Environmental Gentrification

Wen Wang

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February 22, 2021

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Abstract

Policies that are designed to reduce environmental damages have the goal of protecting the environment while promoting efficiency and pursuing equity in their distribution of benefits and costs. This paper measures the differential welfare impacts of environmental policies across household groups. To account for property market responses and re-optimization of residential housing decisions, a dynamic model of housing decisions with endogenous tenure status (renting vs. owning) and forward-looking residents is used. The model extends the distributional analysis in four previously overlooked dimensions: differential impacts of property market appreciation on renters and owners, preference heterogeneity over public amenities, wealth accumulation corresponding to property market changes, and expectations in dynamic housing decisions. The model is estimated taking advantage of an exogenous and unexpected environmental shock and employing a unique data set (L.A.FANS Data) tracking residents locations and tenure choices in Los Angeles County from 2000 to 2007. The results show that environmental improvements have regressive welfare impacts and favor owners more than renters. Welfare impacts can be reduced for renters and can be changed from positive to negative for low-income renters incorporating housing market responses and residential sorting. In contrast, owners of all incomes benefit more due to the capitalization of environmental improvements incorporating housing market responses. Provided that renters are more likely to be low-income earners and people of color, the differential welfare results in this paper raise the concern of environmental justice in policy design and evaluations.

Keywords: Gentrification, Residential Sorting, Tenure, Welfare Analysis

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1. Introduction

Over the past two decades, neighborhoods in many major U.S. cities have experienced amenity improvements or economic shifts due to urban policies or shocks (Banzhaf & McCormick 2012; Ding et al. 2016). Measuring the impacts of urban policies, especially their distributional impacts, has gained increasing attention in the literature (Sieg et al. 2004b; Chay & Greenstone 2005; Parry et al. 2006; Tra 2010; Fullerton 2011; Bento et al. 2013). A central issue in measuring the distribution of welfare impacts stems from the re-equilibration effects that follow neighborhood improvements, which can affect residents differently. Policies, especially localized policies intended to improve run-down neighborhoods occupied by low-income households, may instead lead to gentrification characterized by rising rent, property values, and demographic changes (De Verteuil 2011; Edlund et al. 2015; Baum-Snow & Hartley 2016; Couture & Handbury 2017; Hwang & Lin 2017; Lee & Lin 2018). Residents of different races, tenures (renter vs. owner), and socioeconomic conditions re-optimize their housing choices corresponding to changes in both neighborhood amenities and property markets, and end up in either better or worse neighborhoods. The property market responses and residents' housing re-optimization can redistribute benefits from urban policies and raise equity concerns. The purpose of this paper is to explore the causes of residents' differential responses and to measure the spatial and socioeconomic distribution of welfare impacts from localized environmental changes, taking account of residential sorting based on environmental changes and changes in housing prices and rents.

The dearth of empirical studies on the distribution of welfare impacts from environmental improvements, taking account of responses in the housing markets, can be attributed to methodological and data limitations. Early studies applied hedonic price methods to cross-sectional data to give partial equilibrium measures of welfare impacts, but were unable to recover marginal willingness to pay for environmental improvements accounting for price adjustment and household relocation. To the extent that households respond to market changes based on their differential preferences and socioeconomic conditions, benefits from environmental improvements can be adjusted along these margins. Later work by Sieg et al. (2004b) introduced a general equilibrium sorting model, in which heterogeneous households "sort" across neighborhoods according to their preferences for public goods and their socio-demographic characteristics (Tiebout 1956; Epple & Platt 1998; Bayer et al. 2004; Ferreira 2010; Kuminoff et al. 2013). A sorting model provides a framework to recover residents' MWTP for neighborhood amenities and to calculate the welfare impacts of interventions that result in localized amenity changes (Sieg et al. 2004b,a; Ferreyra 2007; Walsh 2007; Allen Klaiber & Phaneuf 2010; Tra 2010; Binner & Day 2015; Diamond et al. 2019). In this paper, I use a dynamic sorting model of housing decisions with endogenous tenure status (renting vs. owning) to extend the research on valuing environmental impacts.

The central contribution of this paper is to investigate distributional consequences and welfare impacts of neighborhood changes using a sorting model with three extensions — an endogenous tenure choice, a flexible characterization of neighborhood and preference heterogeneity, and a dynamic model with forward-looking agents. These three factors are overlooked in previous literature and determine the differential welfare impacts residents can get from neighborhood changes. First, my model allows a household to choose its tenure and location in each period. Rent increase in response to environmental improvements harms renters, while housing price appreciation benefits owners. Renters can move out of improved neighborhoods and lose from environmental improvements if the increase in rent burden offsets environmental improvements while owners benefit from both environmental improvements and housing price appreciation. Second, I allow residents' preferences for public amenities to be heterogenous by their income, wealth, and race. Preference heterogeneity determines the differential destinations residents choose in housing re-optimization and explains the persistence of environmental injustice.[1] Lower-income households have a lower marginal willingness to pay for environmental improvements and may sort into neighborhoods with worse environmental conditions. Preferences change with socioeconomic evolution. Owners' wealth evolves with changes in their housing prices and mortgage balances, while

[1]See more details in Appendix A

renters' income evolves with changes in their rental prices. Third, residents' forward-looking behavior and wealth evolution are subject to the inherently dynamic nature of the housing choice decisions, and help explain housing appreciation and environmental gentrification in the impacted neighborhoods. Residents choose to own houses in the most impacted neighborhoods, expecting an increase in wealth corresponding to housing appreciation. The influx of medium- and high-income residents brings housing investment and increases both housing prices and rent burdens in environmentally improved neighborhoods. Given property market prices and public amenities, forward-looking residents maximize their current and expected future utilities by choosing housing locations and tenures, taking into account moving costs. Price adjustments and changes in public amenities are the main channels through which environmental improvements affect residents' housing decisions. In the presence of differences in the price effects, moving costs, wealth accumulations, and liquidity, renters and owners get differential welfare impacts from environmental improvements. In the presence of differences in preferences, low-income and high-income residents end up in different neighborhoods after environmental gentrification.

Using this model in combination with a unique data set (L.A.FANS data), which tracks residents' locations and tenure choices in Los Angeles County from 2000 to 2007,[2] I find that the distribution of benefits from a positive environmental shock in Los Angeles County favors high-income households, especially owners, and harms low-income renters. Without property market responses and residential sorting, in a partial equilibrium measure of welfare distribution, owners on average get \$10,000 more welfare gain than that of renters, which is mostly because owners are wealthier and value environmental improvements more than renters do. However, welfare impacts for renters can be reduced once I incorporate housing market responses and residential sorting. Low-income renters who get a small welfare gain (\$3,510) from environmental

[2]To find more information about the survey data, see https://lasurvey.rand.org/. I have obtained the rights to use this restricted access data by securing an agreement between RAND and Duke University.

changes in partial equilibrium experience welfare losses (-$5,220) incorporating housing market responses. In contrast, owners of all income levels benefit more because of the capitalization of environmental improvements in the housing market. Property market responses redistribute welfare and triple the welfare gap between owners and renters. Analyses of the racial and spatial distribution of benefits further reveal that Hispanics and African Americans living in downtown LA (i.e., most impacted areas in Los Angeles County) became worse off after environmental improvements as they were mostly renters and with low income. Evidence that the benefits of environmental improvements are distributed regressively and the fact that renters are on average both poorer than owners and are mostly people of color also raises environmental justice concerns in policy design and evaluations.

The result that property market appreciation and residential sorting make environmental improvements onerous for some residents reveals that policies which attempt to improve the environment to achieve equity aims may have unanticipated and potentially counter-productive consequences, and suggests the need for complementary policies to protect vulnerable groups against potential losses and to mitigate long-term inequality. In Agrawal, Altonji & Mansfield (2019), the authors assess the impacts of neighborhood and school district in shaping student's educational attainment and early career wages. They found that moving from a school/neighborhood combination at the 10th percentile to a 90th percentile combination increases the probability of college graduation by 8% - 9% and increases wages by 10% - 11%. Couture et al. (2018) investigate the impacts of inequality on residents' welfare accounting for spatial sorting responses. They found that changes in the income distribution between 1990 and 2014 exacerbate the growing disparity between the top and bottom income decile by an additional 1.7 percentage points. The goal of this study is to help improve equity in environmental justice and urban growth by revealing the welfare implications of policies resulting in localized environmental changes and advising policy markers with potential compensating policies in the future.

The rest of the paper is organized as follows: Section 2 reviews the related literature; Section 3 describes the environmental shock in Los Angeles County that is the basis of my welfare analysis; Section 4 describes sources of data; Section 5 provides some reduced-form empirical results; Section 6 presents the structural model; Section 7 describes the estimation procedure; Section 8 discusses the results; Section 9 conducts counterfactuals; Section 10 discusses policy implications.

2. Literature Review

This paper builds on literature in environmental valuation and follows methods of equilibrium sorting modeling. A vast literature on environmental valuation sought to measure the benefits of changes in environmental quality. Following early efforts to estimate non-market values of environmental amenities using hedonic methods (Smith & Huang 1995; Chay & Greenstone 2005; Parry & Bento 2002), researchers recognized the price and income effects of environmental changes. They then worked on measuring the general equilibrium effects from environmental changes (Goulder & Williams III 2003; Carbone & Smith 2008; Bayer et al. 2006; Tra 2010; Allen Klaiber & Phaneuf 2010).[3] One canonical paper is Sieg, Smith, Banzhaf & Walsh (2004b), which is the first paper adapting the location equilibrium framework to estimate the general equilibrium benefits from environmental changes. Sieg, Smith, Banzhaf & Walsh (2004b) paper focuses on renters' housing choices and finds that the lowest income households experienced welfare loss in the environmentally improved neighborhoods due to the increase in public amenities being offset by the housing price appreciation. In this paper, I develop a dynamic sorting model with endogenous tenure choices (i.e., renter vs. owner) to capture the dynamic natures in housing market and to measure the welfare distribution across households with different tenure status, income levels and from different race groups.

[3] A comprehensive review of literature measuring the distribution of cost and benefit from environmental policies could be found in Bento (2013).

The sorting models date back to Tiebout (1956)'s household choice model which describes households "vote with their feet" by moving into communities based on their preferred levels of amenities and housing costs. Tiebout (1956)'s model developed into sorting models that characterize heterogeneous households sorting themselves across differentiated communities. Recent literature provide three approaches to recover households' preferences for amenities in a sorting model framework — Epple & Sieg (1999), Bayer, McMillan & Rueben (2004), and Ferreyra (2007). Most applications to date are linked to one of these frameworks.[4] In this paper, I adapt the framework of Bayer, McMillan & Rueben (2004) and extend it into a dynamic sorting model. Bayer et al. (2004) developed a random utility sorting model with great flexibility to estimate households' preferences.[5] The resulting estimates provided preferences for multiple housing and neighborhood attributes and were varied with households' income, race, education, and family structure. While Bayer et al. (2004) inspires my flexible setup of the utility function, Bayer, McMillan, Murphy & Timmins (2016) inspires my estimation strategies for the dynamic sorting model by providing a computationally light method.

Bayer, McMillan, Murphy & Timmins (2016) characterized moving cost and forward-looking behavior in households' housing decisions and developed a dynamic sorting model to capture observed and unobserved preference heterogeneity across households and locations in a flexible way. The central contribution of this paper was to provide a computationally light estimation strategy and to give comparisons of estimates from static models and estimates from dynamic models. The results showed that estimates from static models are subject to biases related to the inherently dynamic nature of household location decisions and overestimate marginal willingness to pay for amenities

[4] A comprehensive review of the three frameworks and various fronts of the equilibrium sorting models could be found in Kuminoff, Smith & Timmins (2013).

[5] The paper adopted the boundary discontinuity strategy from Black (1999) and house price instrument from Berry, Levinsohn & Pakes (1995) to address the endogeneity problem in housing prices and neighborhood amenities. The instrument for housing price of a neighborhood is calculated as a function of housing characteristics and exogenous amenities in all other areas. In my paper, the edogeneity problem is solved using estimation of marginal utility of wealth.

by incorrectly overweighting current value.[6]

While sorting models are broadly used in non-market valuation and developed in various fronts, the majority of the literature makes assumptions that all households rent houses from absentee landlords or that all households are homeowners.[7] Where tenure status has been considered, those papers treated tenure status as a fixed characteristic rather than a choice variable (Bayer et al. 2004, Epple & Platt 1998). However, in reality, households make joint decisions of tenure and location. Binner & Day (2015) is the first paper that includes tenure choices into a general equilibrium sorting model. Binner & Day (2015)'s model was set as a static model in which households had the same preferences and rankings of jurisdictions in terms of the local public goods, and the value of homeownership was characterized by a separate additive term to the utility. This model was then used to explore the distributional outcomes of localized environmental changes in Binner & Day (2018). Due to homogeneous preferences for homeownership and identical rental and purchasing prices as a result of the no-arbitrage rule, there was no utility effect from property value changes and households could only stay in one tenure status. The results showed that homeowners generally benefit from environmental improvements while renters experience welfare losses. While Binner & Day (2018) improved the equilibrium sorting model framework and the measurement of general equilibrium effects, they also left space for capturing the complexity of tenure choices in property markets. My model was inspired by Binner & Day (2018)'s setup and further captures tenure distinctions, including differences in price effects, moving costs, wealth accumulations, and liquidity. In my dynamic framework, property market changes will impact owners' wealth accumulation and renters' incomes in the opposite direction (i.e., housing appreciation will increase owners' wealth while rent

[6]A high value of the amenity today predicts an even higher value in future. In a static model, households will appear to overweight current values of the amenity as static models are limited in distinguishing permanent versus temporary changes in amenities and ignore expectations households have for future dynamics.

[7]Recent modeling extensions allow for moving cost (Bayer et al. 2006; Ferreira 2010; Kuminoff 2009), overlapping generations (Epple et al., 2012) and simultaneous decisions in a parallel labor market (Kuminoff et al., 2007).

burden increase reduces renters' income.)

While numerous attempts have been made to investigate the impacts of environmental changes, this paper is the first one that develops a sorting model that completely describes dynamics and tenure choices. In combination with a novel data tracking households' locations and tenure choices and taking advantage of an exogenous and unexpected environmental shock, my model explores the distribution of welfare impacts from environmental improvements taking account of housing market responses and residential sorting in a gentrification story. Neighborhood improvements spurs rising demand for housing and leads to higher property values and rents. The process of residential sorting and housing market re-equilibration, especially the in-flux of middle- and high-income households into disinvested neighborhoods, is commonly referred to as gentrification. Concerning that most of previous research focus on changes in the demographics of a gentrified neighborhood (Atkinson 2000; Wyly et al. 2010; Osman 2016) and several papers tracked displaced residents and investigate impacts of gentrification on displaced group (Brummet & Reed 2019; Dragan et al. 2019; Qiang et al. 2019), this paper is also the first paper investigating the welfare impacts of gentrification on heterogeneous residents tracking their housing choices.

3. Environmental Gentrification in LA

Environmental gentrification describes the process of gentrification spurred by environmental improvements. In 2000, an environmental shock significantly and permanently decreased pollution levels in a collection of neighborhoods in Los Angeles County. The reason for the shock was that all power plants in L.A. were forced to install the cleanest technologies in order to stay in compliance with the RECLAIM cap-and-trade program during the California Electricity Crisis.[8]

In 1994, the South Coast Air Quality Management District (SCAQMD) implemented a "cap and trade" system— the Regional Clean Air Incentives Market (RECLAIM)

[8] See more details in Appendix B.

— to control emissions of NO_X and SO_X in Southern California.[9] Firms' options to comply with RECLAIM included reducing production, increasing operating efficiency, installing abatement technology, or purchasing sufficient permits. Failure to comply meant incurring a heavy penalty. Since the market price for permits was low and the number of available permits exceeded the number of emissions for a long period after the implementation of RECLAIM, most firms were not constrained by RECLAIM until 2000. However, in 2000, because of the California Electricity Crisis, demand for permits increased as the gas-fired generators had to increase production to avoid blackouts.[10] To fulfill the extra demand for permits and stop the electricity crisis, SCAQMD negotiated with generators, suspending their involvement in the permit market and allowing them to emit more in exchange for installing abatement technologies.

The California Electricity Crisis, therefore, unexpectedly forced most of the gas-fired power plants to install abatement technologies or equipments in a short amount of time, significantly improving the environmental quality of some neighborhoods. As shown in Figure 1, toxicity concentration in many neighborhoods of downtown Los Angeles, Inglewood, Downey, Compton, Lakewood, and Torrance change from higher than 500,000 ug/m^3 to lower than 50,000 ug/m^3.[11]

Sullivan (2016) used this shock as a natural experiment to estimate its resulting impacts on housing costs and neighborhood demographics. He found that housing cost and rent significantly increased in impacted areas, and low-income households fled neighborhoods with improved air quality. In this paper, I exploit the resulting property

[9]The Regional Clean Air Incentives Market (RECLAIM) program aimed to reduce NO_X and SO_X emissions by issuing permits to 392 facilities in Southern California. A tradable but non-bankable permit was required to cover each unit of NO_X or SO_X emitted. The total number of permits issued decreased annually to force firms to either reduce production or increase pollution abatement. The program was expected to get to the "cross-point" (i.e., when the amount of emissions equals the number of permits issued) in the year 2000.

[10]Permit prices increased from \$30/ Mwh to \$240/ Mwh. This increased the marginal supply costs for a peaking turbine from \$100 to \$120/ Mwh.

[11]Data of toxicity concentration comes from Risk Screen Environmental Index (RSEI) data. Toxicity concentration is calculated as the sum of concentrations of chemicals multiplied by inhalation toxicity weight. This measure includes NO_X and SO_X and their reaction impacts with other chemicals.

market changes and households' relocation after the shock and investigate its impacts on residents' welfare.

4. Data

To investigate households' choices on locations and tenures, I bring together information from multiple sources to assemble a unique dataset recording households' socio-demographic characteristics and moving histories with detailed locations and tenure decisions within Los Angeles County from 2000 to 2007.

