	(0.00400)	(0.00400)	(0.00400)	(0.00400)
Year Fixed Effects	X	X	X	X	X	X
5-Digit Zip-code Fixed Effects	X	X	X	X	X	X
Seasonal Fixed Effects	X	X	X	X	X	X
District Trends		X		X		X
Observations	130,009	130,009	129,995	129,995	129,836	129,836
R-squared	0.607	0.608	0.607	0.608	0.608	0.608

Notes: This table presents the impact of air pollution on housing prices from years 2009 to 2014 for the sample of purchased properties that are located within 1 mile of at least one monitor. Observations within 2 months after and before the pollution spike (Dec 2010) are also excluded. All regressions are based on equation (1). The dependent variable is log of real price per-square meter. For each observation, the pollution index is the daily reading of nitrogen dioxide concentration from a monitor that the housing observation lies within the one mile of the given monitor. If a housing observation is close to more than one monitor, the pollution index is the average of readings from all close monitors. For columns (1) and (2), the Pollution Index is average of those daily pollution indices for one week before the time of each transaction. For columns (3) and (4), the Pollution Index is average of those daily pollution indices for one month before the time of each transaction. For columns (5) and (6), the Pollution Index is average of those daily pollution indices for three months before the time of each transaction. All specifications include five-digit zip-code, year, and seasonal fixed effects. The even-numbered columns also include municipal trend effects. Standard errors in all columns are clustered by five-digit zip-code and stars indicate statistical significance level. * = 10 percent level, ** = 5 percent level. *** = 1 percent level.

Table 12: The Impact of Air Pollution on Property Usage

	1 Week	1 Month	3 Months
	(1)	(2)	(3)
Pollution Index	0.0944***	0.125***	0.147***
	(0.0246)	(0.0278)	(0.0302)
Year Fixed Effects	X	X	X
5-Digit Zip-code Fixed Effects	X	X	X
Seasonal Fixed Effects	X	X	X
Observations	648,764	648,594	646,988

Notes: This table presents the impact of air pollution on probability of switching a owner-occupied property to non-owner-occupied property by buyers. The sample covers all purchasing transactions from years 2009 to 2014, excluding observations within 2 months after and before the pollution spike (Dec 2010). All logit regressions are based on equation (2). The dependent variable is an indicator equal to one if a purchased property turns to rental property, zero for all other cases. Pollution index is the daily inverse distance weighted-average of the readings of three closest monitors' measures of $\boldsymbol{NO_2}$ for each zip-code. The Pollution Index is average of those daily pollution indices for one week, one month, and three months before the time of each transaction for columns (1), (2), and (3), respectively. All specifications include five-digit zip-code, seasonal, and region-by-year fixed effects. Standard errors in all columns are clustered by five-digit zip-code and stars indicate statistical significance level. * = 10 percent level, ** = 5 percent level. *** = 1 percent level.

Table 13: Impact of Air Pollution on Housing Prices Controlling for Elevation, Distance from City Center and Neighborhood's Location (Owner-occupied Market)

	1 Week		1 Month		3 Months	
	(1)	(2)	(3)	(4)	(5)	(6)
Pollution Index	-0.0384***	-0.0412***	-0.0457***	-0.0481***	-0.0568***	-0.0573***
	(0.00172)		(0.00195)	(0.00167)	(0.00214)	
Distance from City Center	-1.63e-05**		-1.65e-05**		-1.67e-05**	
	(7.43e-06)		(7.43e-06)		(7.43e-06)	
Distance Square	-1.54e-09***		-1.53e-09***		-1.53e-09***	
	(5.20e-10)		(5.19e-10)		(5.19e-10)	
Elevation	0.00269***		0.00269***		0.00269***	
	(5.93e-05)		(5.93e-05)		(5.94e-05)	
Semiparametric Model Using Neighborhoods' Geographic Locations		X		X		X
Year Fixed Effects	X		X	X	X	X
Seasonal Fixed Effects	X		X	X	X	X
Observations	440,396	440,396	440,310	440,310	439,509	439,509
R-squared	0.462		0.462		0.462	

