RESIDENTIAL MOBILITY AND OZONE EXPOSURE: CHALLENGES FOR ENVIRONMENTAL JUSTICE POLICY

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Abstract

U.S. Census data show that approximately 40 million Americans move each year, raising questions about the role of residential mobility in determining observed pollution exposure patterns. The literature in this area continues to be contested, the relationship between household sorting and exposure is still not well understood, and some aspects of these decisions remain unexplored. We offer new assessments of residential mobility explanations with respect to ozone pollution using a unique data set that combines information from repeat real estate transactions by the same San Francisco Bay Area home buyers. We find that poor/minority households (blacks/Hispanics in particular) who buy more housing services do take on more ozone pollution. Observed housing choices suggest that this may be a result of the rates at which ozone and housing services are traded in the market being different for poor minorities and white homeowners.

JEL Classification Codes: Q52, Q53, Q56, R21, R23
Keywords: Distributional effects, air pollution, environmental justice, housing demand, mobility, household sorting, neighborhood characteristics

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Introduction

A variety of studies suggest that minority and low-income households often live in areas with poor environmental quality (Institute of Medicine 1999; Wernette and Nieves 1992). Annual data also show that 14 percent of the U.S. population, or 40 million people, move to a new residence each year (U.S. Bureau of the Census 2004). Together, these facts raise questions about residential mobility and the observed correlation between race, income, and pollution. For example, when people move to a bigger house, does ozone exposure go up or down? Do minorities tend to take on more pollution for similar housing upgrades? If so, is it because the rates at which ozone and housing services trade in the market place differ or do minorities simply choose to spend less money for upgrades by moving into neighborhoods with more ozone pollution?

We offer a new assessment of these questions using a data set that combines individual real estate transactions with buyer attribute information for San Francisco Bay Area home buyers. Since we can observe individual choices and home buyer economic circumstances on multiple occasions, we can test selected environmental justice hypotheses in a new and more direct way that avoids many of the modeling assumptions that are typically required without these data. As a result, we build on existing analyses that draw conclusions about sorting-induced exposure.

We look for direct evidence that poor/minority homeowners who bought more housing services also got more ozone exposure when they moved, whereas other homeowners did not. This is an important addition to the environmental justice literature, because previous analyses that have looked for verification of the sorting explanation for environmental injustice used indirect evidence (i.e., do the percentages of poor and minority residents in a neighborhood rise when pollution increases?). However, this type of indirect evidence can be consistent with alternative explanations. For example, individuals could move near pollution not because of cheaper housing, but because of proximate job opportunities. As a result, one cannot address the housing/pollution trade-off question directly without seeing the house the individual bought and the house they sold.

Our unique data set helps solve the problem because we are able to follow buyers as they move from one house to another; we directly observe whether ozone exposure increases when particular homeowners buy more housing services. Using the move outcomes data for homeowners who chose to buy more housing services, we find ozone exposure goes up for all groups as a result of the move. The positive relationship between housing services and ozone exposure is also stronger for low income black/Hispanic homeowners than it is for low-income white homeowners. We also measure the rate at which each group (whites and minorities) are able to trade housing services for ozone pollution holding total housing expenditure fixed. The results suggest that minorities' best housing choices lead them to take on more pollution in order to upgrade housing because the costs of more housing services in clean air neighborhoods are much higher than they are for white homeowners.

Related Literature

A large number of papers in the environmental justice literature have provided information to policy makers and stakeholders concerned about environmental justice policy questions. One group of studies documents the correlation between pollution and community characteristics (e.g., Freeman 1972; Asch and Seneca 1978; UCC 1987; GAO 1983; GAO 1995; Brooks and Sethi 1997; Bullard 2000; Houston et al. 2004). Kim and colleagues (2004); Fisher, Kelly, and Romm (2006); and Pastor, Sadd, and Morello-Frosch (2007) are notable recent examples of typical analyses. A second group of papers in the literature investigates the siting decisions of polluting firms to better understand correlation patterns between pollution and community characteristics. The last group suggests the observed correlation between pollution and demographics could be in part explained by a complex sequence of housing market changes and residential mobility decisions that occur over time.

Correlation between pollution and community characteristics

Pastor, Sadd, and Morello-Frosh (2007) also focus on a similar geographic area of interest—the San Francisco Bay Area. These authors were motivated to perform their analysis after finding that no existing empirical studies had addressed the overall distribution of air pollution exposure in this region. Entitled *Still Toxic After All These Years: Air Quality and Environmental Justice in the San Francisco Bay Area*, the report uses a single-year cross-sectional design, a common method used to support claims of environmental injustice.

Pastor, Sadd, and Morello-Frosh leveraged two data sets to compute census tract-level measures of hazardous air pollutant exposure and compared these to contemporaneous socioeconomic characteristics of the tracts. The first data set (EPA's Toxic Release Inventory [TRI]) is commonly used in the environmental justice literature and includes the location of and emissions information on large industrial facilities. Using this data set, the authors specified a binary logit model where the dependent variable describes a census tract's proximity to a TRI facility (= 1 if less than 1 mile, 0 if greater than 1 mile). After controlling for selected factors (i.e., race, population density, and share of manufacturing employment), their analysis found that census tracts with low per capita incomes and homeownership rates were more likely to be in close proximity (i.e., within 1 mile) to stationary TRI facilities with air releases. Although the income and homeownership coefficients have intuitive (negative) signs, their magnitudes and standard errors were not reported; therefore, it is not possible to assess whether the coefficients were large or small. However, the authors were able to reject the hypothesis that these coefficients were zero at the 5 percent level. In addition to examining the influence of economic resources and proximity to toxic releases, the authors also found that black and Hispanic populations were more likely to live within a mile of a TRI facility with air releases after controlling for income and other tract-level characteristics.

The second data set used in the report (1999 National Air Toxics Assessment [NATA]) is unique because it considers mobile source emissions as well as large industrial facilities covered by TRI. In addition, procedures can be applied to the NATA data to describe a census tract's potential cancer and respiratory hazards. Regressing these tract-level estimates of cancer and respiratory risk on income and share of homeownership shows that after controlling for race, population density, and percentage of industrial/ commercial/transportation land use, census tracts with lower incomes and homeownership rates appear to be at a higher risk for cancer and other respiratory hazards.

Although Pastor, Sadd, and Morello-Frosch (2007) present compelling visual evidence of the correlation between Bay Area TRI facility locations and minority populations (see similar data in Figure 1), analogous conclusions cannot necessarily be drawn for a criteria pollutant like ozone since ozone concentrations are influenced by a variety of factors unrelated to the source of the emissions. Winds tend to push ozone away from the coastal areas to the mountains in the east and southeast portions of the San Francisco Air Basin.

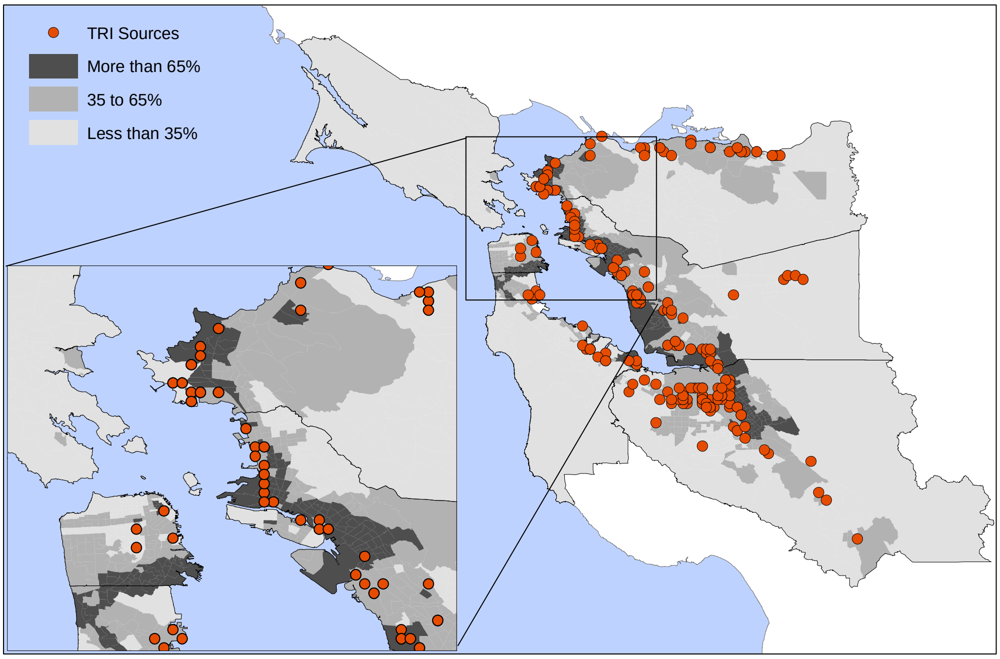


Figure 1. Locations of TRI facilities relative to neighborhood demographics (people of color)

