Are Land Values Related to Ambient Air Pollution Levels? Hedonic Evidence from Mexico City Working Paper*

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Abstract

The average resident of Mexico City suffers unhealthy levels of air pollution for the most part of the year. Nevertheless, the uneven distribution of firms and road traffic across the city, together with wind patterns and differences in microclimates generates localized pollution concentrations. The objective of this study is to investigate whether residents of Mexico City value cleaner air, taking advantage of the variation in pollution levels and land values observed across neighborhoods within the city. Contrary to most studies of this type, commonly focused in developed countries, ours is based on land values reported by external appraisals. The panel nature of our data and inclusion of time varying controls for neighborhood characteristics and local economic conditions allows for correction of potential endogeneity bias arising due to unobserved factors that influence both current pollution levels and property values. Our results suggest that air quality improvements lead to an increase in land values by approximately 3% in Mexico City which is equivalent to a marginal willingness to pay of up to \$170 (2010) pesos per m^2 or \$13.82 USD. We find a land value-pollution elasticity of -0.63 for $PM_{2.5}$, -0.39 for PM_{10} and -0.17 for SO_2, for the period 2006 to 2013. This is consistent with expectations of the affected population about danger to health from exposure to the above-mentioned pollutants. Thus, we provide an estimate of the possible benefits of

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public policy dedicated to air quality improvements, measured as the value that Mexico City's residents have for cleaner air.

Introduction

Air pollution is a relevant problem in most densely populated cities. According to the OECD, air pollution causes more than 3 million related deaths in the world.[1] Similarly, poor air quality is related to the prevalence of different respiratory diseases and exposure to criteria pollutants such as ozone (O_3), particulate matter (PM), nitrogen oxides (NOx) and sulfur dioxide (SO_2) is shown to cause long run health effects. Various types of sources contribute to air pollution, such as mobile (transport) and fixed (industry and construction) sources and both are characteristic features of urban growth. In this study we focus on air pollution in Mexico City. Ranked as the most polluted city by the UN in 1992, Mexico City has witnessed significant improvements in controlling its dire state of air pollution. However, rapidly expanding urban growth means that it is still one of the most polluted cities in the world.

The objective of this paper is to derive monetary estimates for possible benefits of improvement in air quality, in Mexico City. We accomplish this by calculating the willingness to pay for cleaner air amongst Mexico City residents. Air pollution is known to have substantial economic impacts in terms of health of the affected population. However, in developing countries, in particular, quantitative estimates of these damages of pollution are scarce. Hence, we look at the housing market to analyze if the residents of highly polluted cities such as Mexico City value air quality by revealing their preferences for choosing houses located in less polluted areas within the City. Such estimates on willingness to pay can inform policy makers directly on the benefits of improving air quality.

There is a large amount of literature that analyze the economic impact of air pollution translated to social costs but mostly focused on developed countries. Greenstone and Jack (2015) present a recent survey of studies that estimate the impacts of air pollution on health. Among the most relevant for developing countries and Mexico in particular, Arceo-Gómez, Hanna, and Oliva (2012) analyze the effect of air pollution on infant mortality in Mexico. They conclude that air quality (measured by the concentration of criteria pollutants) has an effect on infant mortality in Mexico City. Tanaka (2015) analyzes the effect of a change in pollution regulation scheme in 1998 for China on infant mortality with a difference in difference approach and found that infant mortality decreased by 20% since the implementation. Pollution seems to exert economic damages not only through health but also through its negative impact on labor supply. R. Hanna and Oliva (2015) studied the effect of pollution

[1] OECD (2014). *The Cost of Air Pollution: Health Impacts of Road Transport*, OECD Publishing.

on labor supply using the exogenous variation in pollution due to the closing of a refinery in 1991 in Mexico City. They find that the decline in SO_2 pollution resulted in an increase in 1.3 hours of work per week for the residents of neighborhoods located closer to where the refinery was, compared to others.

This current study fills an important gap in the literature on valuation of environmental benefits, particularly for developing countries. Our research question is of significant importance as comparatively few studies have focused on developing countries where some of the most polluted cities are. According to the World Health Organization, developing countries have the highest records of pollution levels for Nitrogen dioxide, sulfur dioxide and suspended particles.[2] Specifically, we try to quantify the impact of pollution on independent assessments of land value, in Mexico City. We consider a previously unused data base of land value appraisals at zip code level in Mexico City from 2006 to 2013 obtained from the *Sociedad Hipotecaria Federal* (SHF). To our knowledge, Gonzalez, Leipnik, and Mazumder (2013) is the only other study that uses information on individual housing sales from SHF.

We construct a unique dataset linking pollution to land values which has the following characteristics. 1) Our measure of land value based on assessments commissioned by credit institutions avoids the need to control for individual household characteristics for households that purchase these properties or parcels of land. 2) The aggregated nature of our measure of land values (the mean value at the zip code level) allows us to conduct our analysis at the appropriate scale, as we consider zip code level variability to more accurately reflect exposure to ambient air pollution in contrast to individual housing value. 3) We control for type of land parcel: individual houses, condominiums, multiple housing and condos, and location features as captured by center, intermediate, periphery (i.e. semi-urban) and rural zones. 4) We consider four different pollutants, namely, Particulate Matter (PM_{10} and $PM_{2.5}$),Sulfur Dioxide (SO_2) and ozone, since they are some of the most prevalent in Mexico City and together constitute part of the air pollution. 5) The availability of panel data means that we can control for the potential endogeneity bias of unobserved time varying factors that influence both pollution and land values. 6) We explore two such time varying mechanisms—neighborhood's socioeconomic characteristics and local economic conditions. Our regressions control for neighborhood characteristics, by collecting information on socioeconomic status of the nearby population. In particular, we match *AGEB (Area Geostadística Básica Urbana)* level data on number of houses with drainage and electricity, number of houses with three or more rooms, average schooling, health care access, population density and number of households in the area.[3] Second, we control for local economic conditions by including total number of firms or business establishments obtained at the AGEB level from the economic census. Number of industries might also be capturing other (dis) amenities

[2]World Health Organization (2006) *Air Quality Guidelines: Update 2005,* WHO publications.

[3]According to 2010 census, an *AGEB* has 3,622.69 inhabitants on average.

or location specific factors such as closeness to pollutant sources. 7) Finally, we control for spatial correlation by clustering standard errors at the municipality level.