Notes: This table presents the impact of air pollution on housing prices for purchased transactions from years 2009 to 2014. Observations within 2 months after and before the pollution spike (Dec 2010) are excluded. Columns (1), (3) and (5) report estimates from a version of equation (1) that also includes distance from city center, its square and elevation. Columns (2), (4) and (6) report estimates from a semiparametric version of equation (1) that includes each neighborhood's UTM coordinates as a nonparametric component of the model. We report the coefficients of pollution indices as part of the parametric part of the model. The dependent variable is log of real price per-square meter. Pollution index is the daily inverse distance weighted-average of the readings of three closest monitors' measures of $\boldsymbol{NO_2}$ for each zipcode. For columns (1) and (2) the Pollution Index is average of those daily pollution indices for one week before the time of each transaction. For columns (3) and (4), the Pollution Index is average of those daily pollution indices for one month before the time of each transaction. For columns (5) and (6), the Pollution Index is the average of those daily pollution indices for three months before the time of each transaction. All specifications include year, and seasonal fixed effects. In columns (1), (3) and (5), Standard errors are clustered by five-digit zip-code and stars indicate statistical significance level. * = 10 percent level, ** = 5 percent level. *** = 1 percent level.

Table 14: Impact of Air Pollution on Housing Prices Controlling for Elevation, Distance from City Center and Neighborhood's Location (Rental Market)

	1 Week		1 Month		3 Months	
	(1)	(2)	(3)	(4)	(5)	(6)
Pollution Index	-0.00525*	-0.0136***	-0.00539*	-0.0144***	-0.00979***	-0.0190***
	(0.00285)		(0.00323)		(0.00368)	
Distance from City Center	-2.04e-05***		-2.04e-05***		-2.05e-05***	
	(5.73e-06)		(5.73e-06)		(5.73e-06)	
Distance Square	-1.59e-09***		-1.59e-09***		-1.59e-09***	
	(3.90e-10)		(3.90e-10)		(3.90e-10)	
Elevation	0.00216***		0.00216***		0.00216***	
	(5.35e-05)		(5.35e-05)		(5.35e-05)	
Semiparametric Model Using Neighborhoods' Geographic Locations		X		X		X
Year Fixed Effects	X		X	X	X	X
Seasonal Fixed Effects	X		X	X	X	X
Observations	227,764	227,764	227,667	227,667	227,105	227,105
R-squared	0.28		0.28		0.28	

Notes: This table presents the impact of air pollution on housing prices for rental transactions from years 2009 to 2014. Observations within 2 months after and before the pollution spike (Dec 2010) are excluded. Columns (1), (3) and (5) report estimates from a version of equation (1) that also includes distance from city center, its square and elevation. Columns (2), (4) and (6) report estimates from a semiparametric version of equation (1) that includes each neighborhood's UTM coordinates as a nonparametric component of the model. We report the coefficients of pollution indices as part of the parametric part of the model. The dependent variable is log of real rent per-square meter. Pollution index is the daily inverse distance weighted-average of the readings of three closest monitors' measures of $\boldsymbol{NO_2}$ for each zipcode. For columns (1) and (2) the Pollution Index is average of those daily pollution indices for one week before the time of each transaction. For columns (3) and (4), the Pollution Index is average of those daily pollution indices for one month before the time of each transaction. For columns (5) and (6), the Pollution Index is the average of those daily pollution indices for three months before the time of each transaction. All specifications include year, and seasonal fixed effects. In columns (1), (3) and (5), Standard errors are clustered by five-digit zip-code and stars indicate statistical significance level. * = 10 percent level, ** = 5 percent level. *** = 1 percent level.