In Figures 2 to 4, we present more detailed 2000 census tract population information by racial/ethnic group.   Although there are high concentrations of minority populations in areas where ozone tends to be transported, the visual correlation between percentage of minorities (Figures 2 to 4) and ozone pollution is less noticeable than visual correlations between TRI facilities and minorities identified by Pastor, Sadd, and Morello-Frosch (2007).   In addition, mean ozone concentrations taken from our housing sample show slightly higher concentrations for white homeowners; white homeowners had the highest house-specific maximum 1 annual hour ozone concentrations (96.0 ppb), Hispanics were next (95.3 ppb), followed by Asians (94.8 ppb), and blacks (94.6 ppb).

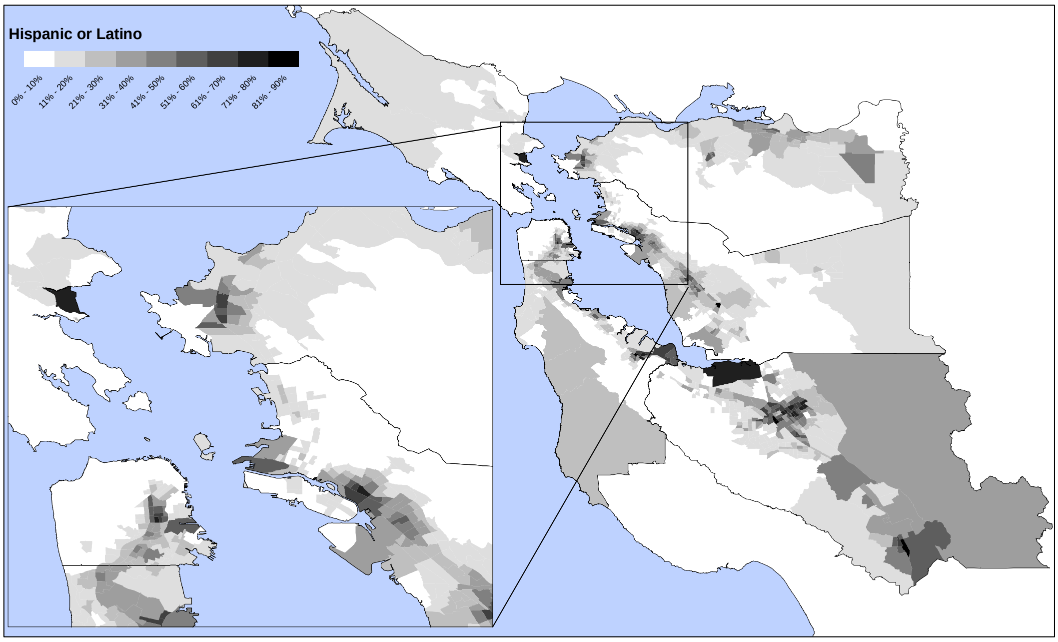


Figure 2. Bay Area Hispanic or Latino population share by 2000 census tract

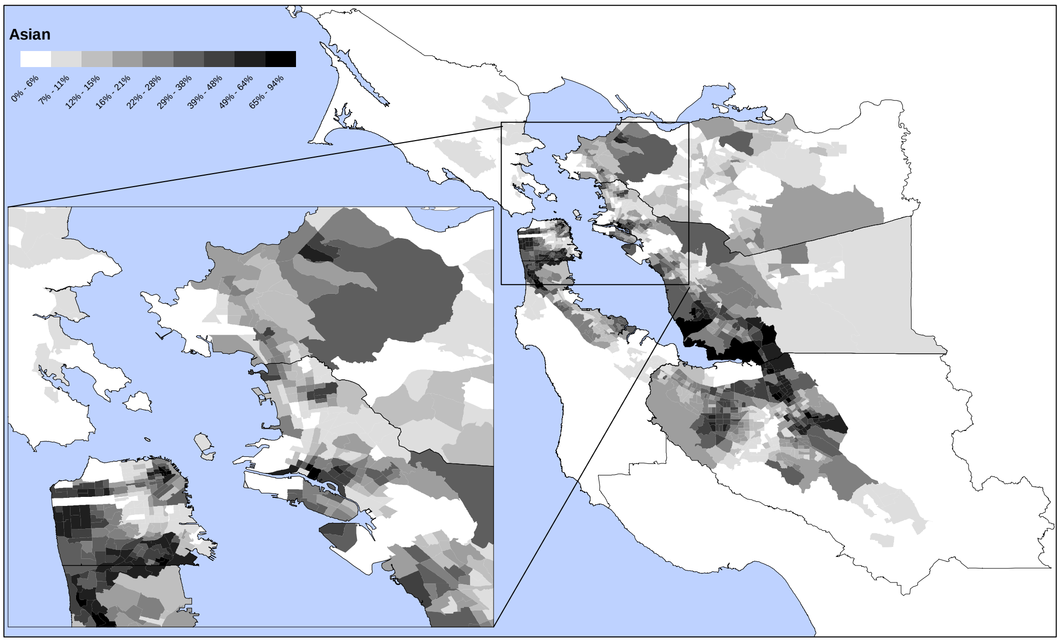


Figure 3. Bay Area Asian population share by 2000 census tract

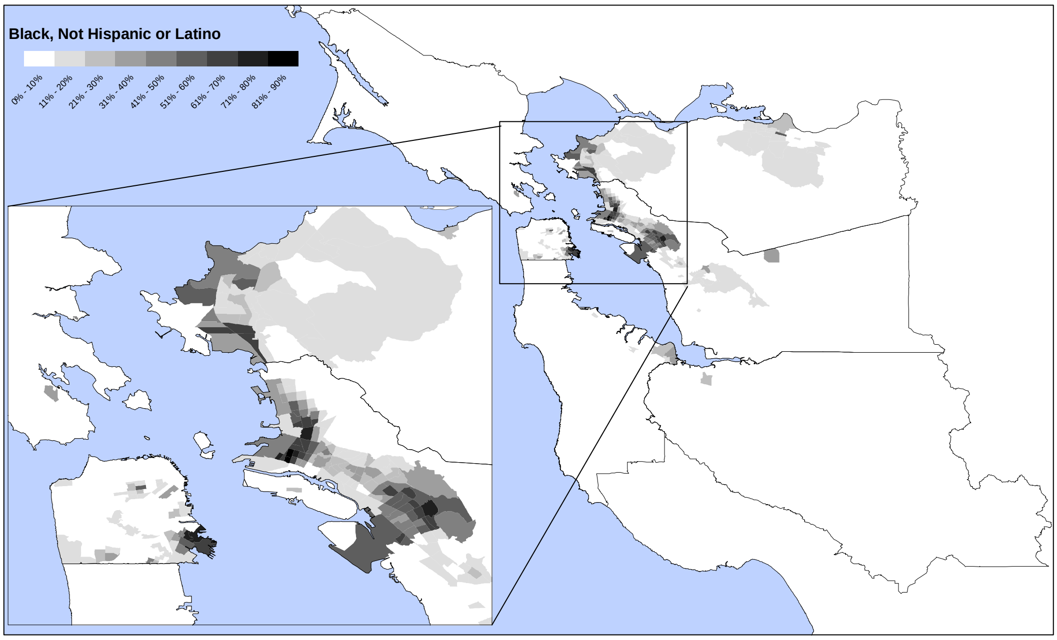


Figure 4. Bay Area non-Hispanic black population share by 2000 census tract

Next, we made similar comparisons between 2000 census tract median real household income and ozone pollution. Figure 5 suggests several areas where Basin census tracts have populations with lower median incomes; but again, it is difficult to make definitive conclusions about an income and ozone pollution relationship using the visual data alone. Evidence from our housing sample suggests income is negatively correlated with house-specific ozone pollution (−0.10); lower incomes are associated with higher ozone concentrations. In addition, homeowners in the lowest income quartile (less than $60,000) had a higher mean house-specific concentration (95.9 ppb) compared to the upper quartile (greater than $200,000) mean (93.7 ppb).