We find that higher pollution leads to lower land value assessments. Our fixed effects results show that a decline in SO_2 pollution by 1 part per billion leads to an increase in zipcode average land values by 3 percent. Similarly, a decline in $PM_{2.5}$ pollution by 1 microgram per cubic meter leads to an increase in land values by 2.4 percent, while a decline in PM_{10} pollution by 1 microgram per cubic meter leads to an increase in land values by about 1 percent. This latter result is expected as $PM_{2.5}$ is known to cause more severe negative health impacts than the larger particulate matter, PM_{10}. As for SO_2, it is known to be primarily emitted from point sources of pollution i.e. factories and hence might be capturing some of the negative emitter effects of proximity to industries. We conclude that an average resident of Mexico City has a positive marginal willingness to pay for cleaner air. Our estimates suggest a magnitude of almost \$178 pesos for a reduction in SO_2, 142.3 pesos for a reduction in $PM_{2.5}$ and 53.3 pesos for a reduction in PM_{10} pollution; all monetary values expressed in constant 2010 pesos.

1 Air quality in Mexico City

Mexico City comprises 16 municipalities with a total of 8'851,000 inhabitants; taking into account suburbs and neighboring municipalities of different states nearby, the Mexico City Metropolitan Area is the most populated region in Mexico with 20'116,842 inhabitants.[4] In economic terms, Mexico City represents 17.03% of Mexico's gross domestic product. The population and economic activity are factors that partially determine pollution concentrations in Mexico City. In this sense, annually almost 10.455 million m^3 are consumed in the transportation sector (gas and diesel), which contribute to 46% of pollutants emissions.[5] Other sources of pollution are industry (21%), residential services (20%) and other services (13%).[6] Besides population and economic factors, geographically Mexico City is located in a zone conducive to the prevalence of pollution. According to Molina and Molina (2004), height, solar intensity and topography contribute to the formation of ozone and trap pollutants that reduce air quality in Mexico City.

In this study we refer only to the criteria pollutants which are the ones more insidious to health and are reported every hour by the Automatic Air Quality Monitoring Network (RAMA by its name in Spanish): sulfur dioxide (SO_2), particulate matter (PM), and ozone (O_3). Each pollutant is related to different health issues. For instance, SO_2 enhances morbidity and mortality of heart and lung patients, NO_2 increases respiratory issues, and PM can lead to lung cancer. Each of these pollutants has different origin and its distribution varies according to local climate, and atmospheric conditions.[7] According to our data, in Mexico City the pollutants whose levels are more frequently exceeded are Ozone and Particulate Matter and Sulfuric Dioxide.

Given the effects of air pollution on health and the associated costs of policies aimed at improving them, it is important to estimate the value that Mexico City inhabitants place on air quality. This would make a contribution towards the assessment of the potential benefits of public policy directed towards diminishing pollution. Figure 1 shows that pollution is not homogeneous in Mexico City due to different atmospheric conditions that each zone presents and the distance to pollution sources (factories or transportation). In general, the north of the city has higher levels of pollution in comparison to the south. Therefore, this study assesses the willingness to pay for a marginal improvement in air quality in Mexico City, as reflected in housing prices. In particular, we find evidence on whether Mexico City residents have preferences over air quality (related to better health or aesthetics) and they consider

[4] INEGI, General Direction of Sociodemographic Characteristics: *Censo de Población y Vivienda 2010.*

[5] Atmospheric Monitoring System of Mexico City Metropolitan Area (SIMAT).

[6] Direction of Atmospheric Monitoring of Mexico City (Dirección de Monitoreo Atmosférico de la Ciudad de México.

[7] National Institute for Ecology and Climate Change (2013). Criteria Pollutants. `http://www.inecc.gob.mx/calaire-indicadores/523-calaire-cont-criterio`

these preferences when choosing where to live.

2 Hedonic Prices Model

There are several goods that share the same market but are not homogeneous, i.e., they have different prices and characteristics associated. When looking at the transactions in a market with differentiated goods, the value of the underlying characteristics of the good can be obtained. The hedonic prices model is an indirect valuation method that allows one to assess the value of a good that does not have an explicit market, like air quality. Rosen (1974) is one of the first authors that describe the hedonic price model.

In this section we present a brief discussion of Freeman (2003) hedonics model, applied to the housing market. An individual's utility is a function of consumption of a composite commodity **X**, a vector of location-specific environmental amenities **Q**, a vector of structural characteristics of the house (size, number of rooms, age of house etc) **S**, and a vector of characteristics of the neighborhood in which the house is located (e.g. quality of schools, accessibility to parks, crime rate) denoted by N. Hence, an individual's utility who occupies house i is given by

$$U = U(X, Q_i, S_i, N_i)$$

Assuming that preferences are weakly separable in housing and its characteristics, the demand for the housing characteristics are independent of the prices of other goods. The individual maximizes $u(\dot{})$ subject to the budget constraint:

