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Michel G. Loustaunau Garcia
University of Texas at El Paso, mgloustaunau@miners.utep.edu

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ENVIRONMENTAL INJUSTICE AND RACIAL/ETHNIC HETEROGENEITY IN HOUSTON, TEXAS

MICHEL G. LOUSTAUNAU GARCIA

MASTER'S PROGRAM IN SOCIOLOGY

APPROVED:

Jayajit Chakraborty, Ph.D., Chair

Sara E. Grineski, Ph.D.

Timothy W. Collins, Ph.D.

Patricia M. Juárez-Carrillo, Ph.D., MPH

Charles Ambler, Ph.D.
Dean of the Graduate School

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ENVIRONMENTAL INJUSTICE AND RACIAL/ETHNIC HETEROGENEITY IN HOUSTON, TEXAS

by

MICHEL G. LOUSTAUNAU GARCIA, B.A.

THESIS

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Abstract

This thesis seeks to contribute to distributive environmental justice (EJ) research by analyzing racial/ethnic and intra-ethnic disparities in potential health risks from exposure to hazardous air pollutants (HAPs) in Harris County, the most populous county in Texas. Previous EJ research in this urban area has not examined intra-ethnic heterogeneity in exposure to air pollutants or attempted to compare social disparities in exposure to air pollution caused by vehicular (mobile) and point (stationary) sources. The goal of this study is to determine how the EJ implications of cancer risks from inhalation exposure to HAPs from mobile and stationary sources differ across and within each major racial/ethnic group (i.e., Hispanics, non-Hispanic Blacks, and non-Hispanic Whites) by disaggregating each group based on contextually relevant social characteristics. This study integrates census tract level cancer risk estimates associated with on road mobile and stationary point HAP sources from the Environmental Protection Agency's National-Scale Air Toxics Assessment (2011) with socio-demographic data from the American Community Survey (2009-2013). Statistical analyses are based on bivariate correlations and multivariate generalized estimating equations (GEEs) which account for clustering of tracts within the study area. The first phase of the study follows a conventional approach based on previous EJ studies where each racial/ethnic category is treated as a single group. The results indicate that both Hispanics and non-Hispanic Blacks are exposed to significantly higher cancer risk from vehicular HAP emissions than non-Hispanic Whites, but similar racial/ethnic disparities are not observed for stationary point sources. In the second phase of the study, three different sets of models are used to separately disaggregate each major racial/ethnic group (i.e., Hispanics, non-Hispanic Whites, and non-Hispanic Blacks) based on six characteristics: poverty, nativity, homeownership, educational attainment, English language proficiency, and age. For on road mobile sources of HAPs, results indicate that those who are in poverty, foreign born, renters, and with limited English

proficiency are disproportionately located in neighborhoods exposed to significantly higher cancer risk, regardless of their major racial/ethnic designation. For stationary point sources, the only socially disadvantaged subgroups facing significantly higher cancer risk include non-Hispanic Whites who are renters and less educated as well as Hispanics without a high school diploma. These differences in EJ results can be explained, in part, by the spatial distribution patterns of these two HAP emission sources in this county. This thesis contributes to EJ research by demonstrating the need to consider racial/ethnic heterogeneity and conduct intra-categorical analysis for uncovering social inequalities that are likely to be concealed when broadly defined racial/ethnic categories are used.

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Chapter 1: Introduction

Environmental justice refers to 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," (USEPA, 2017a). The U.S. environmental justice movement began in Warren County North Carolina in 1982, where the state of North Carolina selected a predominantly African American and low-income area to locate a toxic waste landfill for the disposal of polychlorinated biphenyls (PCBs) dumped illegally in other parts of the state. The site chosen for the landfill was considered by experts to be unsafe and unsuitable, which made residents believe that their community had been targeted due to their race and poverty. This resulted in legal action and a campaign of civil disobedience to keep the landfill out of the neighborhood. Despite all protests and more than 500 arrests, the landfill was placed in that targeted location in 1983 (McGurty, 2001).

Although the residents of Warren County failed to prevent the hazardous waste from coming to their community, they succeeded in attracting national attention to the issue of environmental justice. Consequently, the U.S General Accounting Office (1983) launched an investigation into the distribution of hazardous facilities in the South and found that Black residents comprised the majority of the population in three of the four communities that contained landfills. This report was followed by a more comprehensive national study conducted by the United Church of Christ (UCC) Commission for Racial Justice (1987), which found that race was the most significant factor determining the location of hazardous waste facilities and that three out of five Black and Hispanic individuals in the U.S. lived in communities containing uncontrolled waste sites (UCC, 1987).

Following the widely-cited UCC study, a large number of quantitative case studies have focused on investigating and explaining racial/ethnic and socioeconomic inequities in the distribution and impacts of environmental risks. This distributive environmental justice (EJ) research literature has examined a wide variety of hazards and their sources (e.g., hazardous waste facilities, landfills, industrial manufacturing sites, vehicular pollution, flooding, and urban heat islands) and used a range of spatial and statistical techniques (e.g., comparison of means, linear correlation, least squares regression, and spatial regression). Most of these studies have concluded that racial/ethnic minorities and individuals of lower socioeconomic status are unequally exposed to environmental pollution sources and related health risks in the U.S. (Holifield et al., 2018).