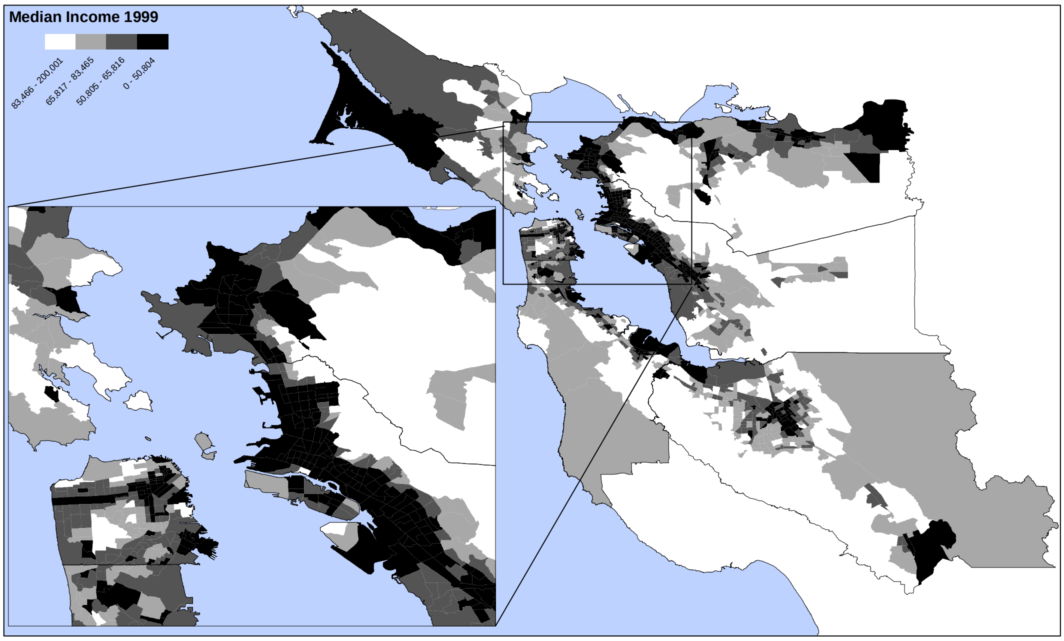


Figure 5. Bay Area median household income by 2000 census tract: 1999

Siting decisions of polluting firms and pollution exposure

Hamilton (1995) used contemporaneous community attributes to explain the planning decisions of commercial hazardous waste facilities. He tested three theories: (1) pure discrimination, (2) Coasian bargaining (i.e., that plants are sited in places where the potential costs of compensating affected residents are low because their demand for environmental quality is weak), and (3) collective action/political economy (i.e., that firms site plants in communities that are less likely to organize to collect compensation). Hamilton found that commercial hazardous waste facilities did avoid sites where potential compensation costs were high and areas were more likely to mobilize against plans for expansion. Arora and Cason (1999) compared 1993 TRI data to 1990 neighborhood attributes in an attempt to limit reverse causality in correlation (i.e., 1990 neighborhood attributes could not be caused by 1993 TRI emissions). They performed tests similar to Hamilton's and found that race, income levels, and unemployment influence release patterns from TRI facilities. Community mobilization variables also influence the level of TRI releases. In contrast, Wolverton (2009) recently examined TRI plant location decisions for two Texas cities and found little support for collective action and discriminatory siting theories; the best explanations of the plant location decisions in these cities were variables associated with profit-maximizing location decisions (i.e., production and transportation costs). Although all the papers offer interesting hypotheses and empirical tests, siting explanations for exposure inequities are less relevant for ozone because mobile sources, rather than specific sites (e.g., TRI plants), are a substantial contributor to air quality problems.

Residential mobility and pollution exposure

Only a few empirical studies have focused on the connection between household mobility and pollution exposure patterns. In one of several versions of the story, declines in environmental quality cause households to leave and property values to fall. In response, low-income minority households may find these communities attractive because they are more willing to trade higher rates of exposure in exchange for a bigger (and now less expensive) house. This process has been referred to as "housing market dynamics" (Been and Gupta 1997), "white-flight" (Oakes, Anderton, and Anderson 1996), and "minority-move in" (Morello-Frosch et al. 2002). However, three early longitudinal studies examining this question found limited or no evidence of community demographic changes after the siting of hazardous waste storage and disposal facilities (Oakes, Anderton, and Anderson 1996; Been and Gupta 1997; Pastor, Sadd, and Hipp 2001).

Banzhaf and Walsh (2008) provide one of the most direct tests of migratory responses with the entry/exit of polluting facilities and emissions of air toxics. Using difference-in-difference and matching program evaluation methods, they find strong evidence of migration patterns that are consistent with the earlier work of Kahn (2000); communities where the air becomes cleaner see population gains, while communities where the air becomes dirtier experience population declines. In addition, they also find evidence of environmental gentrification similar to that found in Sieg and colleagues' (2004) statistical simulations of household responses to air quality changes. Increases in air pollution levels appear to encourage rich households to exit a community, while poor households are more likely to enter.

One of Banzhaf and Walsh's important contributions is their attempt to better control for time-invariant unobserved local factors that determine residential location decisions. Many previous studies have not considered the role these amenities play in household sorting because so many potential factors need to be considered; even if one were successful in developing a comprehensive and agreeable list, complete data would be too difficult and costly to collect. To overcome this challenge yet still address this issue, they used school district and zip code fixed effects in addition to other demographic controls. We follow their lead and use zip code fixed effects to control for unobserved spatially distributed amenities.

The evidence presented by Banzaf and Walsh suggests that people migrate in response to environmental quality changes, and this evidence may help explain pollution exposure patterns that emerge over time. From a public policy perspective, this migration evidence suggests a very different policy response than would, for example, evidence of disproportionate siting. However, research to date has not addressed an important question about what types of constraints movers face, the consequences these constraints may have in terms of pollution exposure, and differences in the trade-offs they make in return for dirtier air (e.g., bigger houses, improved local amenities besides air quality). Well-known social advocate Robert Bullard argued that these mobility constraints are an important concern and that "poor whites and poor blacks do not have the same opportunities to 'vote with their feet'" when it comes to environmental quality choices (2000, 6). Mobility constraint differences (e.g, wealth effects associated with a previous home sale or marketplace ozone and housing service tradeoffs differ for whites and minorities) have not been addressed to date in this empirical literature.

Data

Our analysis uses a sample of 794,162 housing sales obtained from previous data work related to Bay Area real estate transactions (Bayer et al. 2008; Bishop and Timmins 2009). The commercial and public data sources are:

- *DataQuick real estate transactions*: Purchased from a national real estate company, these data provide actual transaction (instead of self-reported) prices and include information about housing characteristics (structural characteristics and geographic coordinates).
- *Home Mortgage Disclosure Act (HMDA)*: The HMDA data provide key demographic information about the home buyers.
- *California Air Resources Board (CARB) air quality data:* CARB provides the latest 27 years of monitor-level air quality data (1980 to 2006).