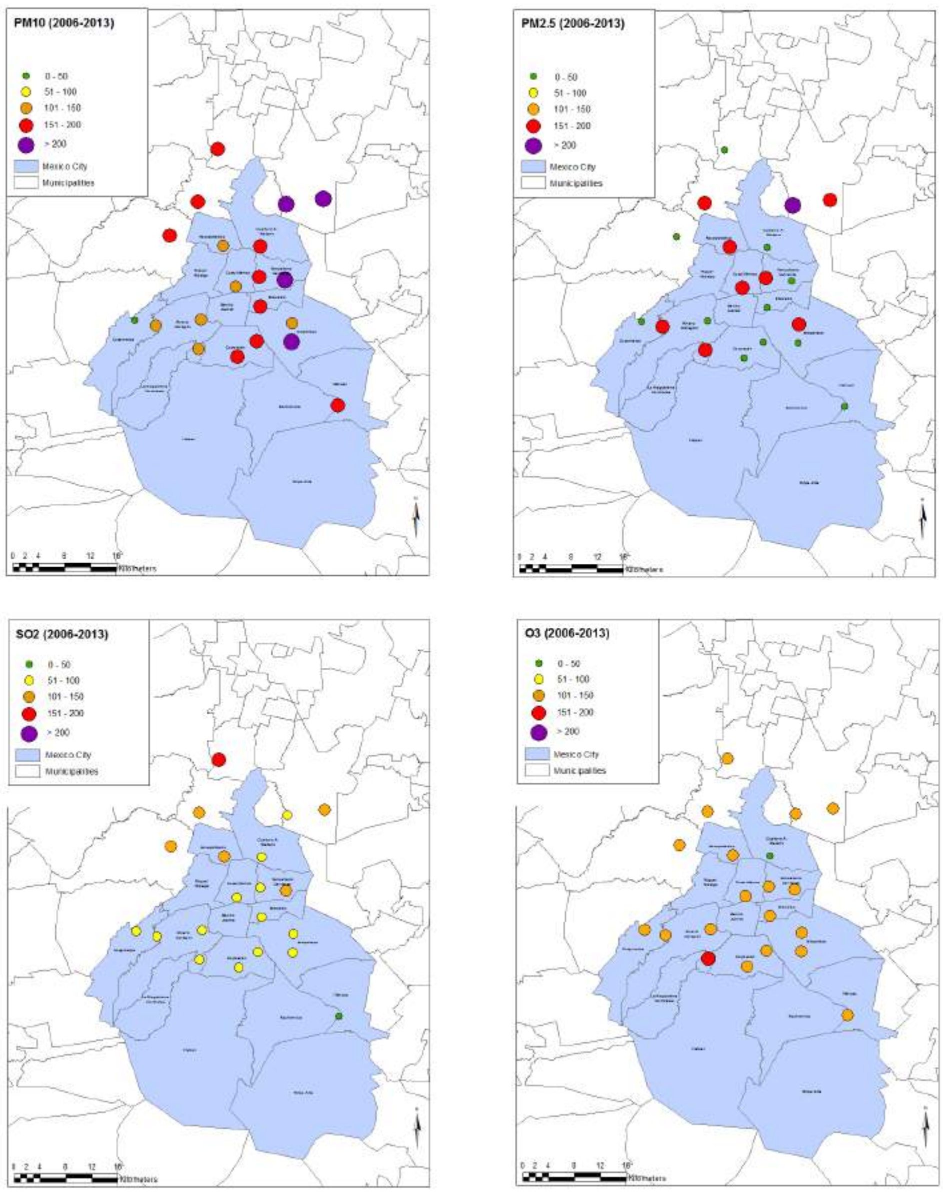
$$M - P_{h_i} - X = 0$$

The hedonic price function $P_h(\dot{})$ can be estimated for an urban area under the assumption that it can be treated as a single market for housing services. In other words, buyers (and sellers) have full information on all alternative choices and are free to choose a house anywhere inside the urban area. To empirically estimate the hedonic price function it needs an additional assumption that the housing market is in equilibrium i.e. all individuals have made their utility-maximizing choices given the prices and that these prices just clear the existing stock of housing alternatives.

$$P_{h_i} = P_h(S_i, N_i, Q_i)$$

Hence, the price of the ith residential location can be expressed as a function of the structural, neighborhood and environmental characteristics of that location. As Freeman (2003) points out, the most preferred source of data is that on actual sales prices of individual

Figure 1: Air Quality Distribution Across Monitoring Stations in Mexico City



Average maximum values recorded by monitoring stations in IMECA values for 2006-2013 houses, along with relevant characteristics. However, this requires the heroic assumption that buyers and sellers have full information on willingness-to-pay and willingness-to-accept offers of other potential buyers and sellers. An alternative source of property value data would be professional appraisals of individual properties for taxation or other purposes (mortgage statement). As we will discuss later, third party neutral assessments provided by experts are used for our present purposes.

The other assumption of a single market in equilibrium is relaxed later in the section on empirical robustness. By and large, Mexico City can be considered as a single housing market as the buyers do not experience any barriers to access the housing markets, across the entire city. However, when considering the causality of pollution levels on housing prices, one must consider the problem of reverse sorting (by households) based on average housing prices, as pointed out in section 4.6 of Kuminoff, Smith, and Timmins (2013). Rich people moving out of polluted areas (and poorer households moving into dirtier neighborhoods further driving down housing prices) leads to biased estimates of the coefficient on pollution because one attributes the fall in housing prices to higher pollution levels, only. So, the bias is upwards i.e. not accounting for sorting gives us bigger negative coefficients on pollution. Inclusion of variables capturing changes in local neighborhood characteristics might mitigate some of this "negative" or inflated impact. In the absence of appropriate data on migration of households, one can control for such changes occurring at the zipcode level through fixed effects. In particular, we allow for sorting based on average zipcode pollution levels and zipcode by year pollution levels (following Currie and Neidell (2005) and Beatty and Shimshack (2014)) in our empirical model where zipcode level land values are regressed on average pollution levels and neighborhood characteristics.

2.1 Hedonic prices and air quality

There is a broad literature that assesses the effect of air quality on housing prices in United States using hedonic prices approaches. Traditional hedonic models that focus at the individual, house or property level, have often found confounding results of higher pollution driving up housing prices or no impact of pollution in the vicinity on house prices (Smith and Huang (1995); Zabel and Kiel (2000)). Neighborhood characteristics such as per capita income affect both pollution and housing values. Higher per capita income drives up the demand for environmental quality and hence exerts a downward pressure on pollution and consequently drives up housing prices. Such omitted/unobserved variables can lead to biased estimates of the effect of local pollution on house prices. These biases might be 'fixed' or unchanging over time which can be differenced out by looking at the effect of change in pollution on change in housing prices (B. G. Hanna (2007)). Bajari, Fruehwirth, Kim, and Timmins (2012) argue that fixed effects may mitigate omitted variable bias in the presence of time invariant observables when panel data are available. However, this approach does not address time varying factors that affect both pollution and house prices.

Chay and Greenstone (2005) use a panel of counties in United States to estimate if changes in exposure to total suspended particulate matter (TSP) pollution has an impact on housing values. In order to solve the omitted variables problem, they use an instrumental variable approach in which they consider the Clean Air Act's (1970) nonattainment status designation for each county as the source of exogenous variability of pollution. According to their estimates, a variation of 1 μ g/m^3 of particulate matter causes an increase of 0.2-0.4 percentage points in the average value of houses, which is a higher value than the ones estimated before.

Leggett and Bockstael (2000) paper is one of the few studies that estimate a separate regression for the value of land defined as a 'residual' of the total price of the house minus the value of the structure. It is one of the earliest studies that address this potential omitted variable bias by incorporating 'emitter effects' in their house values regressions. They are concerned with unaccounted for variables that might actually negatively bias the coefficient on pollution i.e. inflate the negative impact of pollution on house prices. In particular, their study finds that exclusion of aesthetic disamenities i.e. undesirable features of the landscape such as odor, noise and unsightliness, negatively biases the effect of environmental pollution on housing prices.

However, the housing market in United States might be different from other countries, especially developing countries. Yusuf and Resosudarmo (2009) argue that one of the assumptions of the hedonic prices model is that the studied market must be in equilibrium, which might not be the case of the housing market in some developing countries due to information problems, price stickiness, among others. Furthermore, the importance of environmental amenities for some consumers might be very different in developed countries compared to developing ones. A substantial number of studies have tried to identify this initial positive and beyond the threshold, negative relationship between pollution and per capita income called the Environmental Kuznets Curve (EKC). Panayotou (1993) explains that the EKC proposes that in the process of development of a country, environmental degradation increases up to a point at which it diminishes due to several factors such as structural changes in the economy, existence of environment regulation and increases in environmental problem awareness.

Yusuf and Resosudarmo (2009) use hedonic prices to estimate the importance of air quality for the residents of Jakarta, Indonesia. They consider the presence of spatial effects that influence the houses values such as the distance to the district center. The authors conclude that a marginal improvement of SO_2 is associated with \$28 per variation of μg/m3, which is a relatively small amount compared to other (developed) countries. Won Kim, Phipps, and Anselin (2003) perform a hedonic model for Seoul and they conclude that SO_2

levels have a significant effect on house prices. An important contribution of the study is that they consider spatial econometric models(spatial lags and spatial correlation in error term) to control for the possible existence of omitted variables. Marginal WTP for a small change in air quality (a permanent 4% improvement in mean SO_2 concentrations) is about $2,333 or 1.4% of mean housing price.