Although EJ research has continued to grow and expand in new directions in recent years, this thesis focuses on one particular issue that has not been addressed adequately in the current literature. Most previous EJ studies have used broad racial/ethnic categories to define minority populations groups (e.g., percent Black or percent Hispanic) and analyze racial/ethnic inequities in exposure to environmental risks. Such broad racial/ethnic categorizations assume a level of homogeneity within minority populations that may not exist in most U.S. urban areas. A few recent EJ studies have identified this problem and emphasized the need to acknowledge diversity and heterogeneity within the Hispanic category for EJ analysis, especially in immigrant gateway cities such as Miami, Florida (Grineski et al., 2014; Chakraborty et al., 2017a). These studies of Hispanic heterogeneity found significantly higher levels of exposure to vehicular air pollutants for specific Hispanic subgroups in the Miami metropolitan area (e.g., Cubans, foreign-born, and unemployed Hispanics). More systematic research is required to examine the EJ implications of intra-categorical differences for non-Hispanic White and non-Hispanic Black populations in other U.S. urban areas. Following recent research on Hispanic heterogeneity, it is important to analyze how

Black or White racial status combines with other social characteristics in contributing to unequal exposure to environmental risks. Factors such as poverty status, level of education, nativity, English language proficiency, homeownership and age can interact with race/ethnicity to amplify or attenuate environmental risk disparities for specific subgroups within the Black and White categories. There is a growing need to provide new insights on the role of intra-ethnic heterogeneity in shaping patterns of environmental injustice for U.S. metropolitan areas where this issue has not been examined before.

This thesis seeks to contribute to distributive EJ research by a detailed examination of intra-ethnic differences in potential health risks from exposure to hazardous air pollutants in Harris County, Texas. This county is the most populous county in Texas and is located within the Greater Houston Metropolitan Statistical Area (MSA) in southeastern Texas. Harris County is a suitable study area for this research because of its racial/ethnic diversity and air pollution problems caused by both vehicular and industrial emission sources. Prior studies have reported significantly high levels of cancer risk from exposure to toxic air pollutants for Hispanic and non-Hispanic Black populations in Harris County and other counties of the Greater Houston MSA (Linder et al., 2008; Chakraborty et al., 2014; Collins et al., 2015; Grineski et al., 2015). However, previous EJ research has not examined intra-ethnic heterogeneity in exposure to air pollutants in this county, or attempted to compare the EJ consequences of air pollution associated with vehicular (mobile) and point (stationary) sources. This thesis seeks to determine how the EJ implications of cancer risks from exposure to hazardous air pollutants (HAPs) from both mobile and stationary sources differ across and within each major racial/ethnic group (i.e., Hispanics, non-Hispanic Blacks. non-Hispanic Whites) by disaggregating each group based on contextually relevant social characteristics.

The primary research question to be investigated is as follows: is estimated cancer risk from inhalation exposure to HAPs from on road mobile and stationary point sources, respectively, distributed inequitably with respect to race, ethnicity, and socioeconomic status? The specific focus of this thesis is to examine how the answer to this research question, or the EJ implications of cancer risk from HAP emissions from both on road and stationary sources, differ when: (1) each major racial/ethnic category (i.e., Hispanic, non-Hispanic Black, and non-Hispanic White) is treated as a single group, as in most previous EJ studies; and (2) each major racial/ethnic category is subdivided into contextually relevant subgroups based on six specific characteristics: poverty status, nativity, homeownership, educational attainment, language proficiency, and age.

The data source for this analysis is the U.S. Environmental Protection Agency (USEPA)'s 2011 National-Scale Air Toxics Assessment (NATA), which integrates information from multiple air pollution sources and provides modeled estimates of excess cancer risk at the census tract level. Socio-demographic data from 2009-2013 American Community Survey (ACS) five-year estimates, are used to analyze intra-categorical differences for Hispanic, non-Hispanic White and non-Hispanic Black categories. The statistical analyses are based primarily on generalized estimating equation (GEE) models, which account for clustering of census tracts in Harris County and provide more statistically valid inferences regarding the social determinants of exposure to HAP cancer risks compared to traditional linear regression models.

Chapter 2: Background and Literature Review

This literature review examines published studies on environmental justice (EJ) research conducted in Harris County, and the Greater Houston MSA, as well as EJ studies that incorporate racial/ethnic heterogeneity in other U.S. locations. Intra-categorical analysis of the EJ implications of exposure to air pollution risks for this thesis requires an understanding of both: (1) the geographic context and previous EJ research conducted in the Greater Houston area; and (2) methodological approaches used to assess racial/ethnic heterogeneity in prior EJ research. Accordingly, the first section reviews empirical studies that focus on racial, ethnic, and socioeconomic inequities in the distribution of various environmental pollution sources and health risks in the Greater Houston area. The second section provides an overview of quantitative studies that sought to disaggregate specific racial/ethnic categories for distributive EJ analysis in other U.S. urban areas.