DataQuick includes a rich set of real estate transactions for 1990–2006 covering six key counties of the San Francisco Bay Area (i.e., Alameda, Contra Costa, Marin, San Francisco, San Mateo, and Santa Clara). Transaction variables for the analysis include a unique parcel identifier, transfer value (e.g., sale price), sales date, and geographic information (e.g., census tract, latitude, longitude). DataQuick also provides several useful housing characteristics observed at the last transaction: lot size, square footage, number of baths, and number of bedrooms (Table 1). To ensure consistency of zip codes across time, we used geographic information systems (GIS) software and *ESRI Data: U.S. Zip Code Areas: 2000* to add of 5-digit U.S. zip code to each house.

Table 1. San Francisco Bay housing sales variables and descriptions

DataQuick variable	Data set name	Description
SA_PROPERTY_ID	*Idp*	Unique parcel identifier
SR_DATE_TRANSFER	*Saleyear*	Document date for the transaction
SR_YR_BUILT	*Age*	Age computed using sales year and the year in which property was constructed
SR_VAL_TRANSFER	*Price*	Transfer value of the property, also referred to as sale amount or sale
SA_X_COORD	*Longitude*	Longitude coordinate
SA_Y_COORD	*Latitude*	Latitude coordinate
SA_LOTSIZE	*Lotsize*	Lot size expressed in square feet
SA_SQFT	*Sqft*	Total living and/or heated and/or air conditioned area square feet
SA_NBR_BATH	*Baths*	Number of bathrooms
SA_NBR_BEDRMS	*Bedrooms*	Number of bedrooms

The complete DataQuick database was reviewed, and observations were selected for the study using the following criteria. First, we restricted the analysis to houses that sold one to three times during the sample period. These houses are more likely to be representative of typical residential housing transactions versus houses that may be bought and "flipped" for investment purposes or other unusual reasons. For similar reasons, we dropped properties within this group that sold multiple times on the same day or the same year. Next, we screened properties for land-only sales or rebuilds and dropped all transactions for which the year built is missing or the transaction date is prior to the year built. To compute distances between houses and air quality monitors, we needed the property's geographic coordinates. Therefore, we dropped properties for which latitude and longitude were missing or miscodes (i.e., outside of the six counties). We also eliminated transactions without a sales price and dropped 1 percent of observations from each tail of the price distribution to minimize the effect of outliers. Finally, we restricted the sample to include only properties with the following ranges of attributes: only one housing unit, lot size (i.e., 1,000 to 70,000 square feet), square feet (i.e., 500 to 5,000 square feet), bathrooms (i.e., 1 to 5), and bedrooms (i.e., 1 to 5). The sample statistics (e.g., mean and standard deviation) for over a half a million houses (grouped by number of sales) are reported in Table 2.

For the empirical analysis we need a measure each house's housing services. Using the housing sample discussed above, year-by-year regression model was used to create *year-specific* housing service indices. In the model, the log of housing price is regressed on housing characteristics (i.e., lot size, square feet, number of baths, and number of bedrooms), ozone concentration, and zip code indicators.

Table 2. San Francisco Bay housing sales sample statistics, 1990 to 2006

	Homes with:		
Variable	**One sale**	**Two sales**	**Three Sales**
Number of Houses	322,511	153,585	54,827
Total Sales	322,511	307,170	164,481
Price ($1,000)	$411 ($261)	$400 ($259)	$377 ($250)
Age	34.4 (23.4)	33.6 (23.0)	33.6 (22.9)
Lotsize	7,568 (6,440)	6,901 (5,666)	6,300 (4,946)
Sqft	1,756 (671)	1,676 (620)	1,592 (584)
Baths	2.1 (0.7)	2.1 (0.7)	2.0 (0.67)
Bedrooms	3.3 (0.8)	3.2 (0.8)	3.1 (0.8)
Annual Max 1 Hr Ozone Concentration (ppm) (3 yr simple moving average)	0.103 (0.008)	0.104 (0.008)	0.104 (0.008)

Note: Standard deviation reported in parenthesis.

This approach takes advantage of the large number of sales observations in each year and allows the parameters in the regression to vary by year; as a result it provides the most flexible calculation of the housing services indices possible. For each year, we estimate the following model with ordinary least squares:

$$\ln P_{i,j,t} = Z'_j \phi_t + H'_i \lambda_t + A'_{i,j,t} \alpha_t + \eta_{i,j,t}. \qquad \text{Eq. 1}$$

For each buyer, we use the appropriate year's estimated housing coefficients (i.e., λ_t) to compute housing services ($H'_i \lambda_t$) for the new home and old home *in the year of the second purchase*. After making the calculation, we can measure the difference in the services provided by the new house and old house *had the buyer decided not to move*. The difference between the two housing service indices for buyer (*i*) in the year of the second purchase (*t*) is calculated as

$$\Delta \text{ housing services}_{it} = H'_{i2}\lambda_t - H'_{i1}\lambda_t \ . \qquad \text{Eq. 2}$$

Similarly, we use the house-specific pollution measure (3-year simple moving average of annual 1-hour max ozone concentration) for the new house and old house in the year of the second purchase and to calculate the difference the ozone pollution at the new house and old house *had the buyer decided not to move*. The difference between the pollution levels for buyer (*i*) in the year of the second purchase (*t*) is calculated as

$$\Delta \text{ ozone concentration}_{it} = \text{max ozone (new home)}_{it} - \text{max ozone(old home)}_{it}. \qquad \text{Eq. 3}$$

Buyer-based panel

Another feature of the DataQuick/HMDA match process is that the same buyer was linked to other housing purchases that occurred during the sample period (Bishop and Timmins 2009). As a result, a buyer's purchase decision can be observed on more than one occasion. To construct the buyer-based panel, the initial set of housing sales described in Table 2 was restricted to observations where the same buyer makes only two purchases during the sample period. Although there are cases where the same buyer appears to make more than two home purchases, people who bought only two houses were selected because they may be more representative of a "typical" buyer. In contrast, buyers who made three or more purchases in the sample period may have faced unusual and unobserved circumstances that lead to more frequent moves.

For the buyer-based panel, a variable was calculated and added that compares the price the buyer paid at the first observed purchase in the sample with the house's subsequent selling price when the buyer moved (e.g., the home appreciation rate experienced for the first home [sale $price_2$/sale $price_1$ −1]). The variable allows us to examine whether residential mobility behavior might be influenced by the size of the previously owned home's appreciation rate.

In the last step, observations with no race information for either purchase and observations that are missing real income (2000$) for the second purchase were excluded. One percent of observations from each tail of the real income (2000$) distribution and the home appreciation rate distributions were dropped to minimize the effect of outliers for these two variables. In cases where conflicting race information was provided for the first and second purchases, the reported race in the second purchase was used. If race information for the second purchase was not available, the reported race for the buyer's first purchase was used.

As noted above, the buyer-based panel uses only a very small share of the initial housing sample (N=23,156, or 3 percent of my housing sample). In order to assess whether the sample restrictions raise any selection issues with respect to the demographic variables (i.e., race and income), the buyer-based panel sample statistics (Table 3) were compared with earlier versions of the matched

DataQuick/HMDA transactions reported by Bayer and colleagues (2008) and directly with metro data for San Francisco-Oakland-Vallejo, California (id = 736) and San Jose, California (id = 740) included in the 2000 Integrated Public Use Microdata Series (IPUMS) 5 percent sample.   Using the comparisons, the restricted sample can be considered representative of the complete sample and the metro area IPUMS sample.