Moving History

The first data source is the Los Angeles Family and Neighborhood Survey (L.A.FANS) data. This survey was conducted in two waves: Wave 1 lasted from 2000-2001, and Wave 2 was fielded from 2006-2008. The survey collected information from representative neighborhoods and households in Los Angeles County but oversampled poor neighborhoods and families with children.[12] I assemble multiple data files from the survey to get a sample that provides moving histories with detailed housing addresses and tenure statuses between the year 2000 and 2007. The data includes not only the housing addresses at a level of geographic detail (i.e., the census tract), the month and year at which the individual moved to and left the particular location, some socio-demographic information including race, wealth and income, but also detailed information on rent prices, house prices, mortgages, interest rates and terms. The final sample contains 1,719 observations, of which 974 were renters, and 689 moved more than one time. The main strength of this data is that it follows households over time and records residents' movements by time, tenure, and location. This unique feature allows me to fill in the gaps of previous studies and to investigate households' decisions on both tenures and residential locations.[13]

[12] Even though it oversamples low-income families and families with children, L.A.FANS data still includes a sample of households across the entire income range.

[13] Most previous studies tend to use data from the American Housing Survey (AHS) or New York Housing and Vacancy Survey (NYCHVS). The AHS, however, only focuses on changes occurring within

I supplement the L.A.FANS data with a large sample of owners' moving histories assembled using housing transaction data — CoreLogic data and Home Mortgage Disclosure Act (HMDA) data, which allows estimation of a dynamic sorting model with flexible setup of preferences. CoreLogic data records housing transactions, including housing locations, transaction prices, mortgages, and buyers' and sellers' names. I merge CoreLogic data with HMDA data using identical mortgage variables, including the transaction year, the buyers' name, mortgage, and housing location. The matching procedure is detailed in Appendix C. The final sample contains 3,546,106 observations covering owners' movements from 2000 to 2007 and providing their socioeconomic information, including race, income, and housing wealth. To examine the representativeness of the data, I collapse the sample to the census tract level and then compare census tract demographics in my sample to that in census data. See Appendix C for more details. Summary statistics are provided in Panel A and B of Table 1.

Housing Choice

The unit of geography in this paper is neighborhood, which is defined by Los Angeles Times in its Mapping LA project.[14] The project divides the whole Los Angeles County into 272 neighborhoods. Through merging neighborhoods with few residents (i.e., Chatsworth Reservoir, Hansen Dam, ...), I arrive at 253 neighborhoods in which there are more than 10,000 housing units in each neighborhood.[15] The neighborhood boundaries are shown in Figure 4, along with the 16 corresponding regions. I model each household's housing choice as a discrete choice of a neighborhood and a house type. Houses in a neighborhood are heterogeneous by type — single-family homes, condo-

households (e.g., changes in rent and demographics), while the NYCHVS only measures changes in vacancy rates. Because they do not track those that have moved, these data cannot precisely capture residential sorting or even verify that households moved in the first place.

[14]Neighborhood is a larger geographic area than the census tract. The neighborhood is a more reasonable geographic boundary in the sense of common geographic characteristics, administrative area and labor market. In Mapping LA project, neighborhoods are defined by merging tracts within the same geographical, historical, and socioeconomic communities. Large rural areas were divided using rivers, ridgelines, or highways. See more details from http://maps.latimes.com/neighborhoods

[15]The number of housing units in each neighborhood is calculated using housing transaction data — CoreLogic Data

miniums, and multiplexes homes. Such a definition of housing choices captures the fact that different types of houses are likely located in non-overlapping geographic areas and transacted in partial independent real estate markets. The type of houses some renters are looking for can be different from what some buyers are searching for. Condominiums are the dominant houses in downtown areas while single-family homes mostly located in the suburbs. Combining housing locations with housing types and dropping some combinations that have no observations in data, I get 737 "neighborhood×type" in total.

Neighborhood Amenities

Neighborhood characteristics including average house price, rent, crime rate, school quality, pollution level, and racial composition are used to characterize neighborhood conditions.[16]

I calculate the average house prices by getting the average sale prices of houses in a type in a neighborhood transacted in one year using CoreLogic data. Housing appreciation rate is the ratio of increase in average house prices over time. In this paper, the measure of wealth is defined as housing wealth, which is the difference between the market value of a house and the mortgage balance the household hold at the beginning of a year.[17] The market value of a house is defined as the sale price in the transaction year. For years when the house is not transacted, its market value is imputed using the last sale price and housing appreciation rates in the following years. The average rent of a particular type of house in a neighborhood is calculated using average rent by bedrooms from U.S. Census data and the American Community Survey 5-year estimation from 2005 - 2007.

[16] House prices and rent prices are imputed for each choice (i.e., location × type).

[17] Other non-housing assets are assumed to be randomly distributed among renters and owners with the same income. While renters do not own the house, their initial housing wealth is assumed to be 0. When an owner switches to be a renter, he frees up his housing wealth and becomes a renter with wealth > 0.

I use toxicity concentration from Risk-Screening Environmental Indicators (RSEI) Geographic Microdata to measure households' exposure to pollution.[18] Data on violent crimes are taken from the RAND California data base.[19] The measure of school quality comes from Academic Performance Index data, which provides how districts and schools are addressing the needs of their students while identifies the specific strengths of the districts and the schools.[20] Neighborhood racial composition is calculated using the 2000 and 2010 U.S. Census data and the American Community Survey 5-year estimation from 2005 to 2007. For each of these measures, a detailed description of the imputation processes is provided in Appendix C. The list of neighborhood characteristics used in the estimation, along with means and standard deviations, is given in Panel C of Table 1.

5. Changes in Los Angeles County

Neighborhood Characteristics

Figure 5 shows how amenities changed from the year 1997 to the year 2007 in Los Angeles County. Figure 5a demonstrates the significant decrease in toxicity concentration and the correlated increase in house prices following the California Electricity Crisis in the year 2000. Figure 5b indicates that both neighborhood school qualities and safety conditions improved gradually from 2000 to 2007, while neighborhood racial

[18] See more information about this data on website `https://www.epa.gov/rsei` RSEI calculates air concentrations resulting from chemical releases using an EPA dispersion model called AERMOD. The measure of pollution used is toxicity concentration, which is calculated as the sum of "Toxicity Weight × Pounds of the Chemical" to capture the relative releases and transfers of chemicals.

[19] `https://www.randstatestats.org/ca/stats/crime-rates-(ca-only)-(archives,-1987-2009).html?dbc=cmFuZF9jYWxpZm9ybmlh`. This data summarizes counts for eight crimes: homicide, rape, robbery, aggravated assault (together, "violent crimes"), burglary, larceny-theft, motor vehicle theft (together, "property crimes"), and arson. When more than one crime occurred during an incident, only the most serious crime is recorded. A measure of 1000 crime rate for neighborhood i in year t means that there were 1000 violent crimes reported per 100,000 population in neighborhood i in year t.

[20] `https://www.cde.ca.gov/re/pr/api.asp`. The numeric API score ranges from a low of 200 to a high of 1000 across years. The interim statewide API performance target for all schools is 800. A school's growth is measured by how well it is moving toward or past that goal. The API score can be calculated at the school level using the academic performances of all students. I also calculate API scores for each race in a school.

composition was persistent with a slight increase in the percentage of Hispanics and Asians. The spatial distributions of pollution, house price, and racial composition in Figure 1, 2 and 3 illustrate that there were significant variations across neighborhoods — people of color concentrated in communities in downtown LA where houses were inexpensive before 2000 when neighborhoods were heavily polluted.

Effects of Environmental Shock

To investigate effects of the environmental shock on Los Angeles County, I define the most impacted areas as regions in Figure 4 with large toxicity reductions in Figure 1 — Central LA, Southeast, Southbay, and South LA.[21] Figure 6 shows changes in the differences between the most impacted areas and the less impacted areas from 1998 to 2007 in three public amenities — toxicity concentration, violent crime rate, and academic performance index.[22] Figure 6 illustrates that the differences between the most impacted areas and less impacted areas in their pollution level, safety conditions, and school qualities become smaller after environmental gentrification in 2000.[23] The environmental shock significantly improved environmental conditions in the most impacted areas and led to increasing in other public amenities. To further illustrate the differences between the most impacted neighborhoods and the rest of LA after the shock, I use the difference-in-difference regression stated in Equation 1 to measure the changes in public amenity levels, median income, percentage of high-educated residents, and rent burden, to test what happens to the demographic conditions in impacted areas. The results of the regressions is showed in Table 1 and reveal that the environmental

[21]These four regions are showing in Figure 4 and are regions with the most significant reduction of toxicity concentration ranged from 50% to 90% reduction in Figure 1.

[22]I remove regions of Angeles Forest, Antelope Valley and Pomona Valley from the less impacted areas as these are regions frequently impacted by forest fires.

[23]Average differences in crime rate significantly decreased after 2000 and changed from about 500 cases/10,000 population to 200 cases/10,000 population after 2002. Average differences in toxicity concentration decreased from 15,000 $\mu g/m^3$ to 5,000 $\mu g/m^3$ in 2000. Differences in school quality increased gradually from 2000 to 2007. In 2007, the most impacted areas on average had the same quality of schools as that in the less impacted areas.

shock changed the impacted areas.

$$X_{j,t} = \alpha_1(Impacted_j \times post_t) + \alpha_2 Impacted_j + \alpha_3 post_t + \\ \beta_4 control_1 + \beta_5 control_2 + ... + \xi_j + \varepsilon_{j,t} \tag{1}$$

where $X_{j,t}$ are neighborhood characteristics including toxicity concentration, violent crime rate, academic performance index as well as median income, percentage of residents with college degree, and rent burden. ξ_j are neighborhood fixed effects to capture all time-invariant characteristics of the neighborhoods. $Post_t = 1$ if $t > 2000$ indicates all measures are neighborhood characteristics after the shock.

Results in Table 1 shows that the most impacted areas had a larger decrease in pollution and crime, and a larger increase in the percentage of high-educated residents, median income, and rent burden after the shock compared to the less impacted areas. This suggests that, the exogenous positive shock in pollution which was caused by the California Electricity Crisis and the collapse of RECLAIM led households to re-optimize their residential choices. The environmentally improved neighborhoods were gentrified with influx of high-income high-education residents and displacement of low-income residents.

Renters vs. Owners

Property market appreciation has differential impacts on renters and owners — increasing rent burden for renters and increasing housing wealth for owners. As shown in Figure 7, annual rent of the most impacted areas, on average, increased by over $3,000 from 1998 to 2007. At the same time, house prices in the most impacted areas almost doubled, increasing from the average value of $300,000 to $600,000. Renters and owners re-optimized their housing choices corresponding to changes in property markets and neighborhoods. Panel A of Table 2 compares socio-demographic changes between renters and owners in years 2000 and 2007. Renters, on average, are poorer than owners. After housing re-optimization, renters, on average, end up in neighborhoods with pollution level decreased by 83,800 $\mu g/m^3$ while owners end up in neighborhoods with pollution level decreased by 101,300 $\mu g/m^3$. The fact that renters' decreases in pollution exposure are less than those of owners while most renters have been living in previously heavily polluted areas hints that renters moved out of environmentally improved neighborhoods and suggests that some renters were made worse off in housing re-optimization.

Housing Re-optimization

To investigate the housing decisions of residents living in impacted areas, I use a probit model to regress households' moving decisions on the "gentrification" measure, tenure, the interaction of tenure and impacted, and other control variables.[24] The general form of the specification is shown in the following equation 2:

$$moved_i = \beta_0 + \beta_1 Gentrification_i + \beta_2 renter_i + \beta_3 Gentrification_i \times renter_i + \beta_4 control_1 + \beta_5 control_2 + ... \quad (2)$$

where $moved_i = 1$ if household i in question moved to another tract after the crisis; $Gentrification_i = 1$ if household i lived in the gentrified tracts before the crisis happened ; $renter_i = 1$ if household i was a renter before the crisis; and controls includes age, race, education, income and having kids.

The interaction term is critical and is our main variable of interest because it indicates whether renters, as opposed to owners, are more likely to move out of the most impacted neighborhoods. The results shown in Table 2 indicate that lower-income renters are significantly more likely than lower-income owners to leave environmentally improved neighborhoods, which is a sign of welfare loss. While these results provide some indirect evidence of how housing tenure defines the welfare consequences of an environmental improvement, to measure welfare distribution and discover the reasons for the welfare consequences, a structural model is needed to characterize residents' housing and tenure

[24] I defined "gentrification" areas using pollution reduction, housing appreciation rate, rent burden, education.

choices in response to environmental improvements along with subsequent property market responses.

6. The Model

To explore households' differential responses in the housing market and the welfare impacts of environmental gentrification, I use a dynamic sorting model of housing choices with endogenous tenure decisions. Households' preferences for public amenities are allowed to be heterogeneous by race, wealth and income. Housing choices include decisions about tenure status and residential location combined with housing types. Residents of different tenure status experience divergent pathways with respect to property market and neighborhood changes. Owners' wealth accumulates with housing price appreciation while renters' disposable income shrink with an increase in rent burden. Households' sorting behavior is modeled to be forward-looking and based on the current and the expected future property prices and public amenities in a neighborhood according to their preference and moving cost.

6.1. Model Set-up

Choice Set A set of households indexed $i = 1, ..., n$ are living in a geographic region which is divided into J neighborhoods by residential property types and geographic boundaries of communities, city blocks, and jurisdictions. In each period, every household chooses its tenure and location to optimize its value in housing decisions. Tenure choice is indexed by r where $r \in \{1, 0\}$ with $r = 1$ if renting a house and $r = 0$ if owning a house. Location choice within the region is indexed by j where $j \in \{1, 2, 3, ..., J\}$. The outside option is indexed as location $J + 1$ which indicates leaving the Los Angeles County.

Decision Process At time t, a household makes a two-step choice, $d_{i,t} = \{r_{i,t}, j_{i,t}\}$ by first choosing a tenure $r_{i,t}$ and then choosing a location $j_{i,t}$. Making the same choices in two periods, $r_{i,t} = r_{i,t-1}, j_{i,t} = j_{i,t-1}$, means staying in the same house and location.[25] Moving takes place in three different cases, changing tenure $r_{i,t} \neq r_{i,t-1}, j_{i,t} = j_{i,t-1}$, changing location $r_{i,t} = r_{i,t-1}, j_{i,t} \neq j_{i,t-1}$, or changing both tenure and location $r_{i,t} \neq r_{i,t-1}, j_{i,t} \neq j_{i,t-1}$. If the household decides to move, he will choose his tenure, pick a location, and pay a moving cost to settle into a new home. Households are heterogeneous and differ in their socio-demographic conditions. They make decisions based on their preferences and expectations for neighborhood amenities, housing prices, and rental prices.

States Observed state variables at time t are $X_{j,t}, Z_{i,t}$ and $h_{i,t}$. Neighborhoods differ in the levels of public amenities $X_{j,t} = \{g_{1jt}, g_{2jt}, ...\}$. In the empirical analysis, five amenities are used to define states of a neighborhood, including measures of property market prices, environmental condition, education quality, neighborhood safety, and racial composition. Households are heterogeneous, differing in their socio-demographic conditions, $Z_{i,t}$, which includes income $I_{i,t}$, housing wealth $W_{i,t}$, and race $R_{i,t}$.[26] $h_{i,t}$ denotes location chosen in $t-1$. The unobserved state variable at time t is $\xi_{i,t}$, which represents the location characteristics not captured by other variables in a single index. $\xi_{i,t}$ is assumed to be identical for both renters and owners choosing the same location. $\varepsilon_{irj,t}$ is an idiosyncratic stochastic shock which is i.i.d. Type I Extreme Value distributed. The transition probabilities of the states are assumed to be Markovian and conditional independence,

$$
\begin{aligned}
& q(X_{j,t+1}, Z_{i,t+1}, h_{i,t+1}, \xi_{i,t+1}, \varepsilon_{irj,t+1} | X_{j,t}, Z_{i,t}, h_{i,t}, \xi_{i,t}, \varepsilon_{irj,t}, d_{i,t}) \\
& = q(X_{j,t+1}, Z_{i,t+1}, h_{i,t+1}, \xi_{i,t+1} | X_{j,t}, Z_{i,t}, h_{i,t}, \xi_{i,t}, d_{i,t}) q_{\varepsilon}(\varepsilon_{irj,t+1})
\end{aligned}
$$

[25] This model does not allow households to stay in the same house but sell/rent part of it to others. This setup is valid as houses of the same type and in the same location are assumed to be homogeneous and have identical prices. Different from previous literature which defines houses in the same location as a homogeneous good that can be purchased in different quantities at a constant unit price (Epple & Romer 1991; Epple & Platt 1998; Bayer et al. 2004; Ferreyra 2007), in this paper, households purchase or rent their properties as one unit with identical prices in a location×type (Bayer et al., 2016). Choice j in this paper is a discrete choice of both geographic neighborhoods and house types.

[26] Housing wealth $W_{i,t}$ is first calculated as the difference between the market value of a house and the initial mortgage amount the household borrowed. Using data of mortgage, interest, housing transaction price, and housing appreciation rate, I further calculate mortgage balance in each period. The housing wealth of each period t is then $MarketValue_{j,t} - MortgageBalance_{i,t}$.

Households' Utility A household's preferences differ by residents' socio-demographic characteristics $Z_{i,t}$. Utility of household i choosing tenure r and location j at time t is:

$$u_{ijr,t} = \alpha_{i,t} X_{j,t} + \gamma_{i,t} usercost_{j,r,t} + \iota_{i,t} r_{i,t} + \xi_{j,t} + \epsilon_{ijr,t} \tag{3}$$

$$\alpha_{i,t} = \beta Z_{i,t}$$

$$\iota_{i,t} = \zeta Z_{i,t}$$

where $X_{j,t}$ is neighborhood characteristics including toxicity concentration, school quality, crime rate, and racial composition; $Z_{i,t}$ is household characteristics including income $I_{i,t}$, wealth $W_{i,t}$, and race $R_{i,t}$; $usercost_{j,r,t}$ is the flow cost for a household to live in location j with tenure r; $r = 0, 1$ index tenure choice with $r = 1$ indicating renting; $\iota_{i,t}$ captures the preference for renting induced freed up; $\xi_{j,t}$ is the unobserved neighborhood fixed effect, which is assumed to be identical for owners and renters.

The form of the utility function embeds two assumptions:

Assumption 1-$\mathcal{U}$. *$\alpha_{i,t}$ is identical for renters and owners of the same socio-demographic conditions.*

Assumption 2-$\mathcal{U}$. *$\xi_{j,t}$ is local fixed effect, which is identical for renters and owners choosing the same neighborhood.*

The preference for renting, $\iota_{i,t}$, is used to describe the utility from renting-induced freed up through investing on assets with more liquidity than housing assets. In the simple case of switching from an owner to a renter but choosing to locate in the same neighborhood, the household gets the same utility from neighborhood amenities and becomes less wealthy in the switch. The reasons for such a switch could be that the household expects the real estate market or the rental market will be in the doldrums in the future or the household's financial condition changes. The household chooses to be a renter to avoid losses from languishing housing market, to free up capital, or to lower housing cost. The value of liquidity, $\iota_{i,t}$, captures the fact that by selling the home to be a renter, the household gets wealth with more liquidity, which allows for other investment or usage.