2.1 Environmental Justice Research in Houston, Texas

Harris County, Texas, is home to one of the world's biggest petrochemical complexes and hosts two of the four largest refineries in the U.S. This petrochemical industry is served by approximately 400 chemical plants, most of which are located along the narrow Houston Ship Channel inland from to the Gulf of Mexico (Linder et al., 2008; Hernandez et al., 2015). As a result, a large proportion of the Harris County population faces significantly high levels of exposure to multiple air pollution sources. Houston is also the only city in the U.S. that has no zoning laws, and for years city officials had the belief that zoning is an infringement of property rights. An example of environmental injustices due to lack of zoning is the proximity of minority and low-income communities to the port channel, and the exposure of socially disadvantaged groups to toxic air pollution resulting from petrochemical and industrial manufacturing activities

that occur in Harris County (Linder et al., 2008; Chakraborty et al., 2014). In addition, urbanization has resulted in poor city planning that has increased vulnerability to toxic air pollutants. Both industrial and transportation related air pollution are significant health threats for people living in Harris County, Texas (Chakraborty et al., 2017b). Since the 1980s, several empirical studies have analyzed the EJ implications of various technological hazards in this metropolitan area, and these are described in the rest of this subsection.

The earliest published study to examine EJ in the Houston area was conducted by Bullard (1983). This study focused on investigating the process of siting solid waste disposal facilities. Data was obtained from in-depth interviews of employees from the Houston's Solid Waste Management Division and the Houston Air Quality Board, including on-site visits to the waste facilities. Results indicated that incinerators and landfills were located primarily in neighborhoods where minority communities lived. Four out of the five incinerators were in predominantly Black neighborhoods, the sixth site was in a predominantly Hispanic location. The findings suggested that Black residents of Houston were more likely to reside in neighborhoods close to solid waste disposal facilities when compared to Whites, due to institutionalized discrimination.

A few years later, Bullard (1990) published a highly influential and widely cited book titled *Dumping in Dixie Race, Class, and Environmental Quality* that had a significant impact on EJ activism, research, and policy. This book is a compilation of descriptive case studies conducted from 1987-1988 in five African American communities located in Northwood Manor, Houston, with the purpose for examining socioeconomic characteristics and attitudes that influence activism of Black communities who are exposed to environmental hazards and stressors. Three data sources were used: government documents and archival records, in-depth interviews with local activists, and household surveys. The primary focus of the study was on Black mobilization and the survey

content sought to gather demographic data, rate of environmental pollution, social participation and environmental activism. The author found that Black communities suffered from institutionalized discrimination and were the victims of decisions made at their communities resulting in the dumping of hazardous waste in all the five communities from a secondary lead smelter, a chemical manufacturing plant, hazardous waste disposal facilities, and a municipal landfill. Bullard (1990) also describes how environmental movement was linked to the civil rights movement in most of the communities, with local churches and leaders initiating the movement. The significance of this book is in highlighting the importance of the EJ movement and the resistance of Black residents to the siting of hazardous dumping sites in their communities.

Linder et al. (2008) analyzed the spatial distribution of cumulative cancer risks from exposure to hazardous air pollutants (HAPs) in Houston and Harris County, with a primary focus on identifying racial/ethnic and socioeconomic disparities based on data on cancer risk estimates from the 1999 National-Scale Air Toxics Assessment (NATA). The authors concluded that cancer risk exposure in Harris County increases with the percentage of residents who are Hispanic and with key indicators of social disadvantage such as educational attainment and poverty. Cancer risk was significantly higher along a corridor that followed the ship channel, but these high-risk neighborhoods varied substantially in relative disadvantage and much of the cancer risk was driven by only a few HAPs. Since the exposure patterns were more complex at the highest levels of risk, the authors argued for a more detailed neighborhood level analysis for future research.

Chakraborty et al. (2014) sought to analyze social inequities in the distribution of both chronic and acute pollution risks in the Greater Houston MSA. Estimates from chronic cancer risks were gathered from the USEPA's 2011 NATA and chemical accident data was obtained from the

National Response Center's Emergency Response Notification System. Findings indicated that neighborhoods with a higher proportion of Hispanic residents, lower proportion of homeowners, and higher income inequality faced greater exposure to both chronic and acute pollution risks. The non-Hispanic Black percentage was relatively higher in neighborhoods with greater chronic cancer risk, but was found to be lower in areas exposed to acute pollution risks. Results also suggested that households that are isolated by language tend to live in areas with higher exposure to acute events and are more likely to encounter evacuation problems in case of a chemical disaster.

Collins et al. (2015)'s research in Greater Houston examined predictors of residential exposure to cumulative cancer risk from HAPs at the household level. This study was based on data collected from a telephone survey of randomly selected Houston residents, and census block-level cancer risk estimates of HAP exposure. The goal was to identify if racial/ethnic minority status increased HAP cancer risk exposure, and if household-level factors such as socioeconomic status, housing tenure, risk perception, and residential decision making determine cancer risk exposure. Results suggested that homeownership and homophily, defined as the desire to live among people culturally similar to oneself, was strongly associated with increased HAP cancer risk for Blacks and Hispanics but with lower risk among Whites. When it comes to residential locational decision-making, the desire for proximity to public transportation increased exposure to HAP cancer risk regardless of race or ethnicity. However, disproportionate risks experienced by Hispanics and Blacks were not related to lower risk perceptions or the desire to live close to work.