Table 3. Buyer-panel comparison with IPUMS 2000 5% sample

Variable	SF Bay two buyer-panel	IPUMS 5% sample
Years	1990 to 2006	2000
Observations	11,578	Households with: Income: 186,874 Race/ethnicity: 3,702,460
Real income expressed in 2000$ ($1,000)	Mean = $138 Standard Deviation = $63	Mean = $114 Standard Deviation = $63
White	63%	57%
Asian	23%	23%
Black	2%	6%
Hispanic	12%	15%

Note: IPUMS sample restricted to homeowners and two metro areas: San Francisco-Oakland-Vallejo, CA (id=736) and San Jose, CA (id=740).

In Table 4, additional buyer sample statistics are provided by race/ethnicity. As shown, white and Asian buyers have similar income and rates of appreciation from the previously owned home. In contrast, black and Hispanic homeowners had lower average incomes and their home appreciation rates were higher (84 and 75 percent) than white and Asian households (69 and 67 percent).

Air Quality Data: Time and Spatial Variation in Ozone Concentration

The San Francisco Bay Air basin has cleaner air relative to the other California air basins because of its coastal climate (CARB 2007). However, the basin continues to deal with air quality issues; federal and state governments designate the Bay Area as a nonattainment area for ground-level ozone. Figure 6 describes the time path of ozone pollution in the Bay Area. The early 1990s saw the implementation of several programs that would influence air quality trends over time:[1]

Table 4. Buyer-panel sample statistics by race/ethnicity

Variable	All Buyers	White	Black	Hispanic	Asian
Number of buyers	11,578	7,336	286	1,349	2,607
Real income expressed in 2000$ ($1,000)	Mean = $138 Standard Deviation = $63	Mean = $144 Standard Deviation = $65	Mean = $112 Standard Deviation = $46	Mean = $112 Standard Deviation = $49	Mean = $140 Standard Deviation = $60
Previous Home's Appreciation Rate	Mean = 0.69 Standard Deviation = 0.59	Mean = 0.69 Standard Deviation = 0.57	Mean = 0.84 Standard Deviation = 0.70	Mean = 0.75 Standard Deviation = 0.72	Mean = 0.67 Standard Deviation = 0.57

[1] As part of the Bay Area Air Quality Management District's 50th Anniversary celebration, the district published a history of significant events. Additional details are available can be found at http: www.baaqmd.gov/50th/.

the Clean Air Act Amendments, which included a pollution permit program for over 100 major polluting facilities; adoption of the first district Clean Air Plan; and public information programs designed to help reduce emissions from motor vehicles. The mid-1990s provided mixed results for these programs. In the same year (1995), the Bay Area reached attainment under the federal ozone standard based on improvements in the proceeding years, and the area experienced its worst air quality in 10 years. Two years later, the Bay Area rebounded and saw the best air quality on record. However, the improvement was not enough to overcome the poor air quality measures in 1995 and 1996. EPA reclassified the Bay Area as being in nonattainment under federal ozone standards.

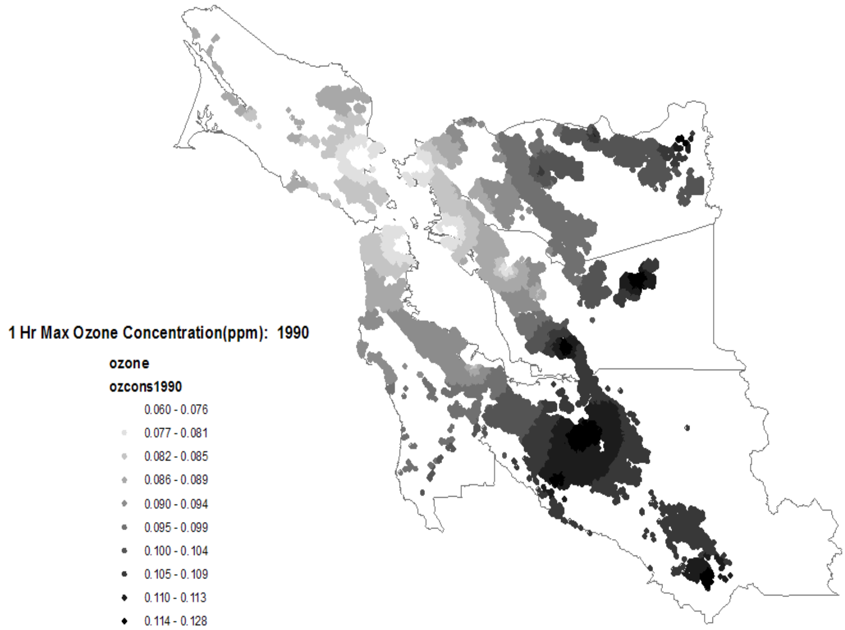
Figure 6.San Francisco Air Basin ground-level ozone pollution, 1990–2006
Source: Data from CARB 2007, Table 4-18.

To meet these new challenges, several clean air initiatives (e.g., clean-burning gasoline, vehicle and lawn mower buyback programs, new vehicle smog testing requirements, and bans on the use of garden and utility equipment during high pollution days) were adopted with some success. Since 2000, monitors measured ozone concentrations that exceeded the federal or state air quality standards on fewer than 20 days.

The spatial distribution of ozone within the air basin is influenced by west to east wind patterns and the mountains surrounding the Bay Area. Winds tend to push pollution away from the coast, and the mountains trap pollution within the region. Air pollution also escapes the Bay Area through certain mountain gaps and reaches other California air basins (CARB 2001, 38). CARB (2001) has identified the two routes in the West—the Carquinez Strait, which carries air pollution to the Sacramento Valley, and the Altamont Pass, which carries pollution into the San Joaquin Valley (Figure 7). The only outside air basin that CARB has classified as a contributor to San Francisco Bay ozone pollution is the broader Sacramento area (CARB 2001). The CARB classification ranges from "inconsequential to significant" because northern winds occasionally switch to a westerly direction and carry ozone to eastern parts of the San Francisco Bay (CARB 2001, 26). Figure 8 provides visual patterns of the spatial distribution of pollution for the first and last years of the data set (1990 and 2006). As shown, the patterns are consistent with descriptions of ozone transport described by CARB (2001).

Figure 7.San Francisco Bay ozone transport
Source: Reprinted from CARB 2001

Thirty-eight monitors in the San Francisco Bay Air Basin provide annual maximum 1-hour ozone concentration statistics. The monitors are part of a statewide system of over 250 monitors that collect pollution measurements (CARB 2007). After recording the measurements, CARB checks data quality, reports, and stores the results.



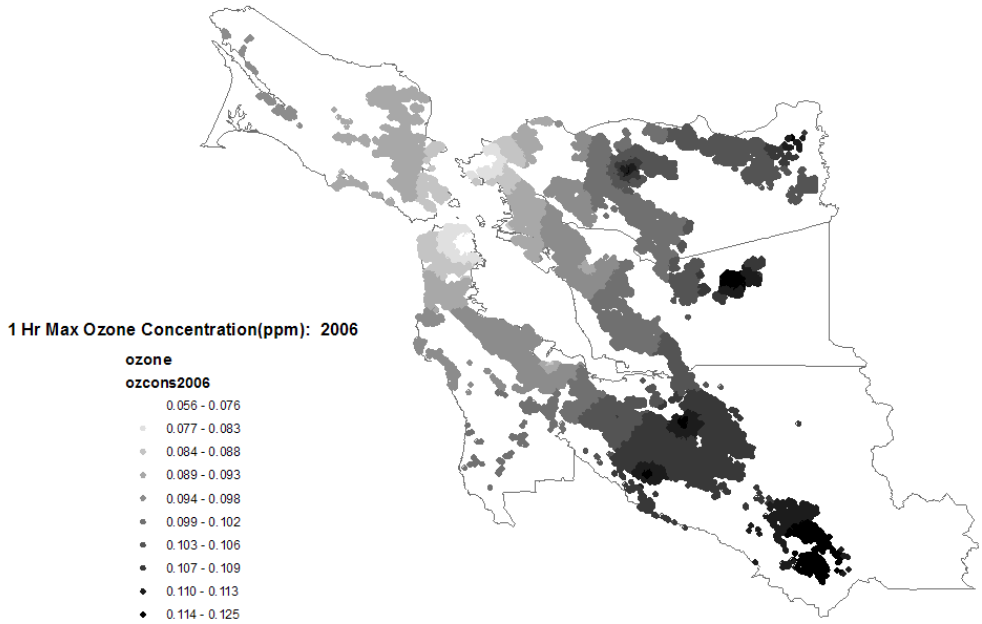


Figure 8. Ozone spatial distribution, 1990 and 2006
Source: Authors' calculations using data from CARB 2008.