Moving Cost Moving cost is different between renters and owners. Renters pay basic moving cost $BMC_{i,t}$ when moving. Basic moving cost is motivated by a number of factors including emotional stress, physical costs, and time cost. In this model, basic moving cost is assumed to be identical for any choices of neighborhood and characterized as a function of households' socio-economic conditions to capture households' cost sensitivity.[27] Besides basic moving cost $BMC_{i,t}$, owners need to pay financial moving cost, $FMC_{i,t}$, which is a standard rate (6%) of the sale price as the realtor fee. Using $P_{i,h,t}$ to indicate prices of houses sold at time t in original location h, $FMC_{i,t}$ and $BMC_{i,t}$ are as follows:

$$FMC_{i,t} = 6\% \times P_{i,h,t} \tag{4}$$

$$BMC_{i,t} = \theta_{bmc}\bar{Z}_{i,t} \tag{5}$$

Financial moving cost takes place in housing transaction and increases with housing appreciation. The fact that financial moving cost is a considerable proportion of the house selling price determines that financial moving cost reduces households' wealth instead of income. Hence, in this model, the moving cost is separated into two parts with different properties. Basic moving cost is assumed to be additive separable to the utility function. If a household moves at time t, his utility is:

$$u^{MC}_{ijr,t} = u_{ijr,t}(X_{j,t}, r_{i,r}, \bar{Z}_{i,t}, \xi_{j,t}) - BMC(\bar{Z}_{i,t}) + \epsilon_{ijr,t} \tag{6}$$

$$\bar{Z}_{i,t} = \begin{cases} [R_{i,t}, I_{i,t}, W_{i,t}] & \text{if } r_{i,t-1} = 1 \\ [R_{i,t}, I_{i,t}, W_{i,t} - FMC_{i,t}] & \text{if } r_{i,t-1} = 0 \end{cases} \tag{7}$$

[27] In this model, I did not characterize the basic moving cost as a function of distance between original or destination locations as the choice set is geographically in one region which is relatively small. The difference in moving cost caused by distance is minor in this setup

where $\bar{Z}_{i,t}$ reflects reduction of owners' wealth by financial moving cost $FMC_{i,t}$. If a household chooses to stay at time t, its utility can be rewritten as:

$$u_{ijr,t}^{MC} = u_{ijr,t}(X_{j,t}, r_{i,r}, \bar{Z}_{i,t}, \xi_{j,t}) + \epsilon_{ijr,t}$$

Renters v.s Owners Choice of tenure status plays a vital role in this model. The model setup allows me to draw a clear contrast between renting and owning in four aspects:

- *Moving Cost*: renters moving out of location j pay less moving cost than do owners in same socio-demographic characteristics. The difference is financial moving cost $FMC_{i,t} = 6\% \times P_{i,h,t}$, which changes owners' wealth $W_{i,t}$ and preferences $\alpha_{i,t}, \iota_{i,t}$.

- *User Cost*: assuming living cost is mainly maintenance fee and insurance, renters' living cost is paid by landlord, $usercost_{ir,t} = 0$ if $r = 1$. Owners' living cost is assumed to be a standard rate (1%) of housing price.

- *Rental and Mortgage*: owners pay mortgage $M_{i,t}$ to banks while renters pay rent $R_{i,t}$ to landlords. The annual net income $I_{i,t}$ is calculated as the difference between annual family earnings and annual rent for renters while it is the difference between annual family earnings and annual mortgage for owners.

- *Liquidity and Wealth Accumulation*:

  Wealth $W_{i,t}$ is defined as housing wealth. Wealth accumulation over time could be expressed as:

$$W_{i,t} = \begin{cases} P_{ij,t} - P_{ij,t-1} + W_{i,t-1} & \text{if } r_{i,t-1} = r_{i,t} = 0, h_{i,t} = j \\ P_{ih,t} - P_{ih,t-1} + W_{i,t-1} - FMC_{i,t} & \text{if } r_{i,t-1} = r_{i,t} = 0, h_{i,t} \neq j \\ P_{ih,t} - P_{ih,t-1} + W_{i,t-1} - FMC_{i,t} & \text{if } r_{i,t-1} = 0, r_{i,t} = 1 \\ W_{i,t-1} & \text{if } r_{i,t-1} = 1 \end{cases} \tag{8}$$

Owners' wealth accumulates with increase in home equity, which comes from both reduction of mortgage balance and housing market appreciation. Renters' wealth won't be changed by housing market. Households who begin as renters start with no housing wealth, $W_{i,0}^{renter} = 0$, while households who begin with owners start with housing wealth defined as $W_{i,0}^{owner} = TransactionPrice_{i,0} - Mortgage_{i,0}$. If a household decides to keep being an owner and stays in the same place in period t, its housing wealth accumulates as housing price appreciates. If a household decides to move in period t, no matter whether it decides to be an owner or a renter, it gets the home equity and pays the financial moving cost.[28] The wealth of renters will not accumulate over time. Hence, if a household is a renter in period $t-1$, in period t, no matter whether the household chooses to be a renter or an owner, its wealth will remain the same as that in the last period, $W_{i,t-1}$. In addition, if an owner decides to be a renter in period $t-1$, its wealth in the transaction period $t-1$ is $P_{ih,t-1} - P_{ih,t-2} + W_{i,t-2} - FMC_{i,t-1}$. From period $t-1$ to period t, since the household is a renter, its wealth will not accumulate and will continue to be $P_{ih,t-1} - P_{ih,t-2} + W_{i,t-2} - FMC_{i,t-1}$ in period t. However, since the household chooses to be a renter, the amount of wealth freed up from selling its house will give it utility, $\iota(I_{i,t}, W_{i,t})$.

Value Function In a dynamic sorting model, households are forward-looking and make decisions based on the current utility and the expected sum of flow utility onward which is a function of the evolution of states. The value function of choosing location j and tenure r at time t is composed of current utility of living in location j being tenure r, and expected optimal value in period $t+1$.

$$v_{i,t}^{MC} = u_{ijr,t}^{MC} + \beta E[V_{t+1} | X_{j,t}, Z_{i,t}, \xi_{j,t}, \varepsilon_{ijr,t}, d_{i,t} = \{j, r\}] \tag{9}$$

[28]If an owner decides to move and purchases another house in a different location q, in the period of moving, I assume the net housing wealth will not be changed.

While $\varepsilon_{ijr,t}$ is i.i.d. Type I Extreme Value distributed, the choice-specific value function is:

$$v_{i,t}^{MC} = u_{ijr,t}^{MC} + \beta E[log(\sum_{r=0}^{r=1}\sum_{j=1}^{J+1} exp(v_{irj,t+1}^{MC}))|X_{j,t}, Z_{i,t}, \xi_{j,t}, d_{i,t}]$$

Households make a sequence of decisions $\{d_{i,t}\}$ to maximize lifetime expected utility:

$$argmax_{\{d_{i,t}\}_t^T} E[\sum_{\rho=t} \beta^{\rho-t}(u^{MC}(X_{j,\rho}, Z_{i,\rho}, d_{i,\rho-1}, \xi_{j,\rho}, \varepsilon_{ijr,\rho}))|X_{j,t}, Z_{i,t}, \xi_{j,t}, \varepsilon_{id,t}, d_{i,t}]]$$

With the optimal decision rule d^* and the Markov structure of the state variables, decision in period t, $d_{i,t}$ is determined as $d^*(X_t, Z_{i,t}, \xi_t, d_{i,t-1}, \varepsilon_{i,t})$. The lifetime expected utility could be rewritten as a Bellman equation with the value function at time t as follows:

$$\begin{aligned} V_{i,t} &= max_{d_{i,t}}\{u_{ijr,t}^{MC} + \beta E[V_{i,t+1}|X_{j,t}, Z_{i,t}, \xi_{j,t}, \varepsilon_{ijr,t}, d_{i,t} = \{j, r\}]\} \\ &= max_{d_{i,t}}\{u_{ijr,t}^{MC} + \beta E[log(\sum_{r=0}^{r=1}\sum_{j=1}^{J+1} exp(v_{irj,t+1}))|X_{j,t}, Z_{i,t}, \xi_{j,t}, d_{i,t}]\} \end{aligned}$$

Each household makes a sequence of decisions about location and tenure $d_{i,t}$ to maximize its lifetime expected utility given public amenities $X_{j,t}$, households' socioeconomic conditions $Z_{i,t}$, households' previous decisions $h_{i,t}$, and vectors of housing prices and rental prices, $P_t = \{P_{1,t}, P_{2,t}, ..., P_{J,t}\}$ and $R_t = \{R_{1,t}, R_{2,t}, ..., R_{J,t}\}$.

7. Estimation

As shown in Figure 9, a household makes housing decisions in two steps — choosing a tenure status in the first step and choosing a neighborhood in the second step.[29] The nested logit probability is composed of two probabilities from the two-step choices. The lower-level choice, $P_{i,t}(j|r)$, gives the conditional probability of neighborhood choices

[29]The choice of tenure is assumed to be the first stage choice since the choice set is in a small region — a county. In reality, for movements within a small region, households mostly will determine tenure first. For movement across a large area (i.e., move from one city to another city), the choice of locations will be made first.

conditional on choosing tenure status. The upper-level choice, $P_{ir,t}$, gives the probability of tenure choice.

$$P_{ijr,t} = P_{ir,t} \times P_{i,t}(j|r)$$

7.1. Type of Household

In the model, per-period utility of household i is:

$$u_{ijr,t} = \alpha_{i,t} X_{j,t} + \gamma_{i,t} usercost_{j,r} + \iota_{i,t} r_{i,t} + \xi_{j,t} + \epsilon_{ij,t}$$

$$\alpha_{i,t} = \beta Z_{i,t}$$

$$\iota_{i,t} = \zeta Z_{i,t}$$

Households' heterogeneous preferences for amenities are characterized by continuous socioeconomic characteristics $Z_{i,t} = [R_{i,t}, W_{i,t}, I_{i,t}]$. To lower computation burden,[30] preference heterogeneity is redefined by discrete socioeconomic categories $Z^{\tau}_{i,t} = [R^{\tau}_{i,t}, W^{\tau}_{i,t}, I^{\tau}_{i,t}]$. With ten wealth categories $W^{\tau}_{i,t}$, three income categories $I^{\tau}_{i,t}$, and five race categories $R^{\tau}_{i,t}$, I separate households into 150 distinct types indexed by τ.[31]

Per-period utility could be rewritten as:

$$u^{\tau}_{jr,t} = \alpha^{\tau} X_{j,t} + \gamma^{\tau} usercost_{j,r} + \iota^{\tau} r_t + \xi^{\tau}_{j,t} + \epsilon_{j,t} \tag{10}$$

$$\alpha^{\tau} = \beta Z^{\tau}_{i,t}$$

$$\iota^{\tau} = \zeta Z^{\tau}_{i,t}$$

Households of same type τ will therefore have the same preferences for amenities. As the financial moving cost will change the wealth of an owner, analogously to the previous

[30] Without simplification or type categories, I need to get a large value function matrix (i.e., a matrix in dimension 737×8 for 737 neighborhoods in 8 years) for each resident i.

[31] Wealth is measured in 10 categories — $<$ \$10,000, \$10,000 – \$20,000, \$20,000 – \$40,000, \$40,000–\$70,000, \$70,000–\$100,000, \$100,000–\$130,000, \$130,000–\$170,000, \$170,000–\$230,000, \$230,000 – \$300,000, $>$ \$300,000 — interacted with three income categories — $<$ \$50,000, \$50,000–\$120,000, and $>$ \$200,000 — and for five race groups — White, Hispanic, African American, Asian, Other.

set-up, households of type τ will change into type $\bar{\tau}$ after moving. Households' utility function under a move can be rewritten as:

$$u^{MC,\tau}_{jr,t} = u^{\tau}_{jr,t}(X_{j,t}, r_{i,r}, Z^{\bar{\tau}}_{i,t}, \xi_{j,t}) - BMC(Z^{\bar{\tau}}_{i,t}) \tag{11}$$

$$Z^{\bar{\tau}}_{i,t} = \begin{cases} [R^{\tau}_{i,t}, I^{\tau}_{i,t}, W^{\tau}_{i,t}] & \text{if } r_{i,t-1} = 1 \\ [R^{\tau}_{i,t}, I^{\bar{\tau}}_{i,t}, (W_{i,t} - FMC_{i,t})^{\bar{\tau}}] & \text{if } r_{i,t-1} = 0 \end{cases}$$

Value function of type τ households is:

$$v^{\tau}_{jr,t} = u^{MC,\tau}_{jr,t} + \beta E[log(exp(v^{\tau}_{jr,t+1}) + \sum_{k \neq j \& q \neq r} exp(v^{\bar{\tau}}_{kq,t+1}) - BMC^{\bar{\tau}})|X_{jr,t}, Z^{\tau}_{t}, \xi_{j,t}, d_t]$$

7.2. Owners' Location Choice

Conditional on being an owner, a household will choose a location with the highest expected lifetime utility by maximizing location-specific value functions. Let $v^{O}_{ij,t}$ denote an owner's conditional value function at time t picking location j. An owner of type τ chooses to live in location j if:

$$v^{O,\tau_t}_{j,t} + \varepsilon^{O,\tau_t}_{j,t} > v^{O,\tau_t}_{k,t} + \varepsilon^{O,\tau_t}_{k,t}, \forall \{k\} \neq \{j\}$$

The decision to move will change the household's type into $\bar{\tau}_t$. The conditional probability of an owner moving to location j could be expressed as:

$$P^{O,\bar{\tau}_t}_{j,t} = \frac{e^{v^{O,\bar{\tau}_t}_{j,t} - BMC^{\bar{\tau}_t}_{t}}}{\sum_{k \neq h} e^{v^{O,\bar{\tau}_t}_{k,t} - BMC^{\bar{\tau}_t}_{t}}}$$

Subject to a normalization and ignoring the identical $BMC_t^{\tau_t}$, owners' conditional probability of moving could be simplified as: [32]

$$P_{j,t}^{O,\bar{\tau}_t} = \frac{e^{\tilde{v}_{j,t}^{O,\bar{\tau}_t}}}{\sum_{k \neq h} e^{\tilde{v}_{k,t}^{O,\bar{\tau}_t}}} \tag{12}$$

$$\tilde{v}_{j,t}^{O,\bar{\tau}_t} = v_{j,t}^{O,\bar{\tau}_t} - m_t^{O,\bar{\tau}_t}$$

The likelihood of moving could be expressed as:

$$L_{iO}^{Move_{j,t}} = \Pi_{j \neq h} (P_{j,t}^{O,\bar{\tau}_{it}})^{I[d_t = j, O]} \tag{13}$$

Households who decide to stay don't need to pay the moving cost — $FMC_{i,t}$ and $BMC^{O,\bar{\tau}_t}$. An owner's decision to stay in location j could be expressed as:

$$v_{j,t}^{O,\tau_t} + \varepsilon_{j,t}^{O,\tau_t} > v_{k,t}^{O,\bar{\tau}_t} - BMC^{O,\bar{\tau}_t} + \varepsilon_{ik,t}^{O,\bar{\tau}_t}, \forall k \neq j$$

Alternatively, this can be rewritten as:

$$v_{j,t}^{O,\tau_t} + \varepsilon_{j,t}^{O,\tau_t} > max_{\forall \{k\} \neq \{j\}} (v_{k,t}^{O,\bar{\tau}_t} + \varepsilon_{k,t}^{O,\bar{\tau}_t}) - BMC^{O,\bar{\tau}_t}$$

Using a normalization, the expression changes into:

$$\tilde{v}_{j,t}^{O,\tau_t} + \varepsilon_{j,t}^{O,\tau_t} > max_{\forall \{k\} \neq \{j\}} (\tilde{v}_{k,t}^{O,\bar{\tau}_t} + \varepsilon_{k,t}^{O,\bar{\tau}_t}) - BMC^{O,\bar{\tau}_t} - (m_t^{O,\tau_t} - m_t^{O,\bar{\tau}_t})$$

If the household chooses to stay, its type remains as τ_t while if it moves, its type changes to $\bar{\tau}_t$. The difference is a result of the financial moving costs, $FMC_{i,t}$, that are incurred by owners when they sell. As I assumed that financial moving cost equals six percent of the house selling price in the previous location $h_{i,t}$, I get that $m_t^{O,\tau_t} - m_t^{O,\bar{\tau}_t}$ is a function

[32] In discrete choice model, $v_{j,t}^{O,\bar{\tau}_t}$ is unique up to a constant. $m_t^{O,\bar{\tau}_t}$ is set to be a normalized constant for which mean of the expected value for each type-year combination.

of $P_{ih,t}$. Assuming the normalization difference is a linear function:

$$m_t^{O,\tau_t} - m_t^{O,\bar{\tau}_t} = \theta_{fmc}^{\bar{\tau}_t} FMC_{i,t} \tag{14}$$

$$BMC_{i,t}^{\bar{\tau}_t} = \theta_{bmc}^{\bar{\tau}_t} Z_{i,t}^{\bar{\tau}_t}$$

The probability of an owner's decision to stay is:

$$P_{j,t}^{O,\tau_t} = \frac{e^{\tilde{v}_{j,t}^{O,\tau_t}}}{e^{\tilde{v}_{j,t}^{O,\tau_t}} + \sum_{k\neq h} e^{\tilde{v}_{k,t}^{O,\bar{\tau}_t} - \theta_{fmc}^{\bar{\tau}_t} FMC_{i,t} - \theta_{bmc}^{\bar{\tau}_t} Z_t^{\bar{\tau}_t}}} \tag{15}$$

The likelihood of staying can be expressed as:

$$L_{iO}^{Stay_{j,t}} = (P_{j,t}^{O,\tau_{it}})^{I[d_{i,t}=h_{i,t}]}(1 - P_{j,t}^{O,\tau_{it}})^{I[d_{i,t}\neq h_{i,t}]} \tag{16}$$

and the combined likelihood function at time t can be expressed as

$$L_{iO,t} = \Pi_{t=1}^{T} L_{iO}^{Stay_{j,t}} L_{iO}^{Move_{j,t}}$$

This can be revised into a log-likelihood form:

$$\begin{aligned} Ln_{i,t} &= \sum_{t=1}^{T} (log(L_i^{Stay_{j,t}}) + log(L_i^{Move_{j,t}})) \\ &= \sum_{t=1}^{T} (log(L_i^{Stay_t}(\tilde{v}_{j,t}^{\tau_{it}}, \theta_{fmc}^{\bar{\tau}_t}, \theta_{bmc}^{\bar{\tau}_t}) + log(L_i^{Move_{j,t}}(\tilde{v}_{j,t}^{\bar{\tau}_{i,t}})) \end{aligned} \tag{17}$$