Appendix A: Additional Figures

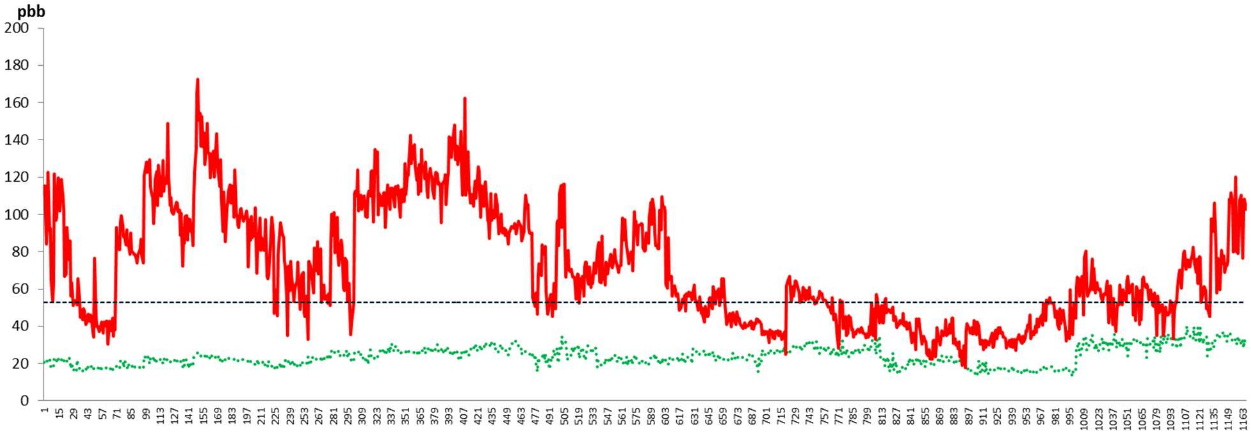

Figure A.1: The Level of One Month Average of Pollution Index across Neighborhoods

Notes: This figure shows the heterogeneous variations in level of distance-weighted pollution index across zip codes for two days; one year before (green) and after (red) the peak of the sanction-induced pollution jump. The figure includes 1166 zip code that contain sales record for both months. Dashed line shows the annual standard for NO_2 set by U.S. EPA.

Appendix B: Additional Tables

Table B.1: Baseline Regression Including Months of Increase (Housing Prices)

	1 Week		1 Month		3 Months	
	(1)	(2)	(3)	(4)	(5)	(6)
Pollution Index	-0.0352***	-0.0352***	-0.0426***	-0.0426***	-0.0550***	-0.0550***
	(0.00149)	(0.00149)	(0.00167)	(0.00167)	(0.00194)	(0.00194)
Year Fixed Effects	X	X	X	X	X	X
5-Digit Zip-code Fixed Effects	X	X	X	X	X	X
Seasonal Fixed Effects	X	X	X	X	X	X
District Trends		X		X		X
Observations	690,223	690,223	690,053	690,053	688,447	688,447
R-squared	0.617	0.618	0.617	0.618	0.618	0.619

Notes: This table presents the impact of air pollution on housing prices for purchased transactions from years 2009 to 2014. All regressions are based on equation (1). The dependent variable is log of real price per-square meter. Pollution index is the daily inverse distance weighted-average of the readings of three closest monitors' measures of NO_2 for each zipcode. For columns (1) and (2), the Pollution Index is average of those daily pollution indices for one week before the time of each transaction. For columns (3) and (4), the Pollution Index is average of those daily pollution indices for one month before the time of each transaction. For columns (5) and (6), the Pollution Index is average of those daily pollution indices for three months before the time of each transaction. All specifications include five-digit zip-code, year, and seasonal fixed effects. The even-numbered columns also include municipal district trend effects. Standard errors in all columns are clustered by five-digit zip-code and stars indicate statistical significance level. * = 10 percent level, ** = 5 percent level. *** = 1 percent level.

Table B.2: Baseline Regression Including Months of Increase (Rental Price)

	1 Week		1 Month		3 Months	
	(1)	(2)	(3)	(4)	(5)	(6)
Pollution Index	-0.00201	-0.00198	-0.00326	-0.00322	-0.00725**	-0.00715**
	(0.00255)	(0.00254)	(0.00292)	(0.00291)	(0.00332)	(0.00330)
Year Fixed Effects	X	X	X	X	X	X
5-Digit Zip-code Fixed Effects	X	X	X	X	X	X
Seasonal Fixed Effects	X	X	X	X	X	X
District Trends		X		X		X
Observations	296,612	296,612	296,439	296,439	295,362	295,362
R-squared	0.409	0.411	0.409	0.411	0.409	0.412

Notes: This table presents the impact of air pollution on rental prices for rental transactions from years 2009 to 2014. All regressions are based on equation (1). The dependent variable is log of total annual real rent per-square-meter. Pollution index is the daily inverse distance weighted-average of the readings of three closest monitors' measures of NO_2 for each zipcode. For columns (1) and (2), the Pollution Index is average of those daily pollution indices for one week before the time of each transaction. For columns (3) and (4), the Pollution Index is average of those daily pollution indices for one month before the time of each transaction. For columns (5) and (6), the Pollution Index is average of those daily pollution indices for three months before the time of each transaction. All specifications include five-digit zip-code, year, and seasonal fixed effects. The even-numbered columns also include municipal district trend effects. Standard errors in all columns are clustered by five-digit zip-code and stars indicate statistical significance level. * = 10 percent level, ** = 5 percent level. *** = 1 percent level.