For Latin America, Carriazo, Ready, and Shortle (2013) develop a hedonic price approach to estimate the value for an improvement in air quality in Bogota, Colombia, on rental property values. Their principal contribution is that they estimate a heteroskedastic frontier regression model to account for the bias that unmeasured quality attributes of residential properties tend to be correlated with the environmental quality attribute of interest and asymmetrically distributed across properties. They find that the price elasticity for air quality was 25% higher in the OLS specification than in a frontier model with asymmetric random errors. This implies that possible omitted variable bias in conventional hedonic models leads to the marginal value of air quality to be overestimated.

2.2 Hedonic prices estimates in Mexico

As Gonzalez et al. (2013) point out hedonic methodology applied to developing countries is rare, in particular, Latin American countries. We hope to fill a gap in this literature, in particular, for one of the most polluted (in Mexico) and one of the largest metropolitan areas worldwide. In a developing country context, willingness to pay estimates for improved environmental quality might be biased towards zero so any significant finding on the influence of local pollution on housing values would directly inform environmental decision making not only at the metropolitan level but nationwide.

Gonzalez et al. (2013) exploit the seasonality of particulate matter (PM_{10}) pollution to use seasons as an instrument for the potentially endogenous PM_{10} concentrations. PM_{10} measurements being higher in the dry season such as winter due to higher resuspension of PM_{10}, in other words, rainfall is an efficient way to remove suspended particles from the atmosphere. Hence, home owners that made property visits in the winter experienced a higher level of pollution in contrast to those that decided during the rainy season. The authors use a cross section of housing sales between January 2003 and May 2004 in the three largest metropolitan areas of Mexico: Mexico City, Monterrey and Guadalajara. The authors use household socioeconomic characteristics such as income, age of head of household, number of dependents, education and type of employment to proxy for neighborhood characteristics such as quality of school and crime rates etc. They find a house price-pollution elasticity of -0.07 for Mexico City and Monterrey and -0.05 for Guadalajara implying that one unit reduction in PM10 levels is valued at $43.47 USD in Monterrey, $41.73 USD in Mexico City and $36.34 USD in Guadalajara. However, we see a potential problem with their instrument as seasonality might be capturing other factors such as market might be more active during vacation periods or after the end-of-year gratification.

Rodríguez-Sánchez (2014) estimates that a household head in Mexico would pay a lower bound of 46.90 dollars (constant 2000 dollars) for a one-unit reduction in Particulate Matter emissions per year. They incorporate migration or mobility costs into the hedonic approach by using a residential sorting model. A two stage model is estimated. In the first stage, a discrete choice model to obtain the probability that a person chooses to live in any location (state) depends on migration costs, income that individual could have earned in any location and the quality of life in every location. In the second stage, these location fixed effects (or quality of life) are regressed on air pollution concentrations to recover the WTP for air quality across states in Mexico. Crime per capita, employment rate, government expenditure per capita, population, life expectancy, rankings of art and number of firms in state are among the other variables considered in this modified hedonic regression.

3 Data

3.1 Land values

The dependent variable of interest is the mean value of land (per square meter) by zip code and quarter for the years 2006-2013. Data were obtained from external appraisals in Mexico City gathered and published by the Federal Mortgage Association (Sociedad Hipotecaria Federal, SHF) where each appraiser must be registered. The appraiser estimates what is the value of each house considering its characteristics and location. The information is obtained by type of property (houses, apartments, condos, and empty lots) and location (central, intermediate, peripheral, extension zone or rural) that is described as the proximity reference of the property. The values are deflated with Mexico City's consumer price index of December, 2010. Of the total number of zipcodes in Mexico City (1445), on average about 73 percent had land value assessments i.e. an average of 1053 zipcodes over the 2006 to 2013 time period.

Table 1 indicates that the average land value for the observed quarters in Mexico City is \$5,670. Also, most of the properties are apartments (52.9%) although there are many houses (28.59%). Regarding the location category, most of the observations are considered as having an intermediate location. Since both the type of property and the location matters for assessing the land value, the panel variable considers the average value at zip code level for the same type of property and location.

Table 1: Housing characteristics in Mexico City

Variable	Average (Standard deviation)	Observations
Land value (per m^2)	5,669.69 (34,033.70)	61,434
Type		
Apartments	52.90%	32,498
Houses	28.59%	17,562
Condos	14.22%	8,733
Multiple houses	2.77%	1,697
Other	0.90%	552
Empty Lots	0.64%	392
Location		
Intermediate	45.82%	28,150
Central	28.82%	17,703
Peripheral	23.88%	14,671
Rural	0.75%	463
Extension zone	0.73%	447
Observations	61,434	