In optimization problem, owners choose $(\tilde{v}, \theta_{fmc}, \theta_{bmc})$ to maximize the combined log-likelihood function. I will use the approach proposed in Bayer, McMillan, Murphy & Timmins (2016) to separate the optimization problem into two steps in order to reduce computation burden. The estimation process is:

1. Choose $\tilde{v}^O$ to maximize likelihood of moving to another location. A closed-form solution to $\bar{v}_{j,t}^{O,\bar{\tau}}$ can be derived from maximizing the log-likelihood function for

movers. Using $\hat{P}^{\bar{\tau}}_{j,t}$ from data,[33] I can calculate $\hat{\tilde{v}}^{O}$:

$$\hat{\tilde{v}}^{O,\bar{\tau}}_{j,t} = log(\hat{P}^{O,\bar{\tau}}_{j,t}) - \frac{1}{J+1}\sum_{k \neq h} log(\hat{P}^{O,\bar{\tau}}_{k,t}) \tag{18}$$

2. Given $\hat{\tilde{v}}^{O}$, choose $\theta^{\bar{\tau}_t}_{fmc}, \theta^{\bar{\tau}_t}_{bmc}$ to maximize combined likelihood function.

$$(\hat{\theta}^{\bar{\tau}_t}_{fmc}, \hat{\theta}^{\bar{\tau}_t}_{bmc}) = argmaxLn(\hat{\tilde{v}}^{\bar{\tau}_t,\tau_t}, \theta^{\bar{\tau}_t}_{fmc}, \theta^{\bar{\tau}_t}_{bmc}) \tag{19}$$

Assuming that households use values of state variables in the current period to directly predict future values, I specify and estimate the transition probabilities of value function $v^{\tau}_{j,t}$ and housing price $P_{j,t}$,[34] and then use housing price to predict type changes. Estimates of $v^{O,\tau}_{j,t}, \hat{\theta}_{fmc}, \hat{\theta}_{bmc}$ and predicted $v^{O,\tau}_{j,t+1}, \tau_{t+1}, P_{t+1}$ are then used to form expectations using the method of simulation. I draw 10,000 of $v^{O,\tau}_{j,t+1}$ and $P_{j,t+1}$ according to their estimated distributions. χ is used to indicate the number of simulation. Using drawn housing price $P_{j,t+1(\chi)}$ to form type in the next period $\tau_{j,t+1(\chi)}$ and combining drawn value function $v^{O,\tau(\chi)}_{j,t+1}$, the simulated flow utility of each type at each period, $u^{O,\tau(\chi)}_{j,t}$, can be recovered based on the following equation 20. The flow utility $u^{O,\tau_t}_{j,t}$ is then calculated as the average of all simulated values $\frac{\sum_{\chi} u^{O,\tau(\chi)}_{j,t}}{10,000}$.

$$u^{O,\tau_t}_{j,t} = v^{O,\tau_t}_{j,t} - \beta E[log(exp(v^{O,\tau_{t+1}}_{j,t+1}) + \sum_{k \neq j} exp(v^{O,\bar{\tau}_{t+1}}_{k,t+1} - BMC^{\bar{\tau}}_{t+1}))|d_{i,t}, X_{j,t}, Z^{\tau_t}_{t}, \xi_{j,t}] \tag{20}$$

Given flow utilities $u^{O,\tau}_{j,t}$, I can decompose the utility function to get preferences using equation 21:

$$u^{O,\tau}_{j,t} = \alpha^{\tau} X_{j,t} + \gamma^{\tau} usercost^{O}_{j,t} + \xi^{\tau}_{j,t} + \epsilon^{O}_{j,t} \tag{21}$$

In the model set-up, households' preferences are defined as heterogeneous by income and wealth. In estimation, I use types to reduce computation burden. With assumptions 1 and 2, I can decompose owners' flow utilities for each type τ and get households'

[33]See Appendix D for details
[34]See Appendix E for details

preferences for public amenities X_j and local fixed effect ξ_j.

The user cost of owning a house is assumed to be a standard rate (i.e 1%) of the housing value, which can cause the problem of endogeneity. The standard approach of solving this problem is to use instrumental variables. In this paper, I adapt the method developed by Bayer et al. (2016) instead of using instrumental variables. Bayer et al. (2016)'s approach is to use the marginal utility of wealth to get marginal disutility of user cost. Households' wealth in the model set-up is defined as housing wealth, which can be reduced by owner's financial moving cost. Estimations of moving cost parameters θ^{τ}_{fmc} can be used to calculate the marginal utility of wealth and the endogeneity problem can be solved by moving the disutility from user cost to the left of the equation.

$$u^{O,\tau}_{j,t} - \gamma usercost^{O}_{j,t} = \alpha^{\tau} X_{j,t} + \xi_{j,t} + \epsilon^{O}_{j,t} \tag{22}$$

$$\alpha^{\tau} = \theta^{\tau} Z^{\tau}_{i,t}$$

$$\gamma^{\tau} = -\theta^{\tau}_{fmc}$$

7.3. Renters' Location Choice

Renters' location choice problem is similar to that of owners. Conditional on being a renter, a household chooses a location with the highest expected lifetime utility by maximizing over location-specific value functions.

The per-period utility of renters is:

$$u^{R,\tau}_{j,t} = \alpha^{\tau} X_{j,t} + \iota^{\tau} r_t + \xi_{j,t} + \epsilon^{R}_{j,t} \tag{23}$$

In the owners' location choice problem, α^{τ} and $\xi_{j,t}$ have been estimated. The problem in renters' flow utility is how to estimate ι^{τ}, which is defined as utility from liquidity. To estimate ι^{τ}, per-period utility of renters can be rewritten as:

$$u^{R,\tau,L}_{j,t} = u^{R,\tau}_{j,t} - \iota^{\tau} r_t = \alpha^{\tau} X_{j,t} + \xi_{j,t} + \epsilon^{R}_{j,t} \tag{24}$$

The value function of a type τ renter is:

$$v_{j,t}^{R,\tau,,MC} = max_{d_{i,t}}\{u_{j,t}^{R,\tau,MC} + \beta E[v_{t+1}^{R,\bar{\tau},MC}|X_{j,t}, Z_t^{\tau}, \xi_{j,t}, \varepsilon_{j,t}^{R}, d_{i,t} = \{j, 1\}]\}$$

Conditional on being a renter, the decision to move will not impose financial moving cost or cost-induced type changes in the renter's problem. With the assumption of separately additive utility, renters' location-specific value functions can be divided into two parts — the lifetime expected utility of choosing location j excluding utility from liquidity and utility from liquidity.

$$v_{j,t}^{R,\tau,MC} = v_{j,t}^{R,\tau,L} + \iota^{\tau}$$

Then the conditional value function can be written as:

$$v_{j,t}^{R,\tau,L} + \iota^{\tau} = u_{j,t}^{R,\tau,L} + \iota^{\tau} + \beta E[log(\sum_{j=1}^{J+1} exp(v_{j,t+1}^{R,\bar{\tau},L} + \iota^{\bar{\tau}})|X_{j,t}, Z_t^{\tau}, \xi_{j,t}, d_t]$$

As τ is heterogeneous by types, after the household chooses to be a renter, the conditional probability of a type τ renter moving to location j can be expressed as:

$$P_{j,t}^{R,\tau_t} = \frac{e^{v_{j,t}^{R,\tau_t,L}}}{\sum_{k\neq h} e^{v_{k,t}^{R,\tau_t,L}}}$$

The conditional probability of a type τ renter staying at location j can be expressed as:

$$P_{j,t}^{R,\tau_t,L} = \frac{e^{\tilde{v}_{j,t}^{R,\tau_t,L}}}{e^{\tilde{v}_{j,t}^{R,\tau_t,L}} + \sum_{k\neq h} e^{\tilde{v}_{k,t}^{R,\tau_t,L} - \theta_{bmc}^{\tau_t} Z_t^{\tau_t}}}$$

The parameter of interest in the renter's problem is ι^{τ}. As mentioned in the model set-up, one difference between renters and owners comes from housing wealth $W_{i,t}$. Households that start as renters are assumed to be in the lowest wealth type and their housing wealth will not change if a renter chooses to keep being a renter in the next period.[35] Variation in a renter's type comes from two sources — change in income as a result of rental changes and change in wealth as a result of tenure changes.[36] Endogenous tenure choices can be used to estimate ι^{τ}.

7.4. Endogenous Tenure Choice

As shown in the decision tree 9, households will first choose their tenure and then choose their location. The tenure specific characteristics is $\iota_t^{\tau} r_{i,t}$. The conditional probability of moving to location j at time t is given as:

$$P_t^{\tau}[j=k|r,X,Z,\xi] = \begin{cases} \dfrac{e^{v_{k,t}^{O,\bar{\tau}_t,MC}}}{\sum_{J+1} e^{v_{j,t}^{O,\bar{\tau}_t,MC}}} & \text{if } r=0 \\ \\ \dfrac{e^{v_{k,t}^{R,\tau_t,L}}}{\sum_{J+1} e^{v_{j,t}^{R,\tau_t,L}}} & \text{if } r=1 \end{cases}$$

The conditional probability of staying at location j is given as:

$$P^{\tau}[j=k|r,h,X,Z,\xi] = \begin{cases} \dfrac{e^{\tilde{v}_{j,t}^{O,\tau_t}}}{e^{\tilde{v}_{j,t}^{O,\tau_t}} + \sum_{k\neq h} e^{\tilde{v}_{k,t}^{O,\bar{\tau}_t} - \theta_{fmc}^{\bar{\tau}_t} FMC_{i,t} - \theta_{bmc}^{\bar{\tau}_t} Z_t^{\bar{\tau}_t}}} & \text{if } r=0 \\ \\ \dfrac{e^{\tilde{v}_{j,t}^{R,\tau_t,L}}}{e^{\tilde{v}_{j,t}^{R,\tau_t,L}} + \sum_{k\neq h} e^{\tilde{v}_{k,t}^{R,\tau_t,L} - \theta_{bmc}^{\tau_t} Z_t^{\tau_t}}} & \text{if } r=1 \end{cases}$$

[35] Household with lowest wealth type and lowest income type is treated as the reference group in normalization.

[36] In this model, since the labor market is not included because of data limitation, family earnings of households are assumed to be constant in all periods. Income is calculated as $AnnualFamilyEarning - AnnualRental$. Wealth type will be constant as the lowest type "0" if households keep choosing being renters. Variation in wealth type comes from changing from an owner to a renter by selling houses. Renters' wealth is different from owners' wealth as it is assumed to be an asset which is easily sold in the market at a stable price (i.e., cash flow) but with lower return rate than other investment alternatives.

The probability of choosing tenure r_t is:

$$P^{\tau}[r_t|X,Z,\xi,r_{t-1},h]=\begin{cases}\dfrac{e^{\tilde{v}_{j,t}^{O,\tau_t}}+\sum_{k\neq h}e^{\tilde{v}_{k,t}^{O,\bar{\tau}_t}-\theta_{fmc}^{\bar{\tau}_t}FMC_{i,t}-\theta_{bmc}^{\bar{\tau}_t}Z_t^{\bar{\tau}_t}}}{e^{\tilde{v}_{j,t}^{O,\tau_t}}+\sum_{k\neq h}e^{\tilde{v}_{k,t}^{O,\bar{\tau}_t}-\theta_{fmc}^{\bar{\tau}_t}FMC_{i,t}-\theta_{bmc}^{\bar{\tau}_t}Z_t^{\bar{\tau}_t}}+\sum_{J+1}e^{v_j^{R,\tau,L}+\iota^{\tau}-\theta_{bmc}^{\tau_t}Z_t^{\tau_t}}} & \text{if } r_t=r_{t-1}=0\\[2ex] \dfrac{e^{\tilde{v}_{j,t}^{R,\tau_t,L}}+\sum_{k\neq h}e^{\tilde{v}_{k,t}^{R,\tau_t,L}-\theta_{bmc}^{\tau_t}Z_t^{\tau_t}}}{\sum_{J+1}e^{\tilde{v}_{k,t}^{O,\bar{\tau}_t}-\theta_{fmc}^{\bar{\tau}_t}FMC_{i,t}-\theta_{bmc}^{\bar{\tau}_t}Z_t^{\bar{\tau}_t}}+e^{\tilde{v}_{j,t}^{R,\tau_t,L}}+\sum_{k\neq h}e^{\tilde{v}_{k,t}^{R,\tau_t,L}-\theta_{bmc}^{\tau_t}Z_t^{\tau_t}}} & \text{if } r_t=r_{t-1}=1\\[2ex] \dfrac{\sum_{J+1}e^{v_j^{R,\tau,L}+\iota^{\tau}-\theta_{bmc}^{\tau_t}Z_t^{\tau_t}}}{e^{\tilde{v}_{j,t}^{O,\tau_t}}+\sum_{k\neq h}e^{\tilde{v}_{k,t}^{O,\bar{\tau}_t}-\theta_{fmc}^{\bar{\tau}_t}FMC_{i,t}-\theta_{bmc}^{\bar{\tau}_t}Z_t^{\bar{\tau}_t}}+\sum_{J+1}e^{v_j^{R,\tau,L}+\iota^{\tau}-\theta_{bmc}^{\tau_t}Z_t^{\tau_t}}} & \text{if } r_t=0,r_{t-1}=1\\[2ex] \dfrac{\sum_{J+1}e^{\tilde{v}_{k,t}^{O,\bar{\tau}_t}-\theta_{fmc}^{\bar{\tau}_t}FMC_{i,t}-\theta_{bmc}^{\bar{\tau}_t}Z_t^{\bar{\tau}_t}}+e^{\tilde{v}_{j,t}^{R,\tau_t,L}}}{\sum_{J+1}e^{\tilde{v}_{k,t}^{O,\bar{\tau}_t}-\theta_{fmc}^{\bar{\tau}_t}FMC_{i,t}-\theta_{bmc}^{\bar{\tau}_t}Z_t^{\bar{\tau}_t}}+e^{\tilde{v}_{j,t}^{R,\tau_t,L}}+\sum_{k\neq h}e^{\tilde{v}_{k,t}^{R,\tau_t,L}-\theta_{bmc}^{\tau_t}Z_t^{\tau_t}}} & \text{if } r_t=1,r_{t-1}=0\end{cases}$$

The nested logit probability could then be expressed as:

$$P^{\tau}[d_{i,t}=j,k|X,Z,\xi,d_{i,t-1}]=P^{\tau}[r|X,Z,\xi,r_{t-1},h]\times P^{\tau}[j=k|r,h,X,Z,\xi]$$

The nested probability can be used to obtain the nested logit likelihood function and the parameters of interest can be recovered via maximizing the likelihood function.

$$L(\bar{v}_O^{\tau},\bar{v}_R^{\tau},\theta_{fmc},\theta_{bmc},\iota^{\tau})=\Sigma_{i=1}^{N}(log(L_i^{location}(\bar{v},\theta_{fmc},\theta_{bmc}))+log(L_i^{tenure}(\bar{v}_O,\bar{v}_R,\theta_{fmc},\theta_{bmc},\iota^{\tau})))$$

$$(\hat{v}^{\tau},\hat{\theta}_{bmc}^{\tau},\hat{\theta}_{fmc}^{\tau},\hat{\iota}^{\tau})=argmax_{(v^{\tau},\theta_{bmc}^{\tau},\theta_{fmc}^{\tau},\iota^{\tau})}L(v^{\tau},\theta_{bmc}^{\tau},\theta_{fmc}^{\tau},\iota^{\tau})$$

In section 7.2, owners' conditional value functions $\hat{v}_t^{O,\tau}$ and parameters of moving cost $\hat{\theta}_{fmc}^{\tau},\hat{\theta}_{bmc}^{\tau}$ have been estimated. $\hat{v}_t^{R,\tau},\hat{\iota}^{\tau}$ can be estimated using the Berry-style contraction mapping to get $v_{jR,t}^{\tau}$ given $v_{jO,t}^{\tau},\theta_{fmc},\theta_{bmc},\iota^{\tau}$:

$$v_{jR,t}^{\tau,\kappa+1}=v_{jR,t}^{\tau,\kappa}+log(\hat{P}_{jR,t}^{\tau})-log(P_{jR,t}^{\tau}(v_{jR,t}^{\tau,\kappa},\iota^{\tau}))$$

. Given ι^{τ}, I use contraction mapping to find the corresponding optimal $v_t^{R,\tau}$. Then, search for parameters of ι^{τ} that maximize combined nested logit log-likelihood function.

8. Results

8.1. Moving Cost

In this paper, renters' moving cost is basic moving cost $BMC_{i,t}$ while owners' moving cost includes both basic moving cost $BMC_{i,t}$ and financial moving cost $FMC_{i,t}$. From the first step of estimation in the owner's problem, I am able to estimate the moving cost parameters reported in Table 3.

Basic moving cost $BMC_{i,t}$ is defined as emotional stress, physical cost, and time cost when moving to another neighborhood and modeled as a separate additive term to the utility. The estimation results suggest that basic moving costs significantly reduce the values households receive when moving to another neighborhood and is decreasing in income and falling over time t. Wealthy residents feel moving is less costly than poor residents do as wealthy residents are better in managing moving stress and getting help. In addition, with the improvements in markets over time, moving resources and external help are easier to get and further lower basic moving costs. Financial moving cost $FMC_{i,t}$ is defined as six percent of house selling price and modeled as a factor that changes residents' wealth when moving to another neighborhood. The coefficients in financial moving cost estimations can be used to calculate the marginal per-period utility of income, $01932 - 0.001 \times income$. The marginal per-period utility of income is decreasing in income. High-income residents have a lower marginal utility of income, which is intuitive and expected. The marginal per-period utility of income can be used in calculating marginal willingness to pay for public amenities.