Table B.3: Panel Analysis Including Months of Increase

	1 Week		1 Month		3 Months	
	(1)	(2)	(3)	(4)	(5)	(6)
Pollution Index	-0.0257***	-0.0255***	-0.0308***	-0.0307***	-0.0372***	-0.0372***
	(0.00512)	(0.00511)	(0.00601)	(0.00599)	(0.00687)	(0.00687)
Year Fixed Effects	X	X	X	X	X	X
5-Digit Zip-code Fixed Effects	X	X	X	X	X	X
Seasonal Fixed Effects	X	X	X	X	X	X
District Trends		X		X		X
Observations	79,292	79,292	79,289	79,289	79,256	79,256
R-squared	0.156	0.158	0.156	0.158	0.156	0.158

Notes: This table presents the impact of air pollution on price-rent ratio from years 2009 to 2014. All regressions are based on equation (1). The dependent variable is zip code-day average price divided by average rent. Pollution index is the daily inverse distance weighted-average of the readings of three closest monitors' measures of $\boldsymbol{NO_2}$ for each zipcode. For columns (1) and (2), the Pollution Index is average of those daily pollution indices for one week before the time of each transaction. For columns (3) and (4), the Pollution Index is average of those daily pollution indices for one month before the time of each transaction. For columns (5) and (6), the Pollution Index is average of those daily pollution indices for three month before the time of each transaction. All specifications include five-digit zip-code, year, and seasonal fixed effects. The even-numbered columns also include municipal district trend effects. Standard errors in all columns are clustered by five-digit zip-code and stars indicate statistical significance level. * = 10 percent level, ** = 5 percent level. *** = 1 percent level.

Table B.4: The Impact of Air Pollution on Housing Prices Using Alternative Pollution Index (1/2 Mile)

	1 Week		1 Month		3 Months	
	(1)	(2)	(3)	(4)	(5)	(6)
Pollution Index	-0.0153**	-0.0153**	-0.0241***	-0.0242***	-0.0330***	-0.0332***
	(0.00669)	(0.00670)	(0.00760)	(0.00756)	(0.00782)	(0.00774)
Year Fixed Effects	X	X	X	X	X	X
5-Digit Zip-code Fixed Effects	X	X	X	X	X	X
Seasonal Fixed Effects	X	X	X	X	X	X
District Trends		X		X		X
Observations	34,081	34,081	34,077	34,077	34,031	34,031
R-squared	0.617	0.617	0.617	0.618	0.617	0.618

Notes: This table presents the impact of air pollution on housing prices from years 2009 to 2014 for the sample of purchased properties that are located within 1/2 mile of at least one monitor. Observations within 2 months after and before the pollution spike (Dec 2010) are also excluded. All regressions are based on equation (1). The dependent variable is log of real price per-square meter. For each observation, the pollution index is the daily reading of nitrogen dioxide concentration from a monitor that the housing observation lies within the one-half mile of the given monitor. If a housing observation is close to more than one monitor, the pollution index is the average of readings from all close monitors. For columns (1) and (2), the Pollution Index is average of those daily pollution indices for one week before the time of each transaction. For columns (3) and (4), the Pollution Index is average of those daily pollution indices for one month before the time of each transaction. For columns (5) and (6), the Pollution Index is average of those daily pollution indices for three months before the time of each transaction. All specifications include five-digit zip-code, year, and seasonal fixed effects. The even-numbered columns also include municipal district trend effects. Standard errors in all columns are clustered by five-digit zip-code and stars indicate statistical significance level. * = 10 percent level, ** = 5 percent level. *** = 1 percent level.