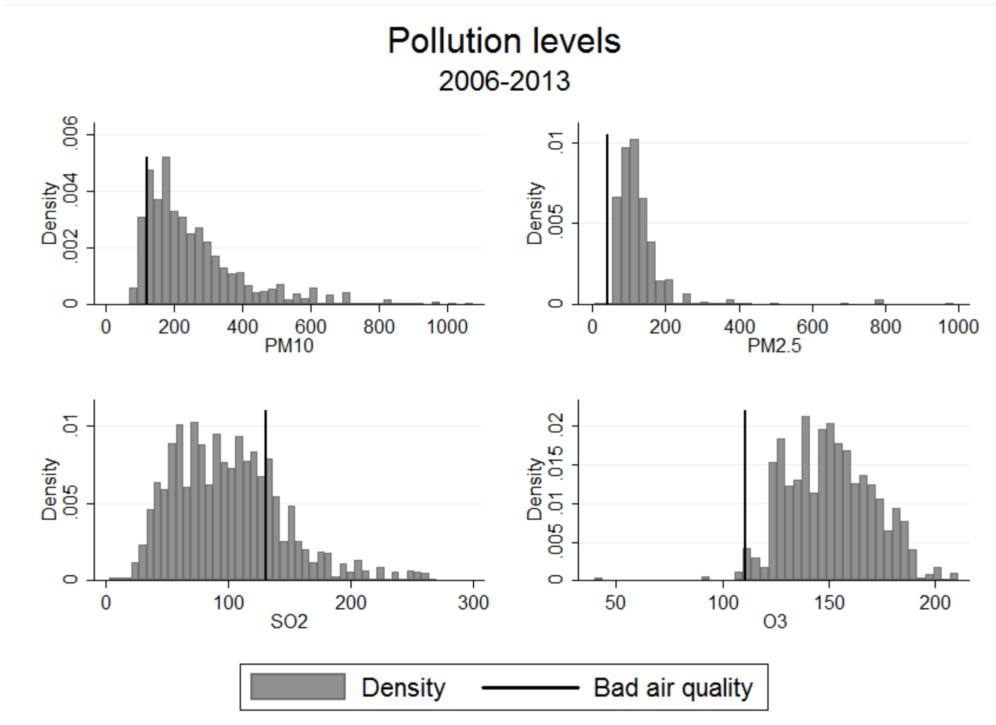
3.2 Pollutants

The information on pollution levels in Mexico City come from the Automatic Air Quality Monitoring Network (Red Automática de Monitoreo Atmosférico, RAMA) that consists of several monitoring stations that report pollution concentrations every hour. Each zip code in the sample is matched with the monitoring stations that are located within 3 miles (from the centroid of each zip code) for estimating the pollution level that the population might be exposed to. The quarterly zipcode level exposure based on maximum values were calculated for the different pollutants reported from the hourly measurements. In order to assign a level of pollution for each zip code, measurements from each nearby monitoring station was weighted by its inverse distance to give higher weights to the nearest stations.[8] Figure 2 shows the maximum values recorded for each pollutant in Mexico City. We consider four pollutants: O_3, SO_2, PM_{10} and $PM_{2.5}$ which are the most prevalent during the period. Table 2 shows the maximum recorded value for each pollutant in the period 2006-2013. "Bad air quality" refers to ambient PM_{10} concentrations of 120 micrograms per cubic meter, $PM_{2.5}$ concentratios of 40.5 micrograms per cubic meter, SO_2 concentrations of 131 parts per billion

[8]Not all monitoring stations have data for pollution concentrations for each quarter of the studied period but this is not much of a problem since we consider the average of all relevant weighted values.

and O_3 concentratios of 110 parts per billion. Whenever this threshold level is reached, the government recommends children and elder people not to perform outdoor activities. Figure 2 shows that quarterly zipcode level exposure was particularly high for PM_{10}, $PM_{2.5}$ and O_3.

Figure 2: Maximum Recorded Values of Pollutants



Average maximum quarterly exposure at zipcode level 2006-2013

Table 2: Maximum Recorded Values of Pollutants, 2006-2013

Variable	Bad Air Quality	Mean	Std. Dev.	Min	Max
PM_{10} [$\mu g/m^3$]	120	257.6296	144.7576	71	1076
$PM_{2.5}$ [$\mu g/m^3$]	40.5	127.269	77.72326	7	988
O_3 [ppb]	110	150.7697	20.5674	40	211
SO_2 [ppb]	131	100.0119	44.86572	3	270.0349

3.3 Socioeconomic and neighborhood's economic activity data

As mentioned before omitted variable bias poses one of the main obstacles to obtain reliable estimates from hedonic specifications. In order to reduce this bias in our estimations we include time varying neighborhood socioeconomic characteristics as they are likely to influence both housing values and pollution levels. In addition, we include proxies for local economic conditions that might also influence both housing values and pollution concentrations. To capture socioeconomic characteristics we include Census data from the 2005 and 2010 years that is available at the AGEB level. AGEBs are fairly small urban areas (more than 2,500 inhabitants) with relatively homogeneous socioeconomic characteristics. We associated each AGEB to a zip code according to the centroids of both polygons using GIS (Geographic Information Systems). We construct a zipcode level measure for socioeconomic characteristics by considering all AGEBs that are within 1 mile of each zipcode centroid.

Mexico's Censuses do not ask questions on income (and/or poverty) directly. Hence, we include proxies for income or socioeconomic status like percentage of houses with drainage and electricity, percentage of houses with 3 or more rooms, education levels like number of years of study and access to formal social security. Number of inhabited houses and population density are also likely to be related with socioeconomic status of the local population. Higher proportion of unoccupied housing and lower population density might be related to poorer economic conditions. Table 3 shows the socioeconomic variables for 2005 and 2010. Most of the variables show significant changes between the two years considered. Finally to capture local economic conditions we consider the total number of economic units or establishments in each zip code. We use the number of firms by major economic activity category (manufacture, services and business) at the AGEB level, obtained from the economic censuses of 2004 and 2009. Figure 3 shows how the distribution of economic activities varies geographically within Mexico City obtained from the 2009 economic census.

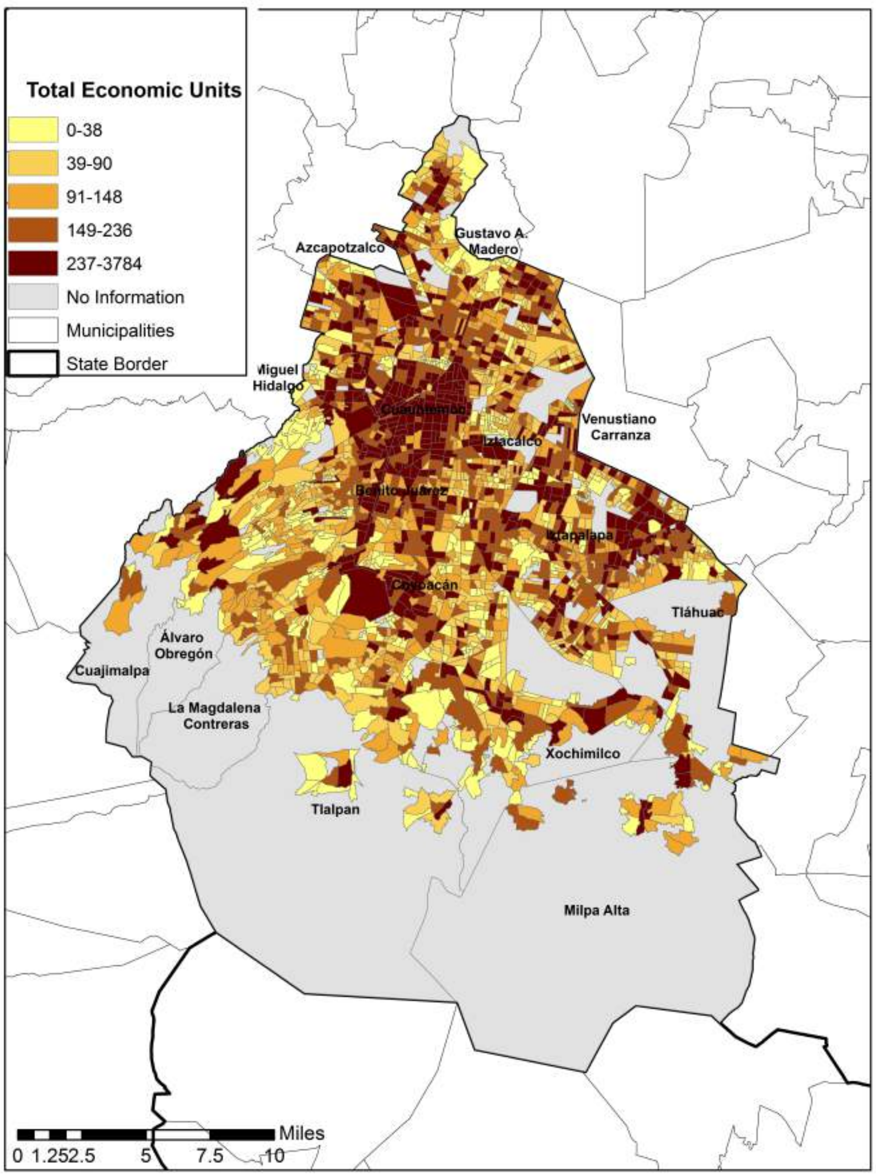
The resulting final dataset is an unbalanced panel of 279 zip codes (out of the total of 1445) from the first quarter of 2006 to 406 zipcodes in the third quarter of 2013.