8.2. Preferences and Marginal Willingness to Pay for Amenities

Households make their housing decisions based on four neighborhood amenities including environmental condition, neighborhood safety, school quality, and racial composition.[37] Households' heterogeneous preferences are characterized by household socio-

[37] Environmental condition is measured in toxicity concentration from RSEI data; neighborhood safety is measured using violent crime rate from RAND; school quality is measured using academic performance index; racial composition is calculated as the percentage of residents with the same race.

demographic characteristics including income $I_{i,t}$, wealth $W_{i,t}$, and race $R_{i,t}$ as follows:

$$u^{\tau}_{jr,t} = \alpha^{\tau} X_{j,t} + \gamma^{\tau} usercost_{j,r} + \iota^{\tau} r_t + \xi^{\tau}_{j,t} + \epsilon_{j,t}$$

$$\alpha^{Toxicity,Crime,School}_{i,t} = f(W^{\tau}_{i,t}, I^{\tau}_{i,t})$$

$$\alpha^{Race}_{i,t} = f(R^{\tau}_{i,t}, W^{\tau}_{i,t}, I^{\tau}_{i,t})$$

A household's preferences for environmental conditions, school quality, and safety in a neighborhood vary only with its wealth and income, while its preference for racial composition varies with wealth, income, and race. Residents of color are assumed to have the same preferences for amenities as Whites do except racial compositions. I assume that different races have different preferences for racial compositions, as the measure of racial composition used is the percentage of populations in their own race. To capture the differences across races and neighborhoods, I specify preferences for racial composition varied by race.[38]

Table 4 reports the parameter estimates for several different utility specifications assuming that households have homogeneous preferences for amenities. The results reported in column I and column II use year dummies and type dummies to give fixed effects. In column I, a Least Absolute Deviations (LAD) regression is used to limit the effect of outliers. For comparison, I present estimates from Ordinary Least Squares (OLS) regression in column II. The magnitude of coefficients from OLS regressions is larger, which is expected as wealthier groups have higher preferences for public amenities. In columns III and IV, I repeat this exercise but shrink the sample by removing households with wealth lower than \$30,000 or higher than \$300,000. Column V and Column VI use the same approach as before but add location fixed effects. Estimates from all kinds of specifications show that households prefer living in locations with less pollution, a higher population of own race group, lower crime rate, and better schools.

[38] The racial makeup of Los Angeles County was 46.52% Hispanics, 11.24% African American, 10.16% Asian, and 31.09% White. 3 gives the dominant racial group in each census tract and reveals the racial segregation in many neighborhoods of Los Angeles County.

To further investigate the differences in preferences, I specify households' preferences for amenities to be heterogeneous by income. Three income categories — $< \$50,000, \$50,000 - \$120,000, > \$120,000$ — is used to define preference heterogeneity.[39] Estimates in Table 5 reveal that higher-income households have larger preferences for public amenities. To aid the interpretation of preference estimates, I calculate households' willingness to pay for a 10% improvement in each amenity.[40] Table 6 reports marginal willingness-to-pay for a 10% improvement from the mean of each amenity. Households are differentiated by their income types: low (less than $\$50,000$), medium ($\$50,000 - \$120,000$), high (higher than $\$120,000$). The results reveal that households with higher income would like to pay more for amenity improvements. Low-income households would like to pay $214.92 for a 10 percent decrease in toxicity concentration, while medium-income households would like to pay $332.01 and high-income households would like to pay $2,604.83 for the same changes.

8.3. Value of Liquidity

In this paper, I assume that residents with the same socioeconomic conditions have the same preferences for public amenities, but renters are assumed to hold wealth with more liquidity and get utility from this. The liquidity term is defined as a function of income and is used to describe preferences for renting-induced freed up through investing in assets with more liquidity than housing assets. Table 7 shows value of liquidity for renters. The results suggest that the marginal value of liquidity is higher for low-income residents and decreases with time. For low-income households, being renters, therefore, gives them higher values. For medium- and high-income households, being renters makes them lose the opportunity for future gains from housing appreciation while placing their wealth in risk conditions of a rent increase.

[39] The three categories corresponds to the $< 30\%, 30\% - 60\%, > 60\%$ quantile of income for the whole owners' population over years.

[40] The amount a household would be willing to pay annually to receive a 10% increase/decrease from the mean of each amenity, holding expectations about future amenities constant. Per-period marginal willingness to pay is given by $-\alpha^{\tau}/\theta^{\tau_t}_{fmc} I_t$.

8.4. Welfare

Between 2000 and 2007, average toxicity concentrations were reduced by 11.82% for all neighborhoods in Los Angeles County. For the most impacted areas, including Central LA, South LA, and Southeast LA, the reduction rate ranged from 50% to 89.71%. The other public amenities and residents' incomes also changed, which are reported in Panel B of Table 2. Residents re-optimize their housing decisions based on changes in neighborhood and property markets. Welfare changes of resident i could be calculated as:

$$\triangle Welfare_i = \frac{-1}{\theta^{\tau_{2007}}_{fmc}}(V^{\tau_{2007}}_{i,j,r,2007} - V^{\tau_{2000}}_{i,k,r',2000} - \sum_{t=2000}^{t=2007} \theta_{bmc}\bar{Z}_{i,t}d_{i,t})$$

where j and r are the location and tenure choice a household made in year 2000 while k and r' are the destination location and tenure in year 2007. $d_{i,t}$ is the decision of moving in period t and $\bar{Z}_{i,t}$ is the socio-economic characteristics of household i after moving. $\sum_{t=2000}^{t=2007} \theta_{bmc}\bar{Z}_{i,t}d_{i,t}$ calculates sum of basic moving cost household i paid from year 2000 to year 2007.

Table 8 gives changes in benefit from 2000 to 2007 for households in different groups. The first two columns in Panel A of Table 8 describe welfare changes for renters and owners. The results show that, on average, a renter gains $17,090 while an owner gains $57,060 at the same time. Low-income renters get a loss of -$8,220 in eight years. Higher-income residents, especially owners, receive a greater increase in benefits. The differences between renters and owners can be explained by the fact that residents of different tenure status (i.e., renters vs. owners) experience very different impacts from neighborhood changes. Owners benefit from housing price appreciation and improvements in environmental conditions, while renters are vulnerable to rent increases and evictions. Owners can stay in the improved neighborhood, enjoying amenity changes, or using capital gains to move to other neighborhoods. Conversely, renters need to make trade-offs between higher rent levels and improved neighborhoods. Low-income renters' loss is mostly due to the increase in the rent burden.

To investigate the gains and losses of incumbent residents in the most impacted neighborhoods, I focus on Central LA, South LA, and Southeast LA.[41] Compared to that of residents in other neighborhoods, I find that low-income renters in the previously heavily polluted neighborhoods suffered losses ($8,990) from large environmental improvement. Property owners and high-income renters in the impacted neighborhoods, however, gained more than owners and high-income renters in less impacted neighborhoods. Environmentally gentrified neighborhoods got significant improvements in neighborhood amenities and higher housing appreciation. High-income residents have a higher marginal willingness to pay for neighborhood amenities and received greater benefit from the increase in amenities than the losses from increased living costs or rent. Both high-income and low-income property owners benefit from property appreciation and increases in amenities. However, low-income home renters get higher rent increases and suffered greater losses.

9. Counterfactual

It is worth noting that in 2000, the significant reduction of toxicity concentration does not necessarily spell a loss for renters in the short-term, because of the constraints built into rental contracts and the lagged rent increases. The losses renters experienced from environmental gentrification came from two sources — increases in rent burden and moving costs — which emerged in the long run. The benefit calculations in Table 8 offer a simple explanation to the distributional impacts of environmental gentrification but do not illustrate the reasons for renters' losses and how responses from the property market and residents' sorting behavior change the initial welfare distribution from environmental change. In this section, I will use my estimates to decompose the welfare and distributional impacts of environmental changes. This analysis is based on three scenarios: (1) In "Counterfactual I", households are "frozen" in their original locations after the exogenous environmental shock when the property markets are "frozen" at

[41] There are 16 regions for Los Angeles County, as shown in 4. Central LA, South LA, and Southeast LA are three regions most impacted.

the 2000 levels. (2) In "Counterfactual II", households optimize their housing choices according to the changes in toxicity concentrations and property market. The other public amenities except toxicity concentrations are "frozen" at the 2000 levels. Property market changes are merely due to environmental improvements and residential sorting. (3) In "Real", households optimize their housing choices according to changes in the property markets and all public amenities. Property market changes are due to neighborhood improvements, including all public amenities and residential sorting.

Beginning with the baseline 2000 household distribution, I compute welfare changes of households in a partial equilibrium in which house prices and rents in all neighborhoods are set to be unchanged since 2000 and residents will be "frozen" in their original locations, which is scenario "Counterfactual I". This could also be regarded as the short-term impacts of environmental changes.[42] I compute the welfare changes from 2000 to 2007 for households initially assigned to each neighborhood as follows:

$$\triangle Welfare_C = \frac{-1}{\theta_{fmc}^{\tau_{2007}}}(V_{i,j,r,2007}^{\tau_{2007}^C}(X_j^C, Z_i^C, \xi_{j,2007}) - V_{i,j,r,2000}^{\tau_{2000}}(X_j, Z_i, \xi_{j,2000}))$$

where j and r are the location and tenure choice a household initially assigned to in year 2000. X_j^C, Z_i^C are toxicity concentration and residents' socioeconomic conditions in 2007 if there was no responses in the property market and residential sorting behavior. τ_{2007}^C is the household's type in year 2007 in the each scenario.

Table 8 illustrate benefit distributions in the three scenarios. Column V illustrates similar results to the welfare calculations in Section 8.4: the distribution of welfare changes from a positive environmental shock favors high-income households, especially owners, and harms low-income renters taking account of property market responses and other amenity changes. This could be regarded as the long-term impact of the environmental shock. Column III and IV describe the average welfare changes for

[42]Measures of other public amenities are assumed to be exogenous and constant at the 2000 levels. To get how value function will be evolved in the case of no property market responses or no housing re-optimization, I assume that transitions of value functions are the same as that in the case with responses. Changes in value functions will be fully contributed to environmental changes.

households in each group in the two counterfactual scenarios. Results in column III reveal that the short-term welfare impacts from environmental changes can benefit all residents. Without property market appreciation and residential sorting, renters, and owners in all income categories get welfare increases from environmental improvements. Residents with higher incomes get a bigger benefit, which is intuitive as they value the environmental improvement more than low-income residents. However, comparing benefit changes in Column III (i.e., the counterfactual scenario I) with Column IV (i.e., counterfactual scenario II), the differences in welfare changes in the two scenarios reveal how changes in property market corresponding to environmental improvements redistribute welfare of residents. Owners get more benefits due to capital gain or welfare increase from housing appreciation, while renters get less benefit or even loss as a result of increased rent burden. Welfare changes in the "Real" scenario further enlarge the differences as environmental gentrification improve other amenities and further increase house price and rent burden.

10. Policy Implication

Empirical results in this paper suggest that environmental policies that are intended to benefit low-income residents in heavily polluted neighborhoods by improving their living conditions may condemn them to lose in the long run. Partial equilibrium gains from environmental improvements in the short run could be offset by the increase in rent burden in the long-term general equilibrium. The distributional effects of environmental improvements benefit property owners more than property renters and benefit high-income residents most. The increased burden to low-income residents raises the question of equity and efficiency in environmental policies and hints of two policy implications. First, cost-benefit analysis to evaluate policies should incorporate residents' re-optimization in the housing market to develop general equilibrium benefit estimates. Localized environmental policies yield spatially differentiated property market changes and residential sorting responses. Empirical results in this paper found that there are large differences between partial and general equilibrium welfare distributions. Second, as equity remains a central concern to policy design and impacts efficiency in the greater economy, the model in this paper provides an approach to understand the distributional impacts of environmental changes and informs how complementary policies should be crafted to adjust the disproportionate distribution. In the future, further work may be able to evaluate the welfare impacts of environmental changes with the adoption of complementary policies and help develop the most appropriate policies. Third, even though I discussed environmental gentrification in this paper, the model can apply to various gentrification cases. Transportation infrastructure, for example, by constructing new metro rail lines or adding new stops, which spur investments on housing market in impacted areas, could be another gentrification story and lead to distributional consequences. Policies aimed at preventing gentrification induced displacement were proposed in many areas of the U.S. such as preserving and creating affordable housing in gentrifying neighborhoods, subsidizing low-income residents' housing, and setting caps on rent or mortgage payments. The framework developed in this paper can also be applied to do further analysis on the impacts of these policies.

11. Conclusion

In this paper, I use a dynamic sorting model with endogenous tenure status and forward-looking agents to capture the differential welfare impacts of environmental improvements for heterogeneous residents. Results in this paper suggest that the welfare impacts of environmental improvements can be redistributed among residents of different tenure statuses and socioeconomic conditions when taking account of property market responses and residential sorting. With no property market responses or residents' behavioral responses in the short run, partial equilibrium analysis showed that environmental improvements benefit all households living in the impacted neighborhoods, with the largest benefits going to high-income residents and owners. High-income owners get a welfare increase of $33,740 in comparison to a $24,670 increase in welfare for high-income renters and a $3,510 increase in welfare for low-income renters. However, property market responses to environmental improvement, and residents' re-optimization can redistribute their welfare. High-income residents, especially owners, get more benefits from endogenously accumulated wealth from housing price appreciation while low-income residents, especially renters, experience a welfare reduction from increasing rent burden. Low-income renters get a welfare loss equivalent to $8,220 incorporating housing market responses in comparison to a welfare gain equivalent to $3,510 in partial equilibrium without housing market responses.

While this paper demonstrates the role of property markets and residential sorting in redistributing welfare outcomes from environmental improvements, it also provides insights into the mechanics of environmental gentrification. In particular, we see how neighborhood changes trigger gentrification when housing markets respond and then induce residential sorting and displacement of vulnerable groups. The model used in this paper has implications for its predictions of displacement and welfare impacts from gentrification and suggests a new approach of gentrification studies — triggers of gentrification.

Despite the fact that the model used in this paper captures dynamics and tenure choices in housing demand, there is much room for investigations from the supply side of the housing market. Potential complementary policies can also be policies affecting housing supply, such as providing more public housing or controlling rent. To evaluate policies taking account of changes in housing stock and in property market prices, a general equilibrium model with housing demand and supply has to be developed. Furthermore, in a dynamic model, to capture changes in households' expectations for housing prices and rent after imposing policies, more research concerning forward-looking behavior in housing and rental markets is needed. These are all topics for my future work.

Table 1: Descriptive Statistics

Panel A: L.A.FANS Data (Renters & Owners)

Variable	Mean	Std.Dev	Min	Max
Race: White	0.2612	0.4926	0	1
Race: Hispanic	0.5864	0.4926	0	1
Race: Black	0.0931	0.2906	0	1
Race: Asian	0.0745	0.2626	0	1
Age	41.8616	12.1568	14	91
Has Kids	0.8377	0.3688	0	1
Education	12.0681	4.5263	0	19
Income ($\times\$10,000/year$)	5.5716	6.8508	0	33.02
Assets ($\times\$10,000$)	6.4307	12.3637	0	94.25
Tenure (renter = 1)	0.5666	0.4957	0	1
Rent ($\times\$1000/year$)	7.6804	3.1111	0.564	25.62
N	1719			

Panel B: CoreLoigc-HMDA Data (Owners)

Variable	Mean	Std.Dev	Min	Max
Race: White	0.4496	0.4975	0	1
Race: Hispanic	0.2651	0.4414	0	1
Race: Black	0.0735	0.2610	0	1
Race: Asian	0.1258	0.3316	0	1
Income ($\times\$10,000/year$)	9.7774	6.6490	0	50
Assets ($\times\$10,000$)	8.0622	12.0036	0	139.5
House Price ($\times\$10,000$)	27.6498	18.7567	1	184
Mortage ($\times\$10,000$)	19.5843	14.4744	0.5000	147.5
N	3,546,106			

Panel C: Neighborhood Characteristics

Variable	Min	p25	Mean	p75	Max
House Price ($10,000)	6.4265	20.1526	28.5348	36.5849	61.0396
Pollution (10,000)	0.0010	0.6173	1.4445	3.6065	182.8392
Crime Rate (1000)	0.7634	1.4590	1.9280	2.3380	3.4445
School Quality (100)	3.9479	6.5505	7.2327	7.9053	9.4489
Percent White	0.0018	0.8564	0.2959	0.6067	0.9097
N	2024				

[1] In Panel A, values for race, age, and tenure status are values of the households' heads in the Wave 1 survey. In Panel B, values for race are values of the households' heads.
[2] In Panel A, income, asset, and annual rent amount are values from the Wave 1 survey (i.e., 2000 - 2002).
[3] In Panel B, income, asset, house price, and mortgage amount are values in the year they moved.
[4] In Panel C, income, asset, house price, and mortgage amount are values in 2000 for the 2024 tracts in Los Angeles County.
[5] In Panel C, pollution is measured using toxicity concentration score from RSEI data, scaled by 1000 in unit of $\mu g/m$); crime rate is measure by violent crime rate from RAND data, scaled by 1000 in unit of case; school quality is measured by Academic Performance Index, scaled by 100 in unit of API points; percentage of White is a measure from Census data.

Table 1: Effect of Environmental Shock on Neighborhood Demographics

	Pollution (10,000)	Crime (100)	API (100)	Income ($10,000)	Education	Rent Burden
Impacted × Post	-4.22***	-2.91***	0.07	0.05	2.86***	1.64***
	(1.12)	(0.26)	(0.06)	(0.22)	(1.23)	(0.86)
Post	-5.26***	-15.83***	1.37***	-0.73***	6.14***	2.34***
	(0.60)	(0.14)	(0.03)	(0.12)	(0.66)	(0.46)
Impacted	5.20***	7.56***	-0.44***	-1.01***	-8.44***	2.18***
	(0.79)	(0.17)	(0.06)	(0.18)	(1.01)	(0.70)
R^2	0.0058	0.3854	0.1582	0.0275	0.0787	0.0245

[1] Pollution is measured using tract-level toxicity concentration from RSEI data; Safety conditions are is measured using tract-level violent crime rate from RAND data; Income is measured using tract-level medium income from census data; School quality is measured by percentage of residents with college degree in each census tract; Rent burden is measured using percentage of medium rent to medium income in each census tract.

[2] Post is a dummy variable which equals to 1 after 2000.

[3] * denotes $p < 0.1$; ** denotes $p < 0.05$; *** denotes $p < 0.01$.