Hernandez et al. (2015) examined the factors that influence Hispanic people's residential decision-making and related exposures to cancer risks form HAPs in Greater Houston. In-depth semi-structured interviews were conducted with 29 Hispanic householders. Data for their comparative qualitative analysis was collect from foreign-born and U.S. born Hispanics living in

areas with high and low risk from HAP exposure. Results indicated that key determinants of HAP risks included economic constraint on residential locational decisions for U.S. born and immigrant Hispanics. For immigrants, residential decision making was associated with attraction to sociocultural benefits in co-ethnic enclaves. For U.S. born respondents, however, the experience of upward socio-spatial mobility combined with detachment from the Hispanic community resulted in decreased HAP risks. Additionally, living in social isolation in a lower cost rental unit protected immigrants from high risks. For Hispanic immigrants, the desire to pursue affordable and comfortable housing units contributed to their disproportionate exposure to HAP.

Grineski et al. (2015) conducted a comparative study that examined the EJ implications of 100-year flood risk and cancer risk from HAP exposure, in both the Miami and Greater Houston MSAs. Patterns of environmental justice were addressed in relation to socioeconomic deprivation (insecurity and instability), race, and ethnicity at the census tract level. Spatial regression results for the Greater Houston MSA indicated that HAP cancer risks are significantly and positively related to the Hispanic proportion and neighborhood economic instability. Spatial regression models for flood risk showed a significant and negative association with both the Black and Hispanic proportions in Greater Houston. Economic security and instability were not significantly related to flood risks in this MSA. Findings also indicate the need to conduct more comparative studies to better understand environmental injustices for Hispanic populations in U.S. metropolitan areas where this ethnic group is both large and diverse.

EJ research conducted in Harris County and the Greater Houston metropolitan areas has revealed spatial and social inequities in exposure to various environmental hazards and risks. Most of these studies have found exposure to hazardous air pollution to be significantly greater in neighborhoods containing a higher proportion of racial/ethnic minorities. Further research and

intra-categorical analysis are needed to understand the EJ implications of exposure for specific subgroups within the major racial/ethnic categories.

2.2 Environmental Justice Analysis of Racial/Ethnic Heterogeneity

Most EJ studies tend to use broad racial/ethnic categories when analyzing the relationship between race/ethnicity and exposure to environmental risks. Although some studies have tried to disaggregate socially disadvantaged groups, they have focused mostly on the Hispanic category to account for differences within the Hispanic population. EJ research on intra-ethnic differences have found several social characteristics (e.g., income, language proficiency, educational attainment, employment status, and country of origin) to significantly influence patterns of exposure to environmental hazards (Collins et al., 2011; Grineski et al., 2012; Chakraborty et al., 2016; Maldonado et al., 2016). From a theoretical standpoint, this research requires an intra-categorical approach. Crenshaw (1991) explains how intersectionality focuses on the lived experience of marginalized groups and how culture, race, class and gender play a role in determining social and environmental inequalities. Intersectionality is a theoretical framework that aims to understand inequalities and how they intersect and are connected to one another. For this proposed study, intra-ethnic heterogeneity will be analyzed through this theoretical framework to improve our understanding of differences in how environmental injustices are experienced within Hispanics, non-Hispanic Blacks and non-Hispanic Whites. The following review examines published EJ research that attempted to conduct intra-categorical analysis at the metropolitan scale.

Collins et al. (2011) represents the first attempt to conduct a comparative and intra-categorical EJ analysis using contextually and locally relevant variables. This study focused on racial/ethnic disparities in cancer risks from air toxics in El Paso County, Texas an urban area where the Hispanic population is substantially higher than the non-Hispanic White population.

Their analysis linked data from the 2005 NATA to census block group level data on traditional EJ and contextually relevant variables, and specific subgroups within the Hispanic and non-Hispanic White categories (e.g., percent without high school education, percent below poverty, percent renters, percent more than 64 years of age, and percent female-headed households). Results indicated that Hispanic ethnic status interacts with class, gender, and age to amplify environmental health risks within this group. In contrast, non-Hispanic White status results in the attenuation of cancer risk disparities associated with class, gender, and age. Their findings suggest that a system of white-Anglo privilege interacts with multiple dimensions of social inequality to create disproportionate cancer risks from air toxics.

Grineski et al. (2013)'s research in Miami analyzed Hispanic intra-ethnic diversity for environmental health injustices associated with on-road sources of air pollutants. The objective of the study was to examine how disproportionate cancer risk for Hispanics would differ when their group was subdivided by country of origin. Hispanic population was disaggregated based on self-identified country of origin (i.e., Cuban, Puerto Rican, Colombian, and Mexican). Results indicated that overall, neighborhoods of a predominately Hispanic population and lower socioeconomic status faced a higher risk of cancer risks. However, when Hispanics were disaggregated by country of origin only Cuban and Colombian neighborhoods faced increased cancer risk from vehicular air pollution, while Mexican neighborhoods faced a significant lower risk. These results highlighted the need for further research that disaggregates other racial/ethnic groups.