Table 3: Socioeconomic and economic units* variables

Variable	Obs	Mean	Standard Deviation	Min	Max
Land value (per m2)	61,434	5669.69	34,033.7	0	5'790,776
PM_{10}	15,346	43.702	10.946	24.539	94.119
$PM_{2.5}$	9,113	26.167	4.167	16.1002	33.238
SO_2	17,583	5.679	2.061	2.0191	15.307
O_3	18,099	29.077	6.516	18.347	46.143
Business economic units	63,686	2,082.54	2,001.11	0	25931
Manufacture economic units	63,686	363.36	263.78	0	1,986
Services economic units	63,686	1,744.80	1,334.36	0	9,114
AGEB population density (pop/m2)	63,686	0.0165	0.00506	0.00073	0.03054
Drainage and electricity (% of total houses)	63,686	0.897	0.0633	0.02802	0.981
3 rooms or more (% of total houses)	63,686	0.781	0.066	0.4309	0.934
Formal social security	63,686	0.3651323	0.0625	0.0476	0.5234
Total number of inhabited houses	63,686	1,097.98	277.13	143	3393
Average years of study	63,686	10.7447	1.2132	7.55	13.56

* Economic units' information is obtained from 2004 and 2009 economic census.

Figure 3: Distribution of economic units



4 Empirical Approach

In our model we use quarterly average land values by zipcode for Mexico City, differentiated by type of property (e.g. individual houses versus condos, apartments or empty lots) and by zonal category (i.e. central, peripheral or suburban). As mentioned before, these are characteristics that are likely to be important in terms of controlling for differences in land values within the same zipcode. However, as part of empirical robustness checks we estimate the model presented below for zipcode average land values, i.e. average taken across all types of properties and zonal locations. Particularly, because our primary explanatory variable, i.e. our pollution measure is constructed at the zipcode level.

The empirical approach is given by:

$$LV_{t,z} = \alpha_z + \beta_1 Poll_{C,z} + \beta_2 S_{SC,z} + \beta_3 EU_{EC,z} + \delta_Q + \rho_Y + u_{t,z} \tag{1}$$

Where LV represents the quarterly average land value at zip code level for the period 2006-2013, by type of property and zonal category. Based on findings of Cropper, Deck, and McConnell (1988), the dependent variable is log transformed. α_z is the zipcode by type of property and zonal category fixed effects.

$Poll_{C,z}$ is the average level of pollution weighted by the inverse distance of the nearest monitoring stations to the zip code and for the current year i.e. the annual average is constructed as the average from the current quarter to 3 quarters ago. We estimate separate regressions for the four pollutants considered as each one of the individual pollutants are likely to be (highly) correlated with the other pollutants considered. But more importantly, people might perceive ambient concentrations of each pollutant reported differently, based on their knowledge and information of their impact on health. Second, we consider the average pollution concentrations which means that our estimates are conservative as opposed to considering the maximum recorded values of different pollutants. Also, the annual averages to focus on longer term pollution measurements as opposed to just one quarter.

S is the vector of socioeconomic controls obtained from the 2005 and 2010 population censuses. For the time period 2006 to 2010 we associate variables corresponding to the 2005 census and for the time period 2011 to 2013 we associate the 2010 census variables. $EU_{EC,z}$ is the vector of controls for local economic conditions: the total number of firms by manufacturing, services and business establishments, for zipcode z and based on the two economic census years 2004 and 2009. For the time period 2006 to 2010 we associate variables corresponding to the 2004 economic census and for the time period 2011 to 2013 we associate the 2009 economic census variables. The assignment of economic and population census variables to observations of land values in future periods reduces the risk of obtaining biased estimates due to simultaneous effects between land values and socioeconomic outcomes. δ

is the quarterly or seasonal fixed effects and ρ_Y is the yearly fixed effects. The annual dummy variables are included to control for differences from one year to the next that are unexplained or not controlled for in the model. The quarterly or seasonal dummy variables control for seasonal variations, particularly, pollution concentrations are different depending on the season—higher particulate matter concentrations during the dry seasons as opposed to rainy seasons. Lastly, the zipcode by type of property and zonal category fixed effects controls for all time invariant factors that could explain variations in the land values assessments.

The error term is likely to exhibit serial correlation as land values assessments within the same zipcode are likely to be correlated from one quarter to the next. However, following Cameron and Miller (2015), we present our results with standard errors clustered at the municipality level which is more aggregate i.e. higher level than the zipcode, to control for arbitrary spatial correlation. In other words, land values within the same municipality are likely to be correlated because of similar location features, for example. Results are overall similar to clustering standard errors at the zipcode level (to control for arbitrary serial correlation).

5 Results

Table 4 presents the results with fixed effects for within zipcode assessments by type of property and zonal category. The fixed effects controls for all unobserved time invariant factors at the level of zipcode but differentiated by type of property and zonal category. The log of quarterly zipcode average land value assessments are regressed on annual average pollution observed in the same zipcode during a year, and controls for socioeconomic characteristics, local economic conditions and seasonal and yearly dummies. Standard errors are clustered within the municipality level. The negative coefficient on the pollution variable shows that higher pollution has a downward impact on zipcode average land assessments. The coefficient in column (1) of Table 4 can be interpreted as, a 1 microgram per cubic meter increase in PM_{10} leads to a decline in land values by 0.7 percent. Evaluating this estimate at the average land value of 5,670 (2010) pesos in Mexico City, one can express the Marginal WTP for lower PM_{10} pollution as 39.7 (2010) pesos. This result is consistent (in sign) with Gonzalez et al. (2013) and Rodriguez's (2014) findings for willingness to pay for lower particulate matter pollution in Mexico. For $PM_{2.5}$, the coefficient is much larger in magnitude as one might expect because of its severe health implications; however, the coefficient is significant only at the 10 percent level. The coefficient in column (2) of Table 4 can be interpreted as, 1 microgram per cubic meter increase in $PM_{2.5}$ leads to a decline in zipcode average land values by 2.2 percent. In pesos, the MWTP for lower $PM_{2.5}$ pollution is 124.7 (2010) pesos. For SO_2, the coefficient is statistically significant at the 1 percent level. The coefficient in column (3) of Table 4 can be interpreted as, a 1 parts per billion increase in SO_2 pollution leads to a decline in zipcode average land values by 2.6 percent. In pesos, the MWTP for lower SO_2 pollution is as much as 147.4 (2010) pesos. The coefficient on O_3 is positive however not statistically significant. The mechanism of ozone accumulation is more of a regional problem compared to the more local problem of vehicular and industrial pollution of SO_2 and particulate matter, which might explain why local ozone measurements do not have a meaningful impact on local land values assessments.