Table 2: Socio-demographic Changes

Panel A: Socio-demographic Changes from 2000 to 2007 by Tenure

	Renter			Owner		
	2000	2007	Change	2000	2007	Change
Income ($10,000)	2.90	4.60	1.72	8.84	10.10	1.25
	(3.11)	(4.59)	(4.05)	(9.07)	(8.81)	(7.62)
Annual Rent ($1000)	7.53	10.57	3.04			
	(3.14)	(4.50)	(3.48)			
House Price ($10,000)				30.79	53.62	22.83
				(23.93)	(32.31)	(21.78)
$\text{Pollution}_{change}$ (10,000)			-8.38			-10.13
Crime_{change} (100)			-2.81			-2.54
School_{change} (100)			1.87			1.51
White_{change}			-0.006			-0.018

Panel B: Socio-demographic Changes from 2000 to 2007 by Income

Income Quantile	<30		30 - 60		60 - 90	
Year	2000	2007	2000	2007	2000	2007
Medium Income ($1000)	41.93	43.92	74.05	76.35	121.33	124.12
	(11.49)	(11.28)	(9.47)	(9.47)	(21.49)	(21.57)
Pollution (10,000)	3.42	1.68	3.42	1.73	2.85	1.54
	(20.04)	(10.30)	(14.27)	(10.22)	(11.19)	(12.21)
P_{White}	0.26	0.18	0.36	0.23	0.54	0.51
	(0.23)	(0.21)	(0.22)	(0.21)	(0.22)	(0.23)
Crime (100)	18.94	19.34	17.75	18.24	16.38	16.44
	(6.12)	(5.68)	(5.46)	(5.61)	(5.29)	(5.28)
School (100)	5.40	6.98	5.87	7.11	7.30	7.21
	(2.21)	(2.57)	(2.41)	(2.61)	(2.48)	(2.63)

[1] $\text{Pollution}_{change}$, Crime_{change}, School_{change}, White_{change} are average changes of amenities including toxicity concentration, violent crime rate, academic performance index, and percentage of White in neighborhoods residents living in from year 2000 to year 2007. They are calculated by $X_{Destination,2007} - X_{Origination,2000}$. Income and income changes are measured in thousands. Pollution changes are measured in 100,000 ug/m^3. Crime rate changes are measured per 1000 cases. School quality is measured per 100 API points.

[2] 14.32% of renters are Whites while 39.68% of owners are Whites.

Table 2: Probit Results for Moves among Lower-Income Households

Move	(1) Pollution	(2) Housing Price	(3) Rent Burden	(4) Education
Gentrification	-0.0892**	-0.3431**	-0.2440*	-0.4286*
	(0.04)	(0.16)	(0.14)	(0.22)
Gentrification×Renter	0.1013**	0.5062***	0.7055***	0.7293***
	(0.05)	(0.19)	(0.23)	(0.29)
Renter	0.1296***	0.3387***	0.3387***	0.3711***
	(0.03)	(0.08)	(0.08)	(0.08)
Kids	0.1098***	0.2775***	0.2655***	0.2701**
	(0.03)	(0.10)	(0.10)	(0.10)
Income	-0.0007***	-0.0151	-0.0176	-0.0162
	(0.00)	(0.01)	(0.01)	(0.01)
constant	0.31***	0.2950	0.3354	0.2765
	(0.09)	(0.26)	(0.26)	(0.26)
N	1719	1719	1719	1719
R^2	0.0676	0.0721	0.0734	0.0723

[1] The first gentrification measure is a dummy variable, defined as 1 if the neighborhood is in region Northeast, Southeast, or South LA.

[2] The second gentrification measure is a dummy variable, defined as 1 if the housing appreciation rate of a census tract between 2000 and 2005 ($P_{2005}/P_{2000} - 1$) is higher than 100% and the average housing price increase between 2000 and 2005 ($P_{2005} - P_{2000}$)) is higher than $200,000. Tracts with average housing price increases higher than $220,000 and with housing appreciation rates higher than 50% are also considered gentrifying to capture tracts that are upscale but have higher initial housing prices. Tracts with populations less than 3,000 and tracts in the top 50 percent of median income are removed from the gentrifying group.

[3] The third gentrification measure of gentrification uses a similar methodology to UCLA's displacement project. A tract is defined as gentrifying if the rent burden is higher than 40% and if it increased by more than 10% between 2000 and 2010 or if the rent burden increased by more than 30% between 2000 and 2010.

[4] The fourth measure of gentrification uses a similar methodology to that in Brummet & Reed (2019). A tract is defined as gentrifying if the increase in college-educated residents is higher than 10% from 2000 to 2010 and the tract is initially low-income with populations larger than 3,000.

[5] denotes $p < 0.1$; ** denotes $p < 0.05$; *** denotes $p < 0.01$

Table 3: Moving Cost Parameters ($\hat{\theta}_{fmc}, \hat{\theta}_{bmc}$)

	BMC	FMC($\times$ 6% House Price)
Constant	12.6388	0.1932
	(0.1904)	(0.0051)
Income	-0.00093	-0.0010
	(0.0003)	(0.00029)
t	-0.2138	
	(0.08)	

[1] Income and house price are in $1,000.

[2] House price is market value of the house in original location in the year of move.

Table 4: Decompose of Flow Utility

Utility	I	II	III	IV	V	VI
Toxic Concentration	-0.0017	-0.0023	-0.0018	-0.0023	-0.0012	-0.0014
	(0.0004)	(0.0006)	(0.0004)	(0.0005)	(0.0003)	(0.0004)
Percentage of Own Group	0.0547	0.0851	0.0595	0.0855	0.0591	0.0845
	(0.0239)	(0.0301)	(0.0207)	(0.0411)	(0.0197)	(0.0300)
Crime Rate	-0.0395	-0.0522	-0.0478	-0.0610	-0.0023	-0.0146
	(0.0094)	(0.0172)	(0.0081)	(0.0142)	(0.0079)	(0.0101)
School Qulity	0.1478	0.1421	0.1594	0.1426	0.1531	0.1551
	(0.0491)	(0.0568)	(0.0477)	(0.0540)	(0.0400)	(0.0439)
Type Dummies	Yes	Yes	Yes	Yes	Yes	Yes
Year Dummies	Yes	Yes	Yes	Yes	Yes	Yes
Location Dummies	No	No	No	No	Yes	Yes
Wealth Outliers	No	No	Yes	Yes	No	No
Estimator	LAD	OLS	LAD	OLS	LAD	OLS

[1] Resutls in Column I to IV corresponds to $u^{\tau}_{jr,t} + \hat{\theta^{\tau}_{fmc}} = \alpha^{\tau} X_{j,t} + \xi^{\tau}_{t} + \epsilon_{j,t}$.

[2] Resutls in Column V and VI corresponds to $u^{\tau}_{jr,t} + \hat{\theta^{\tau}_{fmc}} = \alpha^{\tau} X_{j,t} + \xi^{\tau}_{j,t} + \epsilon_{j,t}$.

[3] Toxicity concentrations are measured in 10,000 ug/m^3; percentages of own group are measured in 1%; Crime rates are measured in 100 cases; School qualities are measured in 100 API score points.

Table 5: Decompose of Flow Utility — By Income

Income	Low	Medium	High
Toxic Concentration	-0.0010	-0.00010	-0.0029
	(0.0001)	(0.0002)	(0.0002)
Percentage of Own Group	0.0473	0.0484	0.0622
	(0.0092)	(0.0084)	(0.0103)
Crime Rate	-0.0056	-0.0327	-0.0822
	(0.0007)	(0.0024)	(0.0059)
School Qulity	0.1478	0.1225	0.1685
	(0.0445)	(0.0610)	(0.0552)

[1] Low-income households are defined as households with annual income less than $ 60,000; medium-income households are with annual income between $60,000 and $120,000; high-income households are with annual income higher than $120,000.

Table 6: Marginal Willingness to Pay for 10 Percent Increase in Amenities by Income

Amenity(10% improvement)	Low ($)	Medium ($)	High ($)
Pollution	-214.92	-332.01	-2,604.83
$P_{OwnRace}$	6,482.65	8,782.80	29,498.56
Crime Rate	-653.54	-5,897.80	-37,908.46
School	4,522.25	5,851.71	20,549.79

[1] Per-period marginal willingness to pay is given by $-\alpha^{\tau}/\theta^{\tau t}_{fmc} I_t$.
[2] Income in Panel A is calculated in $1,000.

Table 7: Renters' Preference for Liquidity

	$Income_{low}$	$Income_{medium}$	$Income_{high}$	t
Liquidity	1.7646	-1.0969	-9.6821	-0.8069
	(0.0399)	(0.0411)	(4.1830)	(0.5432)

[1] Income is calculated in $10,000.
[2] Low-income households are defined as households with annual income less than $ 60,000; medium-income households are with annual income between $60,000 and $120,000; high-income households are with annual income higher than $120,000.

Table 8: Welfare Changes in Los Angeles County, 2000 - 2007

Panel A: Welfare Redistribution (Renters v.s Owners; Gentrified v.s Not Gentrified; Dynamic v.s Static)

Welfare	Tenure		Impacted	
	Renter	Owner	Yes	No
△ Household (total)	17.09	57.06	34.28	31.45
	(3.14)	(19.99)	(13.00)	(24.11)
△ Low-income Household	-8.22	46.64	8.61	3.70
	(1.99)	(3.45)	(2.05)	(0.34)
△ Medium-income Household	15.24	62.30	92.95	88.61
	(5.03)	(23.13)	(34.19)	(23.78)
△ High-income Household	38.94	74.81	98.91	92.84
	(11.04)	(16.78)	(5.89)	(6.11)

Panel B: Welfare Redistribution (Most Impacted v.s Less Impacted)

Welfare	Most Impacted		Less Impacted	
	Renter	Owner	Renter	Owner
△ Household (total)	12.66	63.49	22.43	47.14
	(1.70)	(4.33)	(9.04)	(7.54)
△ Low-income Household	- 8.99	50.39	-7.66	41.28
	(0.91)	(6.28)	(1.50)	(12.46)
△ Medium-income Household	14.89	71.35	15.56	49.08
	(3.07)	(10.02)	(1.87)	(8.54)
△ High-income Household	21.22	80.59	16.18	62.52
	(10.23)	(8.54)	(14.99)	(2.68)

[1] Welfare is calculated in $1000.
[2] Low-income households are defined as households with annual income less than $ 60,000; medium-income households are with annual income between $60,000 and $120,000; high-income households are with annual income higher than $120,000.
[3] As shown in 4 and 1, Central LA, South LA, and Southeast LA are three regions most impacted. The less impacted areas are the other regions except regions of Angeles Forest, Antelope Valley and Pomona Valley which are regions frequently impacted by forest fires.

Table 8: Welfare Impacts of Environmental Changes

Panel C: Three Scenarios

	Real	Counterfactual I	Counterfactual II
Environmental Improvement	Yes	Yes	Yes
Amenity Changes	Yes	No	No
Property Market Response	Yes	No	Yes
Residential Behavioral Responses	Yes	No	Yes

Panel D: Welfare Impacts

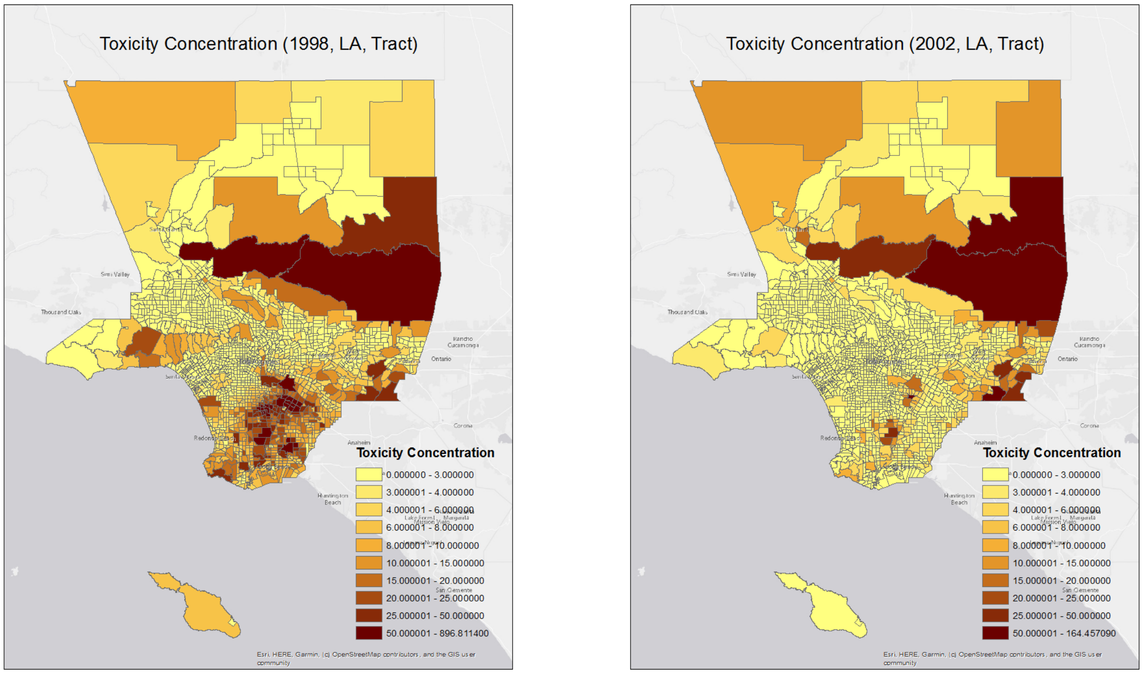
Welfare		Counterfactual I	Counterfactual II	Real
Renters				
	High-income	24.67	19.55	38.94
		(3.11)	(1.43)	(11.04
	Medium-income	11.32	8.73	15.24
		(1.01)	(0.51)	(5.03)
	Low-income	3.51	-5.22	-8.22
		(0.17)	(1.02)	(1.99)
Owners				
	High-income	33.74	61.23	74.81
		(4.91)	(3.29)	(16.78)
	Medium-income	16.80	47.01	62.30
		(1.04)	(7.13)	(23.13)
	Low-income	7.75	39.11	46.64
		(2.62)	(5.05)	(3.45)
Impacted Area				
	Central LA	3.15	14.42	10.49
		(0.14)	(2.17)	(3.84)
	South LA	11.34	29.32	28.60
		(0.77)	(3.62)	(3.41)
	Southeast	9.34	34.33	49.95
		(0.83)	(15.01)	(6.12)
	Southbay	15.16	41.10	51.83
		(1.29)	(8.32)	(19.43)
Race				
	White	2.11	13.99	10.56
		(0.45)	(2.53)	(3.43)
	African American	2.71	2.48	7.14
		(0.85)	(1.2)	(5.34)
	Hispanic	1.09	-3.07	-0.32
		(0.02)	(0.43)	(0.03)
	Asian	3.46	18.97	22.75
		(1.43)	(3.29)	(16.83)

[1] Welfare is calculated in $1000.

[2] Low-income households are defined as households with annual income less than $ 60,000; medium-income households are with annual income between $60,000 and $120,000; high-income households are with annual income higher than $120,000.

List of Figures

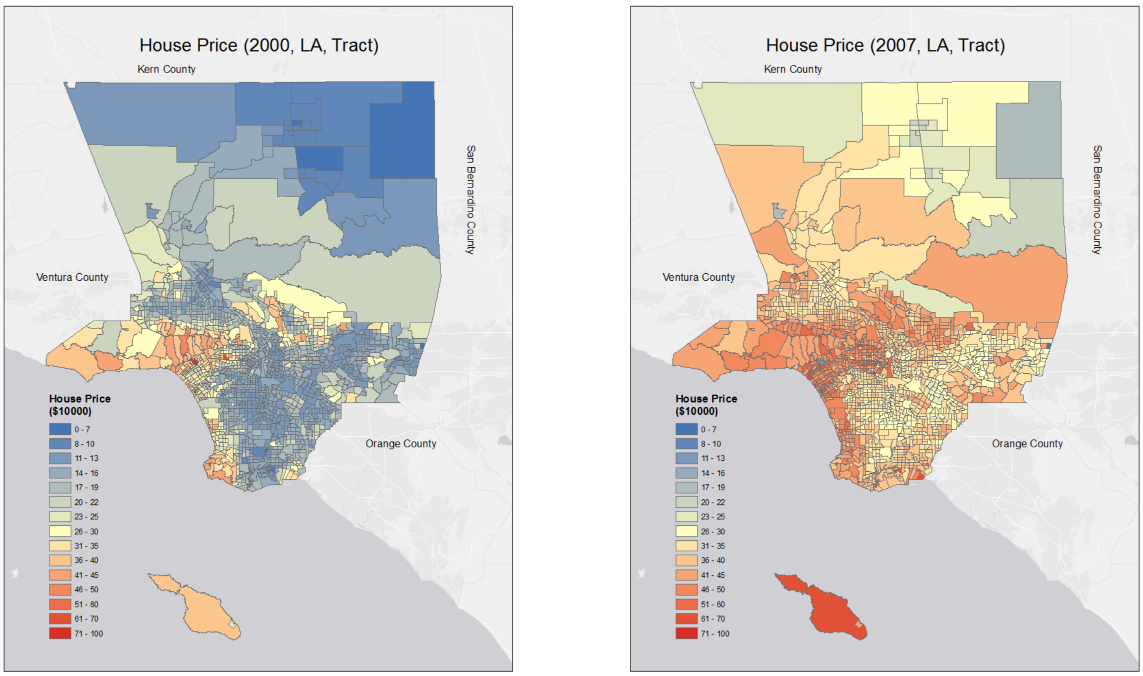
Figure 1: Toxicity Distribution in Los Angeles County (1998 vs. 2002)



(a) **(b)**

Notes: Sub-figure (a) plots the toxicity concentration level in each census tract in 1998. Sub-figure (b) plots the toxicity concentration level in each census tract in 2002.
Map Sources: Shapefiles can be found from `https://www.census.gov/geographies/mapping-files/time-series/geo/tiger-line-file.html`. I use census tract 2000. Tract level toxicity concentrations are imputed using Risk Screen Environmental Index (RSEI) data.