Chakraborty et al.'s (2017a) study focused on utilizing primary household level survey data and cancer risk estimates from the NATA to analyze intra-ethnic inequities in exposure to vehicular pollutants in the Miami MSA, Florida. The Hispanic category was subdivided based on

five specific characteristics (i.e., renter status, socioeconomic status, ability to speak English, Nativity, and unemployment status). The authors concluded that Hispanics who were foreign born, unemployed, and of Cuban origin faced higher cancer risk from on-road sources of air pollutants when compared to Hispanics who were employed, born in the U.S. or were originally from Puerto Rico, Colombia, and Mexico. The results of the study emphasize the importance of considering heterogeneity among the Hispanic population and downscaling EJ analysis to the household level.

While the previous studies of ethnic heterogeneity examine air pollution risks from exposure to HAPs, Maldonado et al. (2016) conducted a recent study in the Miami and Greater Houston metropolitan areas that focused on analyzed exposure to flood hazards. The key goal was to examine whether Hispanic immigrants are disproportionately exposed to risks from flood hazards relative to other racial/ethnic groups, including U.S. born Hispanics. Their results in Houston indicated that Hispanic immigrants have a higher likelihood of household exposure to 100-year flood zones and non-Hispanic Whites have the least likelihood of living in such areas. The authors suggest further research should distinguish between Hispanic subgroups based on nativity status and examine the role of contextual variables in creating risk disparities.

2.3 Summary

This literature review has provided an overview of EJ analysis conducted in Harris County and adjacent counties of the Greater Houston MSA for various environmental hazards, as well as recent studies that have sought to disaggregate racial ethnic/categories in distributive EJ analysis. With regard to this urban area, previous EJ research has not compared disproportionate exposure to multiple sources of air pollution (i.e. on-road mobile and point stationary sources). These studies have also treated major racial/ethnic categories as homogenous groups and have not attempted to disaggregate them. Additionally, previous EJ studies that incorporate an intra-categorical approach

for race/ethnicity have focus mainly on disaggregating the Hispanic population. Further research is required to address these limitations and conduct a more comprehensive intra-categorical analysis in Harris County that encompasses both mobile and stationary emission sources, as well as relevant subgroups within the major racial/ethnic categories (i.e., Hispanics, non-Hispanics Blacks, and non-Hispanic Whites) and determine if specific subgroups are facing greater exposure to specific types of air pollution risks. Environmental injustice continues to be an issue in the Houston area and it is important to examine which subcategories with the major racial/ethnic groups are facing significantly higher health risks from HAP exposure. The following chapter outlines the methodology that will be used to analyze the inequitable distribution of cancer risk from HAPs emissions in Harris County.

Chapter 3: Data and Methods

This section describes the data sources, variables, and analytic approaches that are used to assess the environmental justice (EJ) implications of cancer risk exposure from on road and stationary sources from hazardous air pollutants in the Harris county area, with a focus on intra-ethnic differences in EJ outcomes. The study area is first introduced, followed by a detailed discussion of the data sources, as well as the dependent and independent variables used in this case study. The final subsection summarizes the statistical methodology that is used to analyze relationships relevant to EJ and address heterogeneity within the Hispanic, non-Hispanic White, and non-Hispanic Black categories.

3.1 Study Area

Harris County is located in the nine-county Greater Houston Metropolitan Statistical Area (MSA) in southeastern Texas. As shown in Figure 1, this county is bordered in the southeast by the Gulf of Mexico and is intersected by several interstate highways. Harris County has an estimated population of 4.5 million residents (2014) and contains the city of Houston—the largest city in Texas. In terms of population size, Harris is the largest county in Texas and third largest county in the U.S. As per the 2009-2013 American Community Survey (ACS) estimates, Hispanics (41%), non-Hispanic Whites (33%) and non-Hispanic Blacks (19%) represent the three largest racial/ethnic groups in Harris County, with non-Hispanic Asians accounting for (6%) of the total population.

Harris County is a particularly suitable study area for EJ research due to its racial/diversity and ambient air pollution problems that affect the area and cause serious health problems for its residents. A report authored by the *Mayor's Task Force on Health Effects of Air Pollution* found air pollution levels around Houston to be unacceptable by knowledgeable experts and local

residents, and an important cause of several respiratory and cardiopulmonary health effects (Sexton et al., 2006).