However, in terms of elasticity, the relative magnitude of the estimated coefficients tell a different and perhaps more consistent story about expectations on health damages from exposure to these pollutants. A 1 microgram per cubic meter increase in PM_{10} represents about 2.29 percent increase in PM_{10} (with average pollution levels of 43.7 micrograms per cubic meter). In turn, this means that for a 1 percent increase in PM_{10} recorded, average land values decline by 0.31 percent. Similarly, a 1 microgram per cubic meter increase in $PM_{2.5}$ recorded represents about 3.82 percent increase in $PM_{2.5}$ (with average pollution levels of 26.2 micrograms per cubic meter). This means that for a 1 percent increase in $PM_{2.5}$, average land values decline by as much as 0.58 percent. For SO_2, a 1 ppb increase represents a 17.6 percent increase (with average levels of 5.7 ppb). In elasticity terms, this means that for a 1 percent increase in SO_2, average land values decline by only 0.15 percent.

Controls for local economic conditions as captured by total number of industries (manufacturing) seem to be highly significant; although it is of the opposite sign from what is expected. Higher industrial concentration might be capturing improved local economic conditions leading to higher land values assessments as opposed to Leggett and Bockstael (2000)'s negative emitter effects of higher industrial pollution.

Table 4: Fixed Effects Results of Log of Land Value for each zipcode and quarter, by type of property and zonal category, with controls for socioeconomic and local economic conditions.

	lvalorreal	lvalorreal	lvalorreal	lvalorreal
PM_{10}	-0.007**			
	(0.003)			
$PM_{2.5}$		-0.022*		
		(0.01)		
SO_2			-0.026***	
			(0.008)	
O_3				0.014
				(0.009)
Businesses	0.165***	0.102	0.184***	0.267***
	(0.024)	(0.076)	(0.024)	(0.04)
Manufactures	0.791***	1.602***	1.018***	1.371***
	(0.226)	(0.417)	(0.248)	(0.366)
Services	-0.357	-0.64	-0.503*	-0.501*
	(0.247)	(0.495)	(0.236)	(0.254)
AGEB population	-2.214	-15.828	-16.244	48.789
Density	(34.513)	(33.122)	(25.293)	(33.967)
3 rooms or more (%)	1.218	-0.242	0.235	-5.071*
	(2.236)	(2.69)	(1.868)	(2.437)
Drainage and electricity (%)	-2.054	-0.156	-0.762	3.226
	(1.761)	(2.707)	(1.632)	(2.399)
Access to formal	-2.395	-2.048	-2.885**	-0.36
social security	(1.741)	(2.722)	(1.255)	(0.909)
Total number of inhabited houses	0.122	-0.745***	0.218	-0.704**
	(0.551)	(0.175)	(0.459)	(0.245)
Average years	-0.001	-0.406**	-0.02	0.129**
Of study	(0.05)	(0.136)	(0.038)	(0.045)
Constant	9.862***	14.798***	9.881***	6.951***
	(1.381)	(2.93)	(1.374)	(1.189)
R^2	0.02	0.04	0.02	0.02
N	13,146	7,676	15,015	15,331

***p<0.01, ** p< 0.05, * p<0.1 Controls for socioeconomic characteristics, local economic conditions, and seasonal and yearly dummies included. Standard errors are clustered within municipality level.

6 Robustness Checks

In this section we check whether the impact of pollution on land values is robust to controlling for all possible time varying factors that might be changing within the zipcode and differentiated by type of property and zonal category. In effect, this is a more general specification than the two specific mechanisms of time varying neighborhood socioeconomic characteristics and local economic conditions that are explored in our main results. We control for all annual time varying factors, by including zipcode by type of property and zonal category by year fixed effects. So, log of zipcode average land values differentiated by property type and zonal category is regressed on zipcode by property type and zonal category by year fixed effects, annual average pollution in the current year and seasonal dummy variables. Standard errors are again clustered within the same municipality to control for arbitrary spatial correlation. The model is presented in equation 2 below:

$$LV_{t,z} = \alpha_{ZY} + \beta_1 Poll_{C,z} + \delta_Q + u_{t,z} \tag{2}$$

Our results, presented in Table 5 shows that the effect of pollution is robust to controlling for all time varying factors that might change within the zipcode and by property type and zonal category. The magnitudes of the coefficients are somewhat larger than Table 4, where we control for only two types of time varying features. The coefficient in column (1) of Table 5 can be interpreted as, a 1 microgram per cubic meter increase in PM_{10} leads to lower land values within the same zipcode and property type and zone, by 0.9 percent. In pesos, this translates to a MWTP of 51 (2010) pesos per m^2. For $PM_{2.5}$, the coefficient is now significant at the 5 percent level and the MWTP for lower $PM_{2.5}$ pollution is 136.1 (2010) pesos. For SO_2, we get a coefficient of MWTP for lower SO_2 pollution of almost 170.1 (2010) pesos. The marginal impact of ozone is again positive but not statistically significant. In elasticity terms, the relative magnitudes again shift in line with expectations about health damages. We find a land value-pollution elasticity of -0.39 for PM_{10}, -0.63 for $PM_{2.5}$ and -0.17 for SO_2.

Our second robustness check is to estimate the models in equations 1 and 2 but with our dependent variable averaged over property type and zonal category i.e. we generate a single observation which is the zipcode average land value for each quarter that there is data for. We are particularly interested in this because our primary explanatory variable that of pollution is constructed at the zipcode level. Not to mention that the socioeconomic controls as well as proxies for local economic conditions are constructed at the zipcode level. Effectively, we estimate the models in equations 1 and 2 but only considering a different dependent variable, keeping all the right hand side variables as they are constructed at the zipcode level.

Table 6 presents the results of regressing this zipcode average land value (irrespective of property type and zone) on zipcode fixed effects, annual average zipcode level pollution, seasonal and annual controls and controls for socioeconomic characteristics and number of establishments. Overall, the coefficients are very similar in magnitude to the land values regressions but differentiated by property type and zone within the same zipcode (Table 4). The MWTP estimates that we get range from 147.4 (2010) pesos for $PM_{2.5}$, 124.7 (2010) pesos for SO_2 and 34 (2010) pesos for PM_{10}. Unlike, Table 4, the magnitudes of MWTP for $PM_{2.5}$ is higher than that of SO_2 (in line with expectations on health damages). In elasticity terms too, we find a similar pattern of relative importance. A 1 percent rise in $PM_{2.5}$ leads to 0.68 percent decline in land values, a 1 percent increase in PM_{10} leads to 0.26 percent decline in land values and finally a 1 percent rise in SO_2 leads to only 0.12 percent decline in land values.