In February 2008, CARB provided the latest DVD-ROM with 27 years of air quality monitor data (1980 to 2006) (CARB 2008). In addition to pollution measures, the data set includes information on each monitor's coverage with a variable that ranges from 0 to 100; the variable indicates whether the monitor was active during months where high pollution concentrations are expected. For example, a monitor with a coverage number of 50 indicates that monitoring occurred 50 percent of the time during high-concentration months.

With the house and monitor geographic information (latitude and longitude coordinates), house-specific maximum ozone concentrations (1990 to 2006) were calculated using an inverse-distance weighted average of all 38 San Francisco Air Basin monitors with at least 60 percent coverage for a given year. For example, consider a hypothetical set of 5 monitors at distances of 5, 10, 15, 20, and 25 kilometers from a house. In 1995, assume the annual one hour max concentrations recorded by the monitors are 95, 110, 115, 96, and 102 ppb. The 1995 house-specific ozone measure would be calculated distance as weighted average of all the monitor values is

$$Average\ Ozone = \frac{\frac{1}{5}\times 95 + \frac{1}{10}\times 110 + \frac{1}{15}\times 115 + \frac{1}{20}\times 96 + \frac{1}{25}\times 102}{\frac{1}{5}+\frac{1}{10}+\frac{1}{15}+\frac{1}{20}+\frac{1}{25}} = 101.90 \text{ ppb.} \qquad \text{Eq. 4}$$

Since pollution levels tend to fluctuate from year to year and buyers may take into account recent pollution trends, a simple 3-year lagged moving average of each house-specific measure ([$ozone_t$ + $ozone_{t-1}$ + $ozone_{t-2}$]/3) was also calculated.

Did Bay Area Home Buyers Who Upgraded Housing Services Take on More Ozone Pollution?

If home owners decide to upgrade houses, they can pay for the upgrade in two ways: (i) pay for these services with additional money (giving up other goods); (ii) or "pay" for them by moving to a neighborhood with more ozone pollution. To illustrate the choice, consider Figure 9, where the quantity of housing services is shown on the x-axis and the quantity of ozone pollution is on the y-axis. Within the space, we can trace the original housing expenditure line ($\$E_{original}$). A homeowner who wants a new service level (H') *without* getting more ozone pollution has to spend more money and give up other goods (point A on the new expenditure line $\$E_{new}$). Alternatively, a homeowner could stay on the original housing expenditure line and get the same new service level by taking on more ozone pollution (point B) (i.e., move along the original expenditure line).

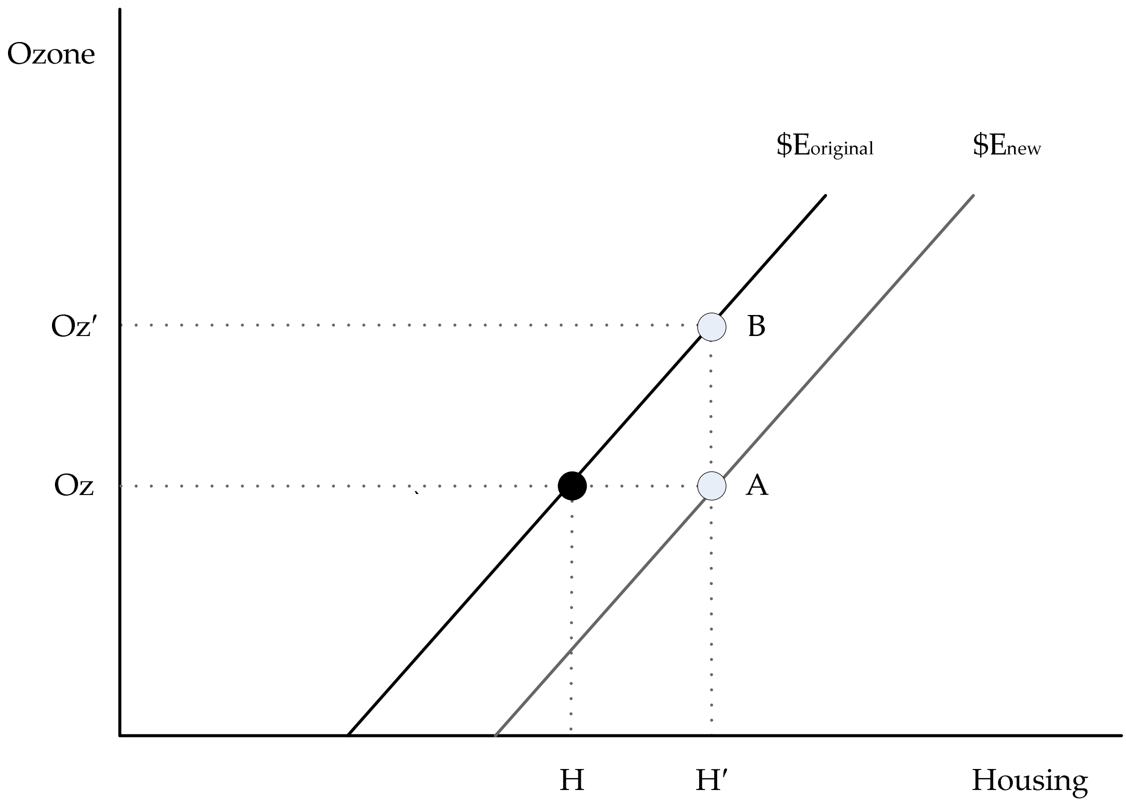


Figure 9. Different Ways Homeowners Might Choose to Pay for More Housing Services

Our homebuyer panel allows us to track individuals, observe the housing choice, and the ozone exposure consequence associated with the choice. Since we are interested in the exposure consequences for homeowners who buy more housing, we focus the subset of homeowners who bought more housing services (over 75 percent of the buyer panel; Figure 10). Initially, we measure the economic and statistical significance of the linear relationship between the two differenced variables (Δ housing services and Δ ozone concentration) using Pearson's correlation coefficient (r). If a group has a high correlation, it means that when they get more housing they tend to "pay for it" by taking on more ozone. If a group has a low correlation, it means that when they get more housing they tend to pay for it with money.

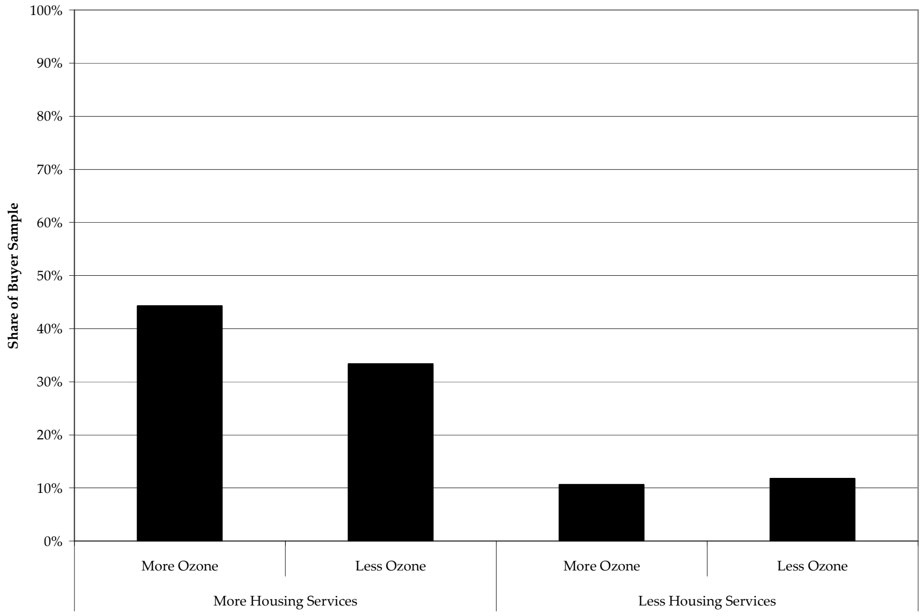


Figure 10. Distribution of homebuyer choices

Results

As shown in Table 6, the black/Hispanic homeowner's housing service/ozone correlation coefficient (0.06) is approximately 1.5 times higher than white homeowners (0.04) and Asian homeowner's correlation coefficient (0.08) is approximately two times higher. However, hypothesis tests show that the minority correlation coefficients are not statistically different from each other at the 0.10 level.