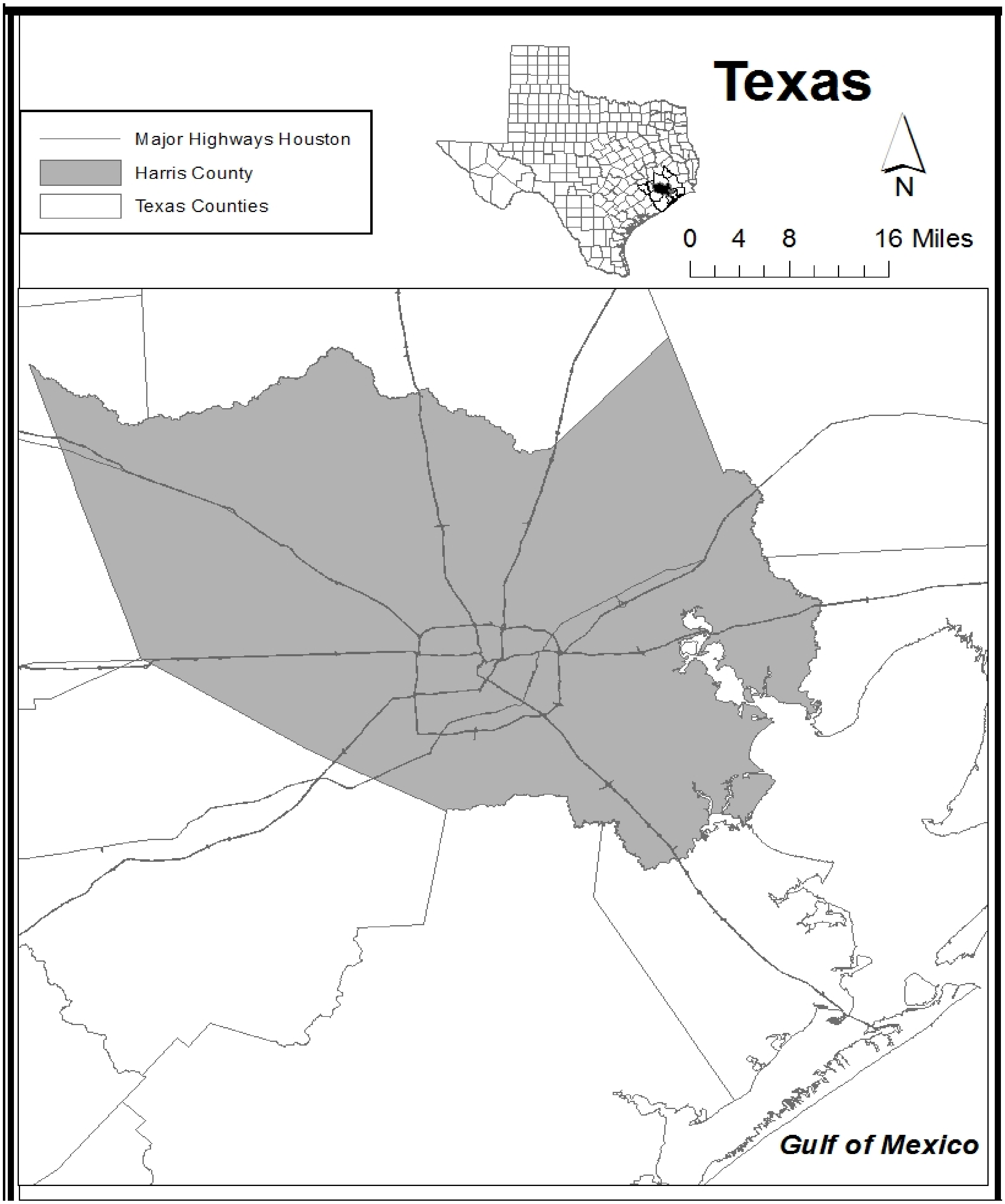

Figure 1. Location of Harris County, Texas.

Both vehicular and industrial air pollution have emerged as major health threats for people residing in the Houston area. With regard to transportation sources, tailpipe emissions from cars, trucks, and buses were identified by the Mayor's Task Force as one of the most important sources for air pollution health risks in Houston. On road emissions from motorized vehicles have been linked to significant increases in daily traffic volumes in the last decade (Chakraborty et al., 2017b). Chronic exposure to industrial air pollutants from stationary sources is another source of health risk because of 400 chemical manufacturing facilities in this area that serve the largest petrochemical complex in the U.S. and are located along the Houston Ship Channel and near the port of Houston. About half of the stationary point sources for air pollution in the Greater Houston MSA are concentrated in the eastern side of Harris County (Sexton et al., 2006). Over 20 of the largest industrial sources are located in eastern Houston. Other small businesses in Houston that generate air pollution are gas stations, coating processes, dry cleaners, and gasoline-fueled lawn maintenance equipment. Houston is the only city in the U.S. without zoning laws, which has contributed to the lack of city planning and disproportionate urban development, and resulted in serious environmental health problems, especially for racial/ethnic minorities who live near the ship channel (Sexton et al., 2006; Linder et al., 2008; Chakraborty et al., 2014).

Previous EJ research has reported how air pollution risks are distributed with respect to socially disadvantaged individuals in this urban area (Linder et al., 2008; Chakraborty et al., 2014; Collins et al. 2015; Grineski et al., 2015). Most of these studies have found potential cancer risks from HAPs to be significantly greater in neighborhoods containing higher proportions of minorities and lower socioeconomic status individuals. Since these studies used broadly defined racial/ethnic categories such as percent Hispanic and percent Black, the proposed thesis research responds to the need for disaggregating traditional categories commonly used in EJ research.