Table 7 presents the results of the log of land values for each zipcode and quarter (averaged over property type and zone), regressed on zipcode by year fixed effects (to control for all time varying factors) and seasonal controls. Again, we see that pollution has a consistent impact on zipcode average land values assessments that is robust to controlling for all possible time varying zipcode level factors. The MWTP is 56.7 for PM_{10}, 181.4 pesos for $PM_{2.5}$ and 119 for SO_2. All estimates are in 2010 pesos. Overall, the marginal impact of $PM_{2.5}$ is larger in magnitude and with higher level of statistical significance in the land values averaged over property type and zone models compared to the estimates where the land values are differentiated based on property type and zones. The marginal effect of SO_2 on the other hand declines in magnitude when compared to the results differentiated by property type and zones (Table 5). In elasticity terms, we again get a consistent picture with the highest magnitude for $PM_{2.5}$ (-0.84), -0.44 for PM_{10} and -0.12 for SO_2.

Table 5: Fixed Effects Results of Log and Land Value for each zipcode and quarter, by type of property and zonal category, and controlling for all possible time varying factors.

	lvalorreal	lvalorreal	lvalorreal	lvalorreal
PM_{10}	-0.009**			
	(0.004)			
$PM_{2.5}$		-0.024**		
		(0.009)		
SO_2			-0.030***	
			(0.008)	
O_3				0.02
				(0.011)
_cons	8.555***	8.601***	8.319***	7.534***
	(0.172)	(0.234)	(0.038)	(0.341)
R^2	0.00	0.00	0.00	0.00
N	13,934	8,203	15,868	16,236

***p<0.01, ** p< 0.05, * p<0.1 Log of land value for each zipcode by type of property and zonal category including year by zipcode by type of property and zonal category fixed effects and seasonal dummy variables. Standard errors clustered within municipality.

Table 6: Fixed Effects Results of Log of Land Value for each zipcode and quarter, with controls for socioeconomic and local economic conditions

	lvalorrealavg	lvalorrealavg	lvalorrealavg	lvalorrealavg
PM_{10}	-0.006**			
	(0.003)			
$PM_{2.5}$		-0.026**		
		(0.009)		
SO_2			-0.022***	
			(0.006)	
O_3				0.006
				(0.007)
Businesses	0.029	0.035	0.058	0.103*
	(0.044)	(0.06)	(0.039)	(0.049)
Manufactures	0.527	2.136***	0.871*	1.191**
	(0.48)	(0.489)	(0.47)	(0.462)
Services	-0.243	-0.864**	-0.309	-0.298
	(0.217)	(0.36)	(0.186)	(0.224)
AGEB population	-27.483	-48.636	-14.889	24.704
Density	(25.432)	(40.6)	(23.431)	(30.493)
3 rooms or more (%)	0.73	-4.058	-0.949	-3.884*
	(1.945)	(2.267)	(2.009)	(1.877)
Drainage and electricity (%)	-1.533	3.496	-0.097	1.94
	(1.503)	(2.76)	(1.632)	(1.978)
Access to formal	-2.217	1.177	-1.652	-0.262
social security	(2.275)	(3.637)	(1.999)	(1.534)
Total number of inhabited houses	0.497	-0.795**	0.166	-0.449**
	(0.485)	(0.285)	(0.408)	(0.158)
Average years	0.027	-0.375***	0.025	0.104***
Of study	(0.041)	(0.105)	(0.053)	(0.034)
Constant	9.972***	14.381***	9.599***	8.132***
	(0.877)	(1.912)	(0.761)	(0.779)
R^2	0.03	0.05	0.03	0.03
N	5,142	3,058	5,825	5,913

***p<0.01, ** p< 0.05, * p<0.1 Log of land values for each zipcode and quarter (averaged over property and zone) including zipcode fixed effects, seasonal and yearly dummies and socioeconomic characteristics and number of establishments variables. Standard errors clustered within municipality.

Table 7: Fixed Effects Results of Log of Land Value for each zipcode and quarter, controlling for all time varying factors

	(1) Land value	(2) Land value	(3) Land value	(4) Land value
PM_{10}	-0.010**			
	(0.004)			
$PM_{2.5}$		-0.032***		
		(0.003)		
SO_2			-0.021***	
			(0.005)	
O_3				-0.003
				(0.008)
cons	8.852***	9.072***	8.500***	8.428***
	(0.176)	(0.088)	(0.028)	(0.224)
R^2	0.00	0.01	0.00	0.00
N	5,462	3,269	6,168	6,268

***p<0.01, ** p< 0.05, * p<0.1 Log of land values for each zipcode and quarter (averaged over property and zone) including zipcode by year fixed effects and seasonal controls. Standard errors clustered within municipality.

7 Conclusion

On average a resident of Mexico City is exposed to high levels of air pollution on a daily basis which is a relevant problem due to the harmful consequences on health. Furthermore, pollutants are not evenly distributed among neighborhoods in Mexico City. We take advantage of this variation in air pollution within Mexico City, to show whether its residents have a preference for cleaner air. This study provides an estimate of the possible benefits of public policy aimed at improving air quality, measured as the value that Mexico City's residents have for cleaner air. The main objective of this study is to analyze the effect of air quality on land value in Mexico City, the most populated city in Mexico. This is the first study to exploit independent land value assessments obtained from external appraisals, in Mexico City. Our study provides estimates of the Marginal Willingness to Pay for the reduction of four different pollutants: SO_2, PM_{10}, $PM_{2.5}$ and O_3.

To our knowledge, there are only a few studies that perform a hedonic analysis to estimate the effect of ambient pollution on land value in Mexico. Our study uses a panel data estimation that allows us to control for all time varying, unobserved factors that affect both pollution levels and property values. Furthermore, we explore two such mechanisms of neighborhood characteristics and controls for local economic conditions. We find that improvements in SO_2 lead to 3% higher land values i.e. a MWTP of almost \$170 (2010) pesos per m^2. Our control for number of industries ensures that our estimates are unbiased (from the negative emitter effects as mentioned in Leggett and Bockstael (2000). Improvements in $PM_{2.5}$ and PM_{10} lead to 2.4% and 1% higher land values, translated into 2010 pesos: \$136.1 pesos and \$51 per m^2, respectively. In elasticity terms, we get a land value-pollution coefficient of -0.17 for SO_2, -0.63 for $PM_{2.5}$ and -0.39 for PM_{10}. Additionally, we show that pollution has a robust impact on land values at zipcode level, irrespective of the type of property or zonal category assessed within the same zipcode.

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