Table 6. Correlation coefficients (conditional on buying more housing services) by race/ethnicity

Racial/ethnicity group	Variables: Δ Housing services and Δ Ozone concentration	Statistically different from White Homeowners?
Black/Hispanic	0.06*	No
Asian	0.08*	No
White	0.04*	–

*Denotes the correlation coefficients conditional on buying more housing services are statistically different from zero at the 0.10 level

Note: For each buyer, the new home's housing services and ozone concentration are compared with the previous home's housing services and ozone concentration had the buyer decided not to move.

Next, we looked more closely at the real income differences to see what role (if any) income plays in mobility-induced exposure patterns. To do this, we divided the buyers in each race/ethnicity group into two income groups in each year: buyers with real income (2000$) above the median value (taken from the set of all home buyers) and buyers with real income(2000$) equal to or below the median value. As shown in Tables 7 and 8, black/Hispanic households are the only low income racial group where the conditional correlation is positive and statistically different than zero. In addition, their correlation coefficient is statistically different than low income whites (higher).

Table 7. Correlation coefficients (conditional on buying more housing services) by income group: Black/Hispanic and white

	Variables: Δ Housing services and Δ Ozone concentration		
Real income (2000$) group	**Black/Hispanic**	**White**	**Absolute difference (row)**
Above the median	0.05	0.07*	−0.02
Below or equal to the median	0.09*	0.02	0.07*
Absolute difference (column)	−0.04	0.05*	

*Denotes the correlation coefficients conditional on buying more housing services are statistically different from zero at the 0.10 level

Note: For each buyer, the new home's housing services and ozone concentration are compared with the previous home's housing services and ozone concentration had the buyer decided not to move.

Table 8. Correlation coefficients (conditional on buying more housing services) by income group: Asian and white

	Variables: Δ Housing services and Δ Ozone concentration		
Real income (2000$) group	**Asian**	**White**	**Absolute difference (row)**
Above the median	0.12*	0.07*	0.05
Below or equal to the median	0.05	0.02	0.03
Absolute difference (column)	0.07	0.05*	

*Denotes the correlation coefficients conditional on buying more housing services are statistically different from zero at the 0.10 level

Note: For each buyer, the new home's housing services and ozone concentration are compared with the previous home's housing services and ozone concentration had the buyer decided not to move.

We also considered whether changes in homeowner housing wealth (measured by large and small house appreciation rates for the previously owned home) influence the correlation coefficients. The idea is that households that make more money from the previous home sale relative to the initial purchase price may be better positioned to minimize additional ozone exposure. Additional resources may be especially beneficial for lower income homeowners because the resources can expand the available affordable housing options.

To analyze the effects of house appreciation rates within each racial/ethnic group, we further sub-divide the buyers into two additional house appreciation rate groups in each year: buyers with large appreciation rates (i.e., above the median) and buyers with small (or negative) appreciation rates (equal to or below the median). As shown in Tables 9 to 11, the only statistically different conditional correlation coefficient between high and low appreciation group is for low income Asian homeowners. For the remaining race/ethnicity and income groups, differences cannot be distinguished from zero.

Table 9. Correlation coefficients (conditional on buying more housing services) by income and home appreciation rate: White

	Variables: Δ Housing services and Δ Ozone concentration	
Appreciation rate (%) group	**Real income (2000$) below or equal to the median**	**Real income (2000$) above the median**
Above the median	0.00	0.06*
Below or equal to the median	0.04	0.07*
Absolute difference (column)	-0.05	0.00

*Denotes the correlation coefficients conditional on buying more housing services are statistically different from zero at the 0.10 level

Note: For each buyer, the new home's housing services and ozone concentration are compared with the previous home's housing services and ozone concentration had the buyer decided not to move.

Table 10. Correlation coefficients (conditional on buying more housing services) by income and home appreciation rate: Black/Hispanic

	Variables: Δ Housing services and Δ Ozone concentration	
Appreciation rate (%) group	**Real income (2000$) below or equal to the median**	**Real income (2000$) above the median**
Above the median	0.09*	0.02
Below or equal to the median	0.09*	0.07
Absolute difference	0.00	-0.05

*Denotes the correlation coefficients conditional on buying more housing services are statistically different from zero at the 0.10 level

Note: For each buyer, the new home's housing services and ozone concentration are compared with the previous home's housing services and ozone concentration had the buyer decided not to move.

Table 11. Correlation coefficients (conditional on buying more housing services) by income and home appreciation rate: Asian

	Variables: Δ Housing services and Δ Ozone concentration	
Appreciation rate (%) group	**Real income (2000$) below or equal to the median**	**Real income (2000$) above the median**
Above the median	−0.02	0.11*
Below or equal to the median	0.12*	0.13*
Absolute difference	−0.14*	-0.01

*Denotes the correlation coefficients conditional on buying more housing services are statistically different from zero at the 0.10 level

Note: For each buyer, the new home's housing services and ozone concentration are compared with the previous home's housing services and ozone concentration had the buyer decided not to move.

Why Did Poor Minorities take on More Ozone Pollution?

One limitation of the correlation analysis is that we don't know whether (poor) minorities took on more pollution in exchange for more housing because (i) they face a different constraint (i.e., ozone and housing services were traded in the market place at different rates for poor minority homeowners relative to white homeowners), or (ii) they face the same constraint but simply choose to spend less money on housing upgrades. Alternatively, we could ask how much more the minority would have to spend (i.e., how much income would have to be taken away) to get to the same consumption of housing services (H) and ozone (O3) as the white homebuyer. Paying this extra amount would presumably force him to consume less of other goods, leading him to choose to optimally end up with more ozone than the white homebuyer (conditional upon the increase in H being the same).

To better understand the reason why minorities took on more pollution, consider a function where total housing expenditures is a function of two independent variables: ozone pollution and housing services:

$$P = f(O3, H) \qquad \text{Eq. 5}$$

The total differential *dP* measures the change in total housing expenditures brought on by a move with small changes in ozone pollution (*dO3*) and housing (*dH*):

$$dP = f_{oz} dO3 + f_H dH \qquad \text{Eq. 6}$$

where f_{oz} and f_H are the partial derivatives of P with respect to ozone pollution and housing services. Holding expenditure constant ($dP = 0$), we can see how ozone and housing services are traded (i.e., the slope of an iso-expenditure function):

$$\frac{dO3}{dH} = -\frac{f_H}{f_{oz}} \qquad \text{Eq. 7}$$

Since, houses with more services are more expensive $\left(f_H > 0\right)$ and houses with more ozone are cheaper $\left(f_{oz} < 0\right)$, the slope is positive; a homeowner can get more housing services without spending additional money by taking on more pollution.