3.2 Dependent Variables: Cancer Risks from On Road and Stationary Sources of Hazardous Air Pollutants

The Clean Air Act of 1990 separated air pollutants into two distinct categories: criteria air pollutants and hazardous air pollutants (HAPs). Criteria air pollutants include common contaminants such as particulate matter, sulfur dioxide, nitrogen, oxides, ozone, carbon monoxide, and lead. HAPs, also known as air toxics, include 187 specific substances identified by the Clean Air Act Amendments of 1990, that are known to cause cancer and other serious health effects such as developmental and respiratory problems, damage to the immune system as well as neurological and reproductive problems (USEPA, 2017b). HAPs include chemicals such as asbestos, benzene, dioxin, and, toluene, as well as metals such as cadmium, mercury, chromium, and lead compounds (USEPA, 2017b).

The USEPA established the National-scale Air Toxics Assessment (NATA) as a database that provides a comprehensive evaluation of HAPs in the U.S., based on modeled air quality. The NATA is intended to serve as a tool for the USEPA as well as state, local, and tribal agencies to prioritize air toxics, emission sources, and locations of interest for further study in order to gain a better understanding of public health risks (USEPA, 2017c). The USEPA conducted the first NATA assessment in 1996, which included only 32 air toxics from the 187 on the Clean Air Act list. The USEPA released the second (1999) NATA based on emissions from the National Emission Inventory (NEI) that included 177 air toxics. In 2009, the USEPA released the third NATA that was based on emissions estimated for 2002, including 181 air toxics. The USEPA released the fourth NATA in 2011 that was based on emissions from the 2005 National Emissions Inventory, including 179 of the 187 air toxics. In 2015, the USEPA released the results of the 2011 NATA, the fifth national assessment that includes estimates of ambient exposure concentrations

for 180 of the 187 Clean Air Act HAPs and diesel particulate matter (PM). Using these concentration estimates for the 180 air toxics plus diesel PM, the 2011 NATA estimates cancer risk and noncancer health risks for 138 of these pollutants (USEPA, 2017c). Several quantitative EJ studies have used the NATA to measure cancer or respiratory risks from ambient exposure to HAPs (Pastor et al., 2005; Linder et al., 2008; Chakraborty, 2009; Collins et al., 2011; Chakraborty et al., 2014; Grineski et al., 2014; Collins et al., 2015; Grineski et al., 2015; Chakraborty et al., 2017a). While the NATA has become a popular and important data source for conducting EJ research on health effects of air pollution, it is also considered to be the most reliable database for spatially explicit characterization of HAP risk exposure in U.S. urban areas (Morello-Frosch et al., 2006; McCarthy et al., 2009; Marshall et al., 2014; Collins et al., 2015; Chakraborty et al., 2017a).

The 2011 NATA includes a four-step process to develop the assessment for estimating cancer risks at the census tract level. The first step is to compile the national emissions inventory from outdoor sources, the second step is to estimate ambient concentrations of air toxics, the third step is to generate exposure concentrations, and the fourth step is to identify possible health risks associated with the inhalation of air toxics. The result of the USEPA's four-step process is a database containing modeled estimates of cancer and non-cancer risks. This information can be downloaded as Access and Excel files at the nationwide, state, county, and census tract levels (USEPA, 2017c).

The 2011 NATA estimates potential cumulative risks to public health from HAP exposure following the USEPA's risk characterization guidelines that assume a lifelong exposure to 2011 levels of emissions. Cancer risks in the 2011 NATA, which will be used for this research, are derived using risk estimates (URE), an upper bound estimate of an individual's probability of contracting cancer over a lifetime of exposure to a concentration of one microgram of the pollutant

per cubic meter of air. For each census tract, the individual lifetime cancer risk associated with each HAP is calculated by combining exposure concentration estimates with available UREs and inhalation reference concentrations. Although the type of cancer and available evidence varies by pollutant, the cancer risks of different HAPs are assumed to be additive and are assumed to estimate an aggregate lifetime cancer risk for each census tract, measured in persons per million. These risk estimates are considered to be upper-bound estimates of the probability that an individual will contract cancer over a 70-year lifetime as a result of exposure to HAPs. A lifetime cancer risk of five in a million, for example, implies that five out of a million equally exposed people would contract cancer if exposed continuously to that specific concentration over 70 years. This would be an excess cancer risk in addition to other cancer risks borne by a person not exposed to these HAPs (USEPA, 2017c).

The 2011 NATA cancer risk estimates for this study were obtained directly from the USEPA NATA website for all census tracts (based on 2010 U.S. Census boundaries) in Harris County. The census tract is the smallest geographic unit for which this information is available in the 2011 NATA. The dependent variables for this study comprise estimates of lifetime cancer risk (measured in persons million) associated with inhalation exposure to HAPs released from two different emissions sources: on road mobile and stationary point sources. On road sources includes those that operate on roads and highways for transportation of passengers or freight, and include cars, trucks, buses, and motorcycles. Stationary sources focus on those that do not move and include large industrial sources such as power plants and refineries, as well as smaller industrial and commercial sources such as dry cleaners (USEPA, 2017c).