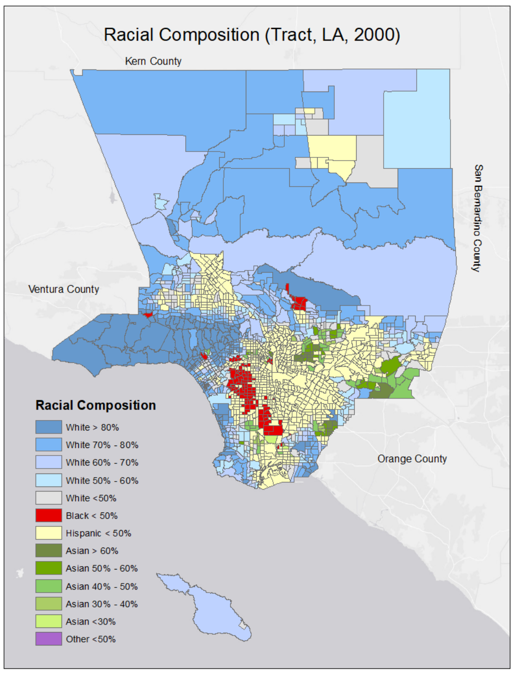
Figure 2: House Price in Los Angeles County (2000 vs. 2007)



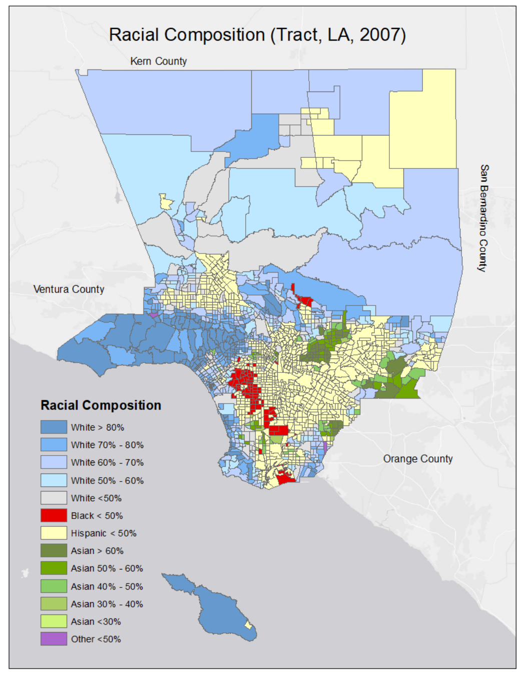
(a) **(b)**

Notes: Sub-figure (a) plots the tract level average house price in 2000. Sub-figure (b) plots the tract level average house price in 2007.
Map Sources: Shapefiles can be found from `https://www.census.gov/geographies/mapping-files/time-series/geo/tiger-line-file.html`. I use census tract 2000. Tract level average house prices are imputed using CoreLogic Data.

Figure 3: Racial Segregation in Los Angeles County (2000 vs. 2007)



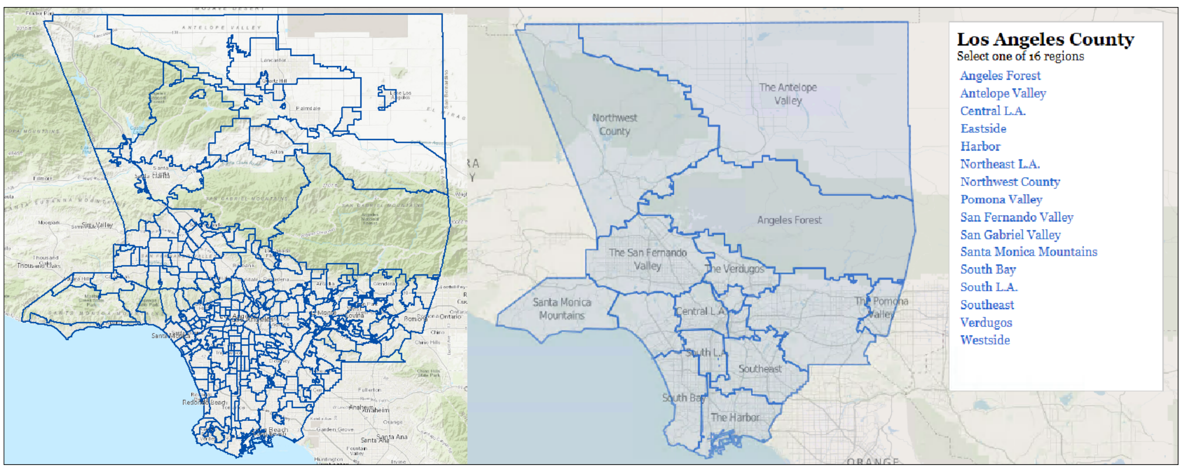
(a)



(b)

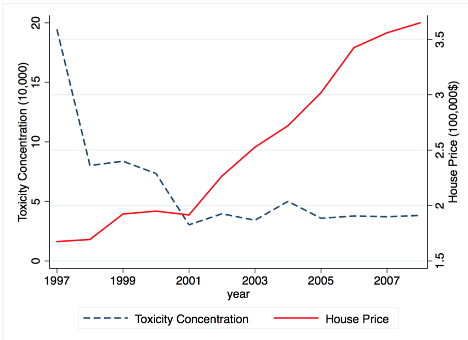
Notes: Sub-figure (a) plots the dominant race group and its percentage to the total population in each census tract in 2000. Sub-figure (b) plots the dominant race group and its percentage to the total population in each census tract in 2007.
Map Sources: Shapefiles can be found from `https://www.census.gov/geographies/mapping-files/time-series/geo/tiger-line-file.html`. I use census tract 2000. Population of each races in a census tract and their ratios are imputed using Census Data 2000 and Census American Community Survey Data 2005-2009.

Figure 4: 272 Neighborhoods in 16 Regions of LA

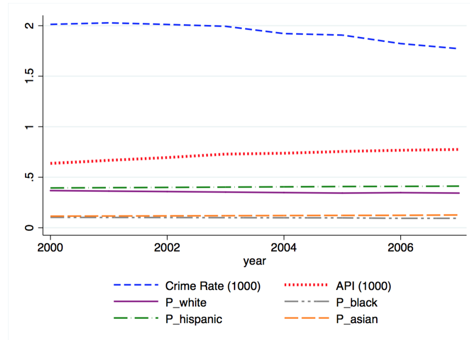


Notes: the neighborhoods are drawn and maintained by the Data Desk, a team of Times reporters and Web developers in downtown L.A..
Map Sources: shapefiles can be found from http://maps.latimes.com/about/.

Figure 5: Trends of Amenities in Los Angels County



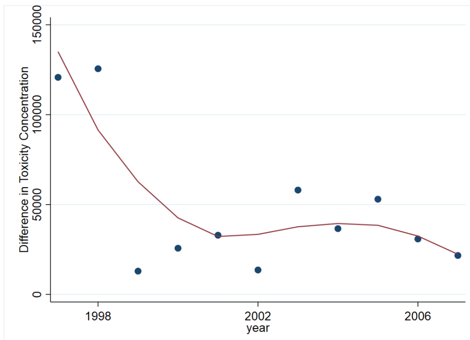
(a) House Price and Toxicity Concentration



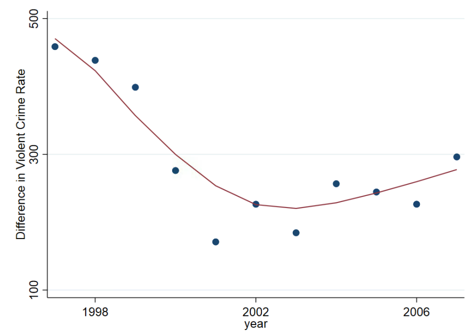
(b) Crime Rate, API, Racial Composition

Notes: This figure provides a graphical illustration of the changes in neighborhood amenities from year 1997 to year 2007. Measure of amenities is calculated as the average value of neighborhood amenities in one year.
Data Sources: House price is imputed using CoreLogic Data; Toxicity Concentration is imputed using RSEI data; Crime rate is imputed using RAND violent crime rate data; School Quality is imputed using API data; Racial compositions come from census data.

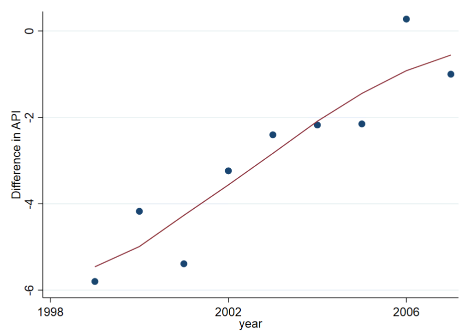
Figure 6: Differences in Public Amenities (Most Impacted Areas – Less Impacted Areas), 1998 - 2007



(a) **Difference in Toxicity Concentration**



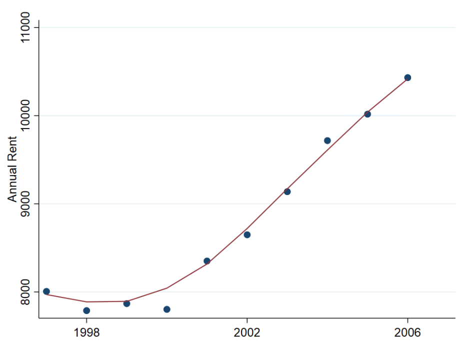
(b) **Difference in Violent Crime Rate**



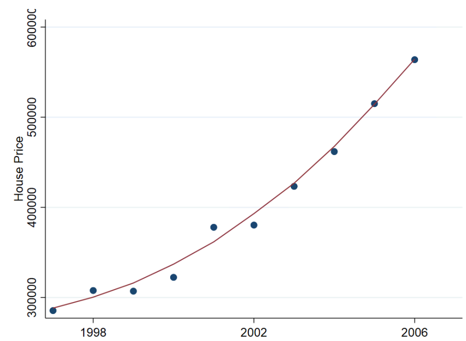
(c) **Difference in Academic Performance Index**

Notes: The differences in public amenities is the average difference in tract-level amenities between most impacted areas (i.e., Central LA, Southeast, Southbay, and South LA) and the less impacted areas (i.e., the other regions except regions of Angeles Forest, Antelope Valley and Pomona Valley which are regions frequently impacted by forest fires.). Sub-figure (a) plots the trend of average difference in toxicity concentrations between the most impacted areas and the less impacted areas from 1998 to 2007. Sub-figure (b) plots the trend of average difference in violent crime rate between the most impacted areas and the less impacted areas from 1998 to 2007. Sub-figure (c) plots the trend of average difference in academic performance index between the most impacted areas and the less impacted areas from 1998 to 2007.
Data Sources: toxicity concentration is imputed using RSEI data; violent crime rate data is imputed using RAND data; academic performance index is imputed using API data.

Figure 7: Property Market in Most Impacted Area, 1998 - 2007



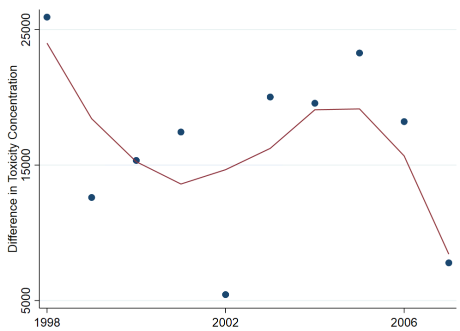
(a) **Renters' Average Annual Rent**



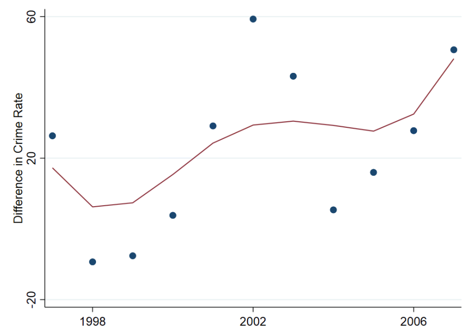
(b) **Owners' Average House Price**

Notes: Sub-figure (a) plots the trend of average annual rent in the most impacted areas (i.e., Central LA, Southeast, Southbay, and South LA) from 1998 to 2007. Sub-figure (b) plots the trend of average house price in the most impacted areas from 1998 to 2007.
Data Sources: Annual rent is imputed using Census Data 2000 and American Community Survey 2005 - 2007; House price is imputed using CoreLogic data.

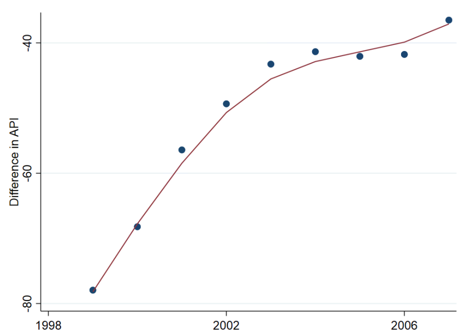
Figure 8: Differences in Public Amenities in Most Impacted Areas (Renter – Owner), 1998 - 2007



(a) **Difference in Toxicity Concentration**



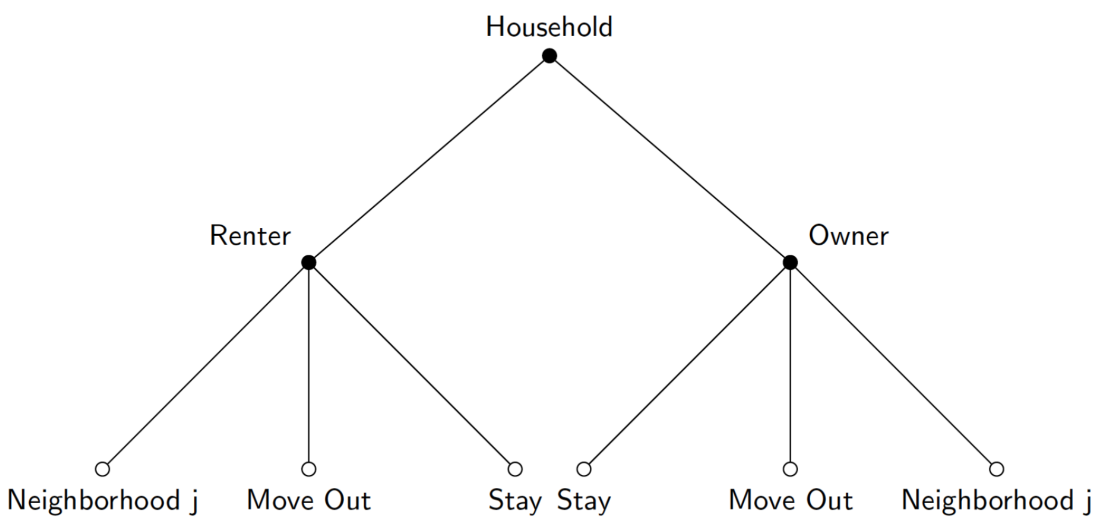
(b) **Difference in Violent Crime Rate**



(c) **Difference in Academic Performance Index**

Notes: The differences in public amenities is the average difference in tract-level amenities between renters and owners living in the most impacted areas (i.e., Central LA, Southeast, Southbay, and South LA). Sub-figure (a) plots the trend of average difference in toxicity concentrations between renters and owners living in the most impacted areas from 1998 to 2007. Sub-figure (b) plots the trend of average difference in violent crime rate between renters and owners living in the most impacted areas from 1998 to 2007. Sub-figure (c) plots the trend of average difference in academic performance index between renters and owners living in the most impacted areas from 1998 to 2007.
Data Sources: toxicity concentration is imputed using RSEI data; violent crime rate data is imputed using RAND data; academic performance index is imputed using API data.

Figure 9: Decision Tree



Appendix A. Environmental Justice

Environmental Justice is defined as "the fair treatment and meaningful involvement of all people regardless of race, color, national origin, or income, with respect to the development, implementation, and enforcement of environmental laws, regulations, and policies" by the U.S. Environmental Protection Agency (EPA).

Table A.1: Environmental Justice Report (EJSCREEN, LA vs. USA)

Sites reporting to EPA	
Superfund NPL	17
Hazardous Waste Treatment, Storage, and Disposal Facilities (TSDF)	645

Selected Variables	**Value**	**USA %tile**
Environmental Indicators		
Particulate Matter (PM 2.5 in $\mu g/m^3$)	11.3	96
Ozone (ppb)	50.8	90
NATA* Diesel PM ($\mu g/m^3$)	0.661	70-80th
NATA* Air Toxics Cancer Risk (risk per MM)	40	80-90th
NATA* Respiratory Hazard Index	0.6	80-90th
Traffic Proximity and Volume (daily traffic count/distance to road)	3600	95
Lead Paint Indicator (% pre-1960s housing)	0.46	74
Superfund Proximity (site count/km distance)	0.24	88
RMP Procimity (facility count/km distance)	1.6	87
Hazardous Waste Proximity (facility count/km distance)	5.9	92
Wastewater Discharge Indicator (toxicity-weighted concentration/m distance)	60	99
Demographic Indicators		
Demographic Index	56%	78
Minority Population	74%	80
Low Income Population	38%	63
Linguistically Isolated Population	13%	88
Population with Less Than High School Education	22%	81
Population under Age 5	6%	55
Population over Age 64	13%	45

[1] Data Source: EJSCREEN data, https://www.epa.gov/ejscreen/download-ejscreen-data; The 2019 version of EJSCREEN data includes 2013-2017 ACS 5-year summary file data, which is based on 2017 Census boundaries.
[2] Percentiles are a way to see how residents living in Los Angeles County compare to the rest residents in the United States. The USA percentile tells what percent of the US population has an equal or lower value in environmental measure or a lower demographic measure.
[3] A Demographic Index is based on the average of two demographic indicators; Percent Low-Income and Percent Minority.
[4] Overview of Environmental Indicators in EJSCREEN can be found from EPA's website: https://www.epa.gov/ejscreen/overview-environmental-indicators-ejscreen.

Los Angeles County stands out as the nation's worst environmental injustice area, according to the Environmental Justice Report (Table A.1) developed by the EPA.

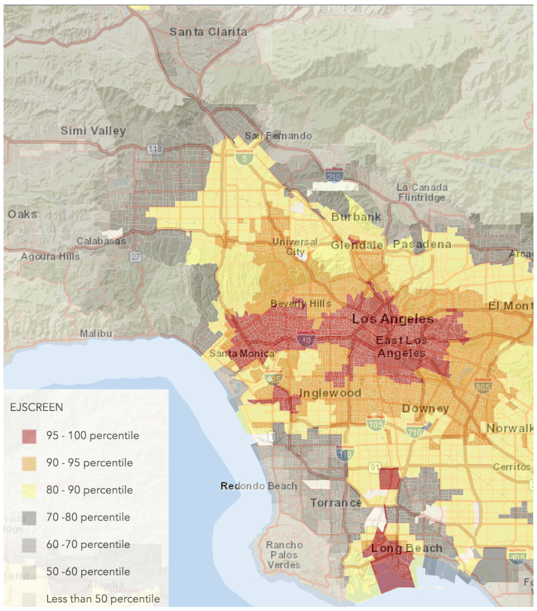
Residents living in Los Angeles County exposed to higher level of pollution in 11 environmental indicators than 80% of residents in the U.S. The interactive online map, known as EJSCREEN map (Figure A.1), reveals that low-income, low-educated, minority groups in Los Angeles County face the greatest health risks from pollution.