For the empirical analysis of the tradeoffs made by different demographic groups, we switch from a simple correlation analysis to an estimator that compares total housing expenditure (i.e., price), ozone pollution, and housing services for each individual (i) who buys two homes (j=1, j=2) and increases housing services consumption with the move.

$$P_{i,j} = O3_{i,j} + H_{i,j} + v_{i,j} \qquad \text{Eq. 8}$$

Other unobserved factors ($v_{i,j}$) can be broken into two groups: a fixed component that is specific to the buyer (a_i) and a idiosyncratic error (u_{ij}):

$$v_{i,j} = a_i + u_{i,j} \qquad \text{Eq. 9}$$

Using one of the strengths of the data (i.e., we see the buyer making two purchases), we estimate a differenced equation where we subtract the expenditure associated with the new house and the expenditure on the old house had the buyer decided to stay and repurchased the home. The approach provides a way to control for the unobserved individual buyer fixed effect.

$$P_{i,2} - P_{i,1} = \beta_1 \left(O3_{i,2} - O3_{i,1} \right) + \beta_2 \left(H_{i,2} - H_{i,1} \right) + \left(u_{i,2} - u_{i,1} \right) \qquad \text{Eq. 10}$$

The ratio of the coefficients on ozone and housing services $-\left(\frac{\beta_1}{\beta_2}\right)$ reveals the constraint faced by the individual (i.e., the slope of the iso-expenditure function). We re-run this procedure for both whites and minorities in an effort to determine whether the constraints faced by these two groups are different. Results of this procedure are described in Table 12.

Table 12. Regression Results for Ozone and Housing Service Tradeoffs in the Market Place by Race/Ethnicity

	Variable	Whites	Black/Hispanics	Asian
β_2	Change in housing services (*dH*)	327,351	370,838	448,926
β_1	Change in ozone (*dO3*)	−3,672,208	−2,543,142	−5,126,330
Ratio: $-\left(\frac{\beta_2}{\beta_1}\right)$		0.09	0.15	0.09
R^2		0.075	0.109	0.117
Observations		5,793	1,224	1,977

Note: β_1 and β_2 were statistically different from zero at the 0.01 level for each demographic group.

The results of these regressions indeed indicate that white and black/Hispanic house buyers do face different tradeoffs between housing services and pollution in the housing market. In contrast, whites and Asians appear to face similar tradeoffs. For some reason (e.g., more predominantly white/Asian neighborhoods offering higher housing services alternatives), whites/Asians are able to increase housing consumption without having to take on as much additional ozone. Holding the increase in ozone concentration constant across the two racial groups, the black/Hispanic house buyer has to increase expenditure by more to get the same increase in housing services (Figure 12; point X to point Y).

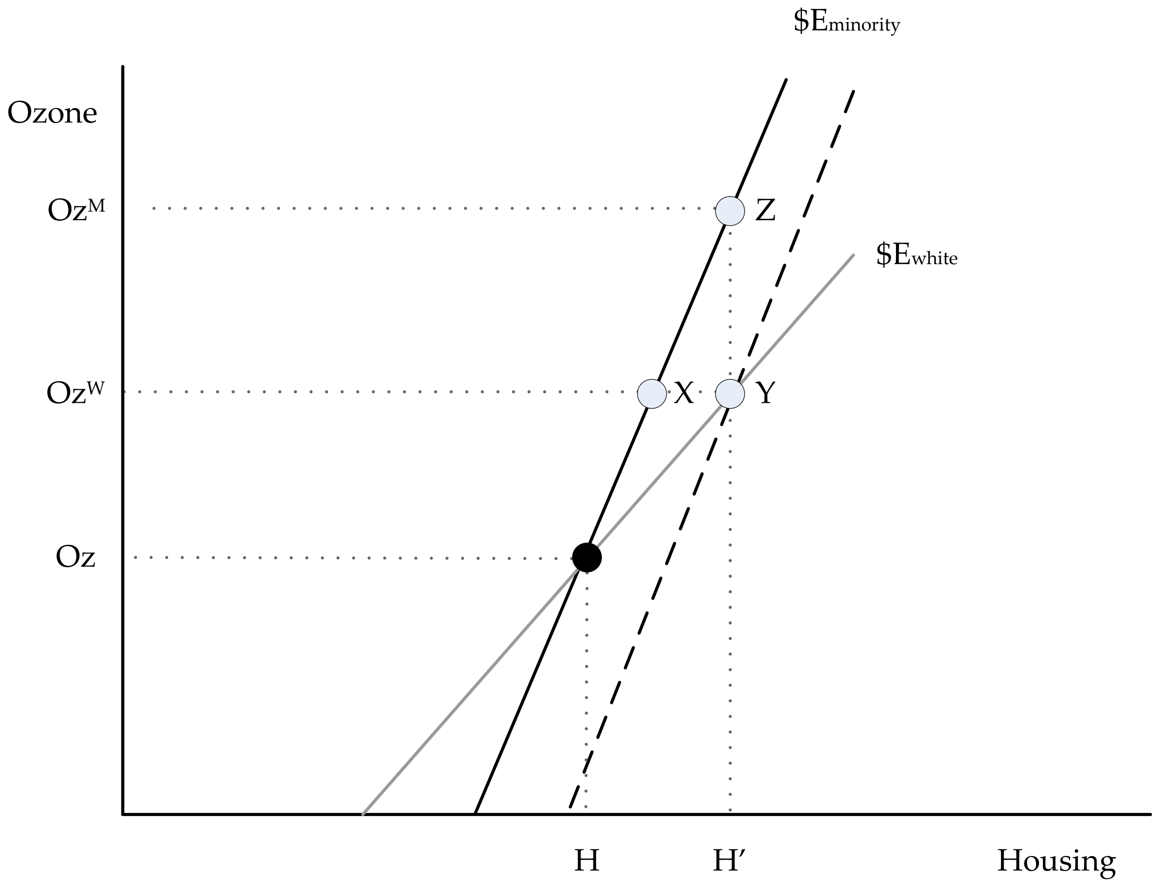


Figure 12. Different Ozone and Housing Service Tradeoffs in the Market Place

This suggests that blacks/Hispanics may be incurring more ozone simply because they are unwilling to pay to avoid it. For the same increase in expenditure, the minority home buyer has to take on more additional ozone than his white counterpart, for an identical increase in housing services (point Z versus point Y).

Conclusions

We offer a new assessment of environmental justice questions in the San Francisco Bay Area using a unique data set that combines individual real estate transactions with home buyer information. A correlation analysis shows that homeowners who buy more housing services also take on more ozone pollution as a result of the move. In addition, the positive relationship between housing services and ozone exposure is statistically stronger for low income black/Hispanic homeowners than it was for low income white homeowners, suggesting that (at least at low income levels) race may force some individuals into a worse tradeoff. These findings are consistent with sorting induced exposure stories and can help explain observed correlation patterns between race and pollution. That said, they do cannot determine whether minorities are simply less willing to give up other consumption to get additional housing services, choosing rather to pay this premium in the form of increased ozone consumption. Alternatively, they may face different tradeoffs in the marketplace. We go on to test this hypothesis by running a series of regressions that measure the rate at which each group (whites and minorities) are able to trade housing services for ozone pollution holding total housing expenditure fixed. These results suggest that blacks/hispanics do face a very different (and disadvantageous) tradeoff compared with whites. This speaks to the mechanism underlying observed patterns of environmental injustice – minorities find it optimal to take on more pollution in exchange for more housing services because the cost of getting those services without doing so is greater than for whites.

Although our analysis finds that wealth taken from appreciating housing stocks can increase the ability of lower income Asian homeowners to avoid the conventional sorting story (e.g., pay for more housing services with money versus taking on more pollution), these gains do not seem to help other low-income groups. This finding has two implications. First, certain households living in a declining neighborhood that want to improve their housing situation could be at a significant disadvantage; they own a house that will not appreciate by as much as a house in an improving neighborhood. Second, policies designed to increase homeowner housing wealth and expand access to mortgages may not enhance all homeowners' ability to move to cleaner neighborhoods in the same way. Policy makers could consider this as they weigh the many other benefits and costs of these policies.

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