The social and economic forces leading to inequality in pollution exposure are still hotly debated. Empirical evidence has tended to support the "siting" over the "sorting" explanation. The "siting" explanation contends that disproportionate exposure arises from the siting decisions of local governments that permit hazardous waste facilities and nuisances in minority neighborhoods (Been & Gupta 1997; Shaikh & Loomis 1999; Manuel et al. 2001; Morello-Frosch et al. 2001; Pastor Jr et al. 2004). The "sorting" explanation contends that exposure results from post-siting housing market dynamics. Low-income (often minority) individuals may voluntarily take on greater exposure to a nuisance in order to retain more income to spend on other necessities (Been 1994; Cameron & McConnaha 2006).

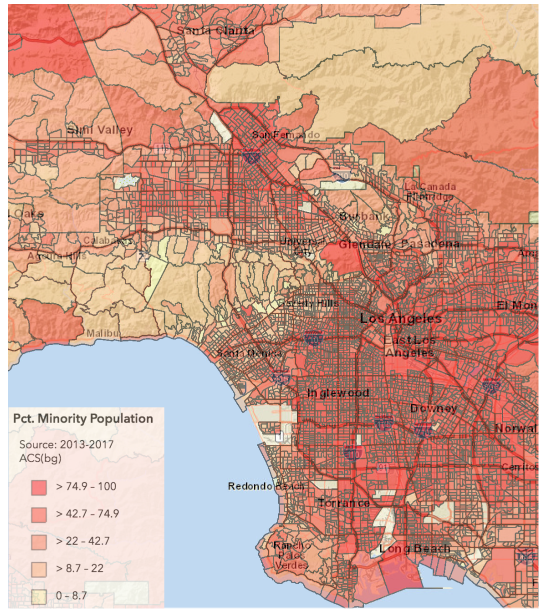
Appendix B. California Electricity Crisis

In 1996, state government of California passed Assembly Bill 1890 to restructure its electricity sector. In the restructuring process showed in Figure B.2, three major utility companies such as PG&E were required to sell their fossil-fuel capacity to establish a more competitive electricity market. Government officers thought it would be a seller's market and could lower electricity price. But the truth was that because of seasonal unbalance and uncertainty in electricity generating, in 2000, with a serious drought happened in Northwest and no import of electricity, California faced a lack of electricity supply and consequently got widely black out. Local power plant used all the facilities to produce more electricity. But reusing of old facilities and generators means higher cost and more pollution when producing. With manipulation of market and increase in permit price, electricity price skyrocketed. However, at the same time, government set a cap on utility company's retail price, which made utility companies in debt of ten billion dollars and went bankruptcy. Until the summer of 2001, with increase in

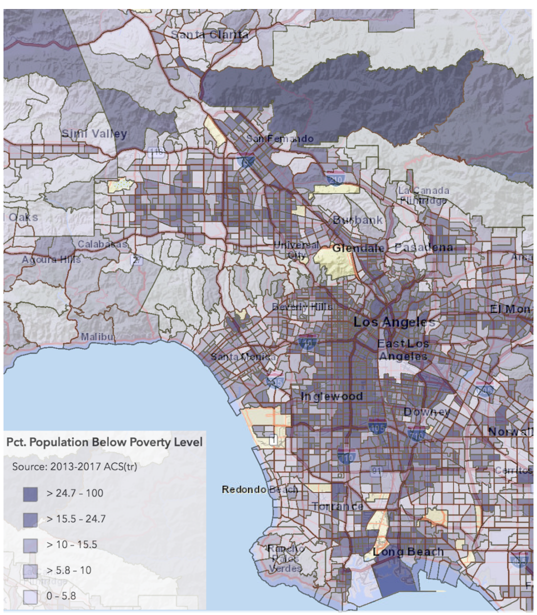
Figure A.1: Environmental Injustice in Los Angeles County



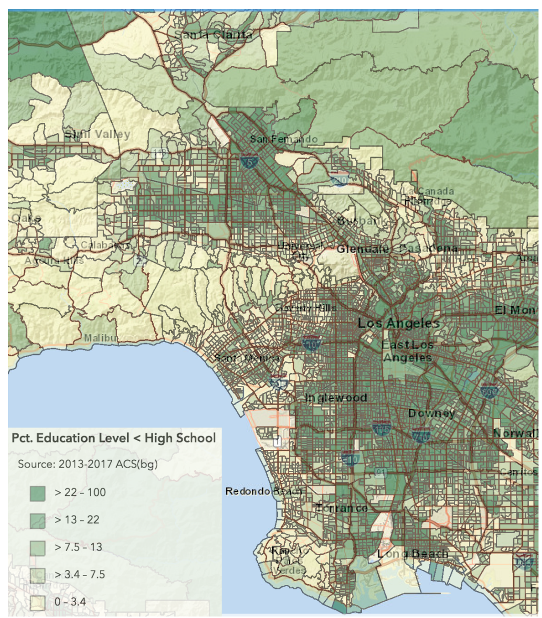
(a) Nata Cancer Risk



(b) % Minority



(c) % Poverty



(d) % Low-educated

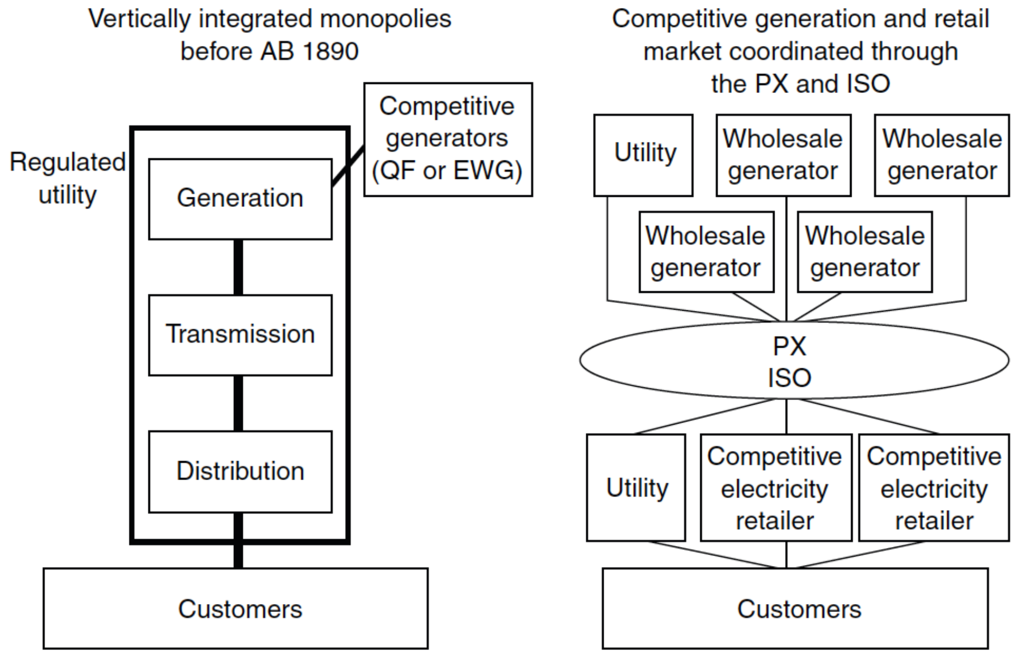
available capacity and reduction in cost of production, the crisis faded. The time line for the crisis is showed in B.3.

Weare (2003) summarized the causes of the crisis as: *"A satisfactory explanation for the severity of the crisis and its consequences cannot be composed based on any single factor. Rather, a number of factors must be considered. These include:*

- *A shortage of generating capacity,*
- *Bottlenecks in related markets,*
- *Wholesale generator market power,*
- *Regulatory missteps, and*
- *Faulty market design".*

In terms of environmental protections, during the California Electricity Crisis, the prices for pollution permits skyrocketed. Under an cap-and-trade program called Regional Clean Air Incentives Market (RECLAIM), industrial plants in the South Coast Air Quality Management District (SCAQMD) that emit NO_x must purchase permits for each ton of emissions. SCAQMD lowered the number of permits available every year and 2000 was the first year that the number of permits would control emissions significantly. The increase in demand for electricity and the adaption of high-polluting facilities during the crisis exacerbated the imbalance in demand of permits and supply of permits. SCAQMD recorded that average monthly permit price increased from under \$3/lb in May 2000 to over \$60 in February 2001. (see Figure B.4) Electricity price had a much larger increase — from the \$19 - \$35/MW range in May 2000 to more than \$250/MW in October 2000. (see Figure B.5)

Figure B.2: AB 1890 Restructured Electricity Sector



Sources: Weare (2003).

Figure B.3: California Electricity Crisis: Timeline

1993 — Regional Clean Air Incentives Market (RECLAIM) was set;
RECLAIM controlled pollution emissions using permits.

1996 — California passed AB 1890 to restructure electricity sector;
An electricity retail rate freeze was imposed on the utilities.

2000 — A shortage of generating capacity happened;
Cost of producing electricity (e.g.RECLAIM permit price) increased.

2001 — Regulatory missteps and faulty market design existed in AB 1890;
Wholesale utility companies declared bankruptcy.

2001.07 — Available capacity increased;
RECLAIM was suspended to reduce cost;
The Crisis faded.

Figure B.4: Average Monthly NO_x Permit Price

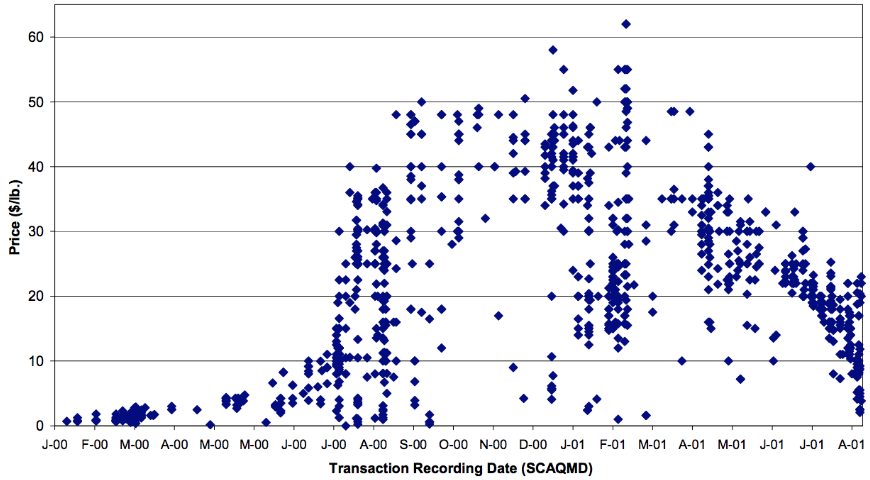
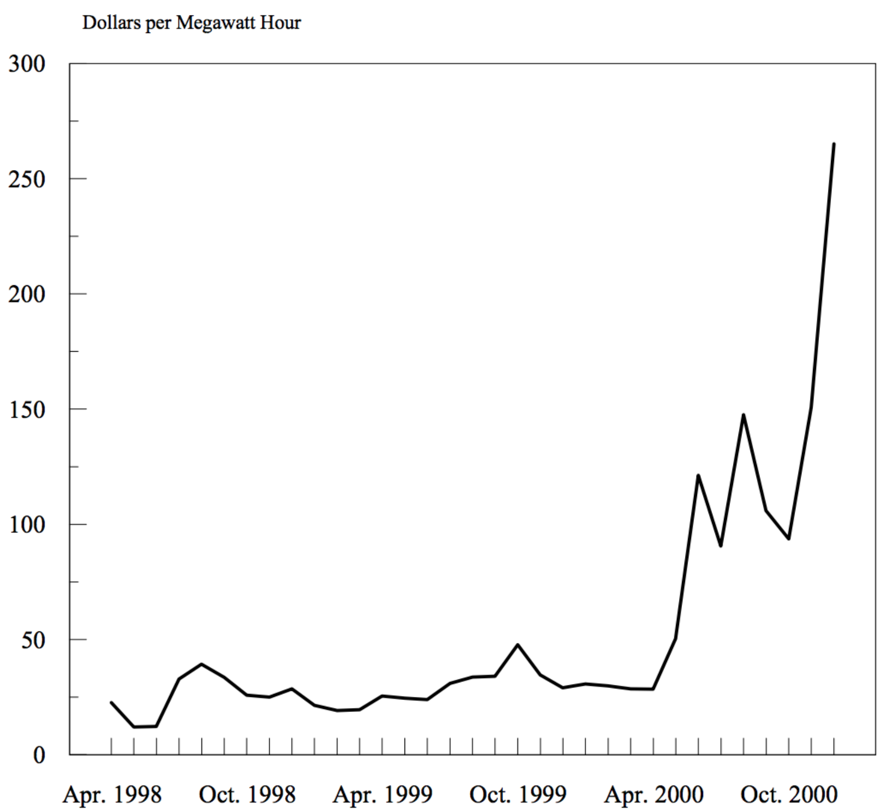


Figure B.5: Electricity Price in 2000



SOURCE: Congressional Budget Office based on data for the northern and southern regions from the California Energy Commission (available at www.energy.ca.gov/electricity/wepr/monthly_day_ahead_prices.html).

Appendix C. Data Appendix

Owners' data

A large sample of owners' moving histories is assembled using housing transaction data — CoreLogic data and Home Mortgage Disclosure Act(HMDA) data. The two data sets are merged based on common mortgage variables, including the transaction year, the buyers' name, the mortgage amount, and the housing location. Using this method and keep high quality matches, I got unique matches for approximately 50% of transactions. Because there is a unique identifier for each property in the data, I can merge two transactions using the unique identifier to get when a household moved into a house and when they left it. Using this method, I got a sample that contains 3,546,106 observations covering owners' movements from 2000 to 2007 and provides owners' socioeconomic information, including race, income, and housing wealth.

Pollution

Measurement of toxicity concentration is imputed from RSEI data by summing up grid-cell level toxicity concentrations into neighborhood-level using geographic weight-s. RSEI calculates air concentrations resulting from chemical releases using an EPA dispersion model called AERMOD. The measure of pollution used is toxicity concentration, which is calculated as the sum of "Toxicity Weight $\times$ Pounds of the Chemical" to capture the relative releases and transfers of chemicals. Toxicity concentration is a useful environmental disamenity to study in this paper for three reasons: First, RSEI toxicity concentration is provided at the small grid-cell level. It combines the impact-s of emissions from multiple facilities that may have on the same area. It includes the concentrations of pollutants from different chemicals and does not correlate with population changes in the areas. Second, impacts from off-site transfers and toxicities of chemicals are attributed to the measures that correspond to the area. Third, the toxicity concentration is directly related to facilities instead of other sources (i.e., transportation and weather), and some other toxicities such as ozone and carbon dioxide (CO_2) kept being in low levels after 1998. Much of the variation in toxicity concentration is due to changes in those facilities. There is no reason to expect that any other programs would have caused environmental changes or would have had special economic consequences for housing prices, aside from those operating through changing amenity values.

Neighborhood Amenities

Measurement of safety conditions is imputed from RAND's violent crime rate data by summing up city-level violent crime rate into neighborhood-level violent crime rate using distance weights. Measurement of school quality is imputed from API data by summing up school-level performance index into neighborhood-level performance index using distance weights. I also impute two measurements of school quality — school quality in each neighborhood and school quality for each race in each neighborhood. School quality in each neighborhood is imputed using the average academic performance index of schools, while school quality for each race in each neighborhood is imputed using academic performance indexes of students in each race group. The measurement of racial composition is imputed from census data. I sum up tract-level percentages of the population in each race into neighborhood-level percentages of the population in each race group using geographic weights.

Appendix D. Kernel Smoothing

$\hat{P}_{j,t}^{O,\bar{\tau}}$ is the percentage of owners of type $\bar{\tau}$ choosing location j at time t. To solve the problem of small numbers, I use a standard normal kernel to calculate the probability of each household with type τ being another type $\bar{\tau}$. I use $Z_{i,t} = \{Income_{i,t}^{\tau}, Wealth_{i,t}^{\tau}\}$ to define a type τ household i. The probability of being type $\bar{\tau}$ for household i is:

$$W^{\bar{\tau}}(Z_{i,t}^{\tau}) = \frac{1}{b_1}N(\frac{Income_{i,t}^{\tau} - Income^{\bar{\tau}}}{b_1})\frac{1}{b_3}N(\frac{Wealth_{i,t}^{\tau} - Wealth^{\bar{\tau}}}{b_3}) \tag{D.1}$$

Then I could use all the observations to get weighted probability of a type τ.

$$P_{j,t}^{\hat{O},\tau} = \frac{\Sigma_{i=1}^{N} I[d_{i,t} = \{j\}]W^{\tau}(Z_{i,t})}{\Sigma_{i=1}^{N} W^{\tau}(Z_{i,t})} \tag{D.2}$$

where N is the number of observations, $Z_{i,t}$ is the socioeconomic characteristics of household i.

Appendix E. Transition Probability of Value Functions and Housing Prices

In this part, I will mainly focus on estimating the transition probability of house prices and value functions. House price plays an important rule in my framework and affects welfare distribution in three channels: first, owners get benefits from capital gain or welfare increase if housing prices increase. Second, housing price appreciation increases the financial moving cost owners pay when moving. Third, wealth accumulation due to housing price appreciation changes owners' types and preferences for public amenities.

Assuming that households use states of current period to predict future values v_{t+1} and future house price P_{t+1}, house price and households' values for choices will be auto-regressive process. I use house price and public amenities including crime rate, toxic concentration, school quality, and racial composition in period $t-1$ and period $t-2$ to predict house price and households' values of choices in period t.

$$P_{j,t} = \alpha_{1,j} + \sum_{l=1}^{L} X'_{j,t-l}\alpha_{2,l} \ + \zeta_{j,t}$$
$$v^{O,\tau}_{j,t} = \beta_{1,j} + \Sigma^{L}_{l=1} X'_{j,t-l}\beta_{2,l} + \Sigma^{L}_{l=1} v^{O,\tau}_{j,t-l}\beta_{3,l} + \varsigma_{j,t}$$

where $X'_{j,t-l}$ is public amenities includes crime rate, pollution, school quality, and racial composition of each choice. I use two period lag, $L = 2$, to get the transition probabilities. $v^{O,\tau}_{j,t}$ is value function of period t in location j for households in type τ. $\zeta_{j,t}$ and $\varsigma_{j,t}$ are neighborhood fixed effects.

Appendix F. Property Tax and Proposition 13

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