3.3 Independent Variables

Socio-demographic variables for this analysis were extracted from the 2009-2013 American Community Survey (ACS) five-year estimates, released in 2014 at the census tract level of aggregation. Census tracts represent the smallest geographic unit for which reliable estimates of population characteristics are available from the ACS. To ensure stable proportion estimates for all variables, two tracts with a population of less than 500 were excluded leaving a total of 784 tracts that were used to conduct the analysis. Variables analyzed in the study encompass traditional racial/ethnic categories used in previous EJ research, as well as variables used to disaggregate the traditional racial/ethnic categories in multiple ways.

To examine the effect of race and ethnicity, the analysis included separate variables that collectively cover the entire population: the proportion of individuals self-identifying to be of Hispanic or Latino origin (of any race), the proportion of individuals self-identifying as non-Hispanic White, the proportion of individuals self-identifying as non-Hispanic Black, the proportion of individuals self-identifying as non-Hispanic Asian, and, the proportion of individuals self-identifying as non-Hispanic and belonging to a race other than White, Black or Asian (i.e., American Indian or Alaskan Native, Pacific Islander, or some other race).

The six characteristics that are used to disaggregate the three major racial ethnic/categories mentioned above include poverty, nativity, homeownership, educational attainment, language proficiency and age. Income below poverty level (i.e., family income below federal poverty level) was selected since previous studies using the NATA have found that exposure to HAPs in the U.S. are more likely to occur in areas with a higher proportion of people in poverty (Linder et al., 2008; Chakraborty, 2009; Collins et al., 2011). Nativity (i.e., U.S. born or foreign born) was considered since is known to be associated with social disadvantage for Hispanics in the U.S. which could be

the case for non-Hispanics Whites, and non-Hispanic Blacks (Duncan et al., 2006; Chakraborty et al., 2017a). Homeownership (i.e., renter or owner) was chosen since this variable is linked with wealth, political engagement, and participation in local decision making (Chakraborty, et al., 2014; Collins, et al., 2015). Educational attainment (i.e., grade level less than high school or high school/diploma or equivalent) was chosen because limited access to educational opportunities and advancement is associated with social disadvantage (Collins et al., 2011). Language proficiency (i.e., the ability to speak English very well) was selected because the inability to communicate in English could influence a person's ability to participate in decisions that affect chronic environmental exposure. Language barriers are also associated with isolation from the broader community (Chakraborty et al., 2014). Finally, age was also chosen to distinguish between younger (i.e., those who are less than 65 years old) and older (those who are aged 65 or more years) residents, following EJ studies have found older age to be related to health risk disparities (Chakraborty, 2009; Collins et al., 2011).

These six characteristics in this study are significant contributors to the heterogeneity that exist among the three major racial/ethnic groups in Harris County, and potentially lead to differences in how environmental injustices are experienced within each major group. While the Hispanic category has been disaggregated using some of these characteristics in previous EJ research that examined intra-ethnic disparities, non-Hispanic White and non-Hispanic Black categories have not been unpacked in this fashion (except for Collins et al., 2011).

Following prior EJ studies, population density was included as a control variable based on the assumption that densely populated areas are more likely to contain air pollution-generating activities or roadways which increase cancer risks for residents (e.g., Pastor et al., 2005; Linder et al., 2008; Chakraborty, 2009; Chakraborty et al., 2014). Median household income was also used

as an additional control variable, since areas with higher air pollution health risks are associated with lower economic status in most EJ studies. A description of all explanatory variables is provided in Table 3.1. The six variables used for the intra-categorical analysis were calculated separately for each major racial/ethnic group.

Table 3.1 Definition of explanatory variables.

Variable	**Definition**
Proportion Hispanic	Individuals identifying themselves as Hispanic/Latino (of any race) as a proportion of the census tract total population.
Proportion Non-Hispanic Black	Non-Hispanic individuals identifying themselves as Black as a proportion of the census tract total population.
Proportion Non-Hispanic White	Non-Hispanic individuals identifying themselves as White as a proportion of the census tract total population.
Proportion Non-Hispanic Other	Non-Hispanic individuals, identifying themselves as American Indian or Alaskan Native, Asian, Pacific Islander or some other race, as a proportion of the census tract total population.
Proportion Non-Hispanic Asian	Individuals, having origins in any of the original peoples of the Far East, Southeast Asia, or the Indian subcontinent, including, Cambodia, China, India, Japan, Korea, Malaysia, Pakistan, the Philippine Islands, Thailand, and Vietnam, as a proportion of the census tract total population.
Population Density	Total population within a census tract divided by the land area of that tract measured in square miles.
Median household income	Includes annual income of the householder and all other people 15 years and older in the household (in dollars), whether or not they are related to the householder. The median is based on the income distribution of all households, including those with no income
Poverty: Proportion Above Poverty	Individuals within a census tract with an annual family income above federal poverty level, in each major racial/ethnic group.

Proportion Below Poverty Denominator:	Individuals within a census tract with an annual family income below federal poverty level, in each major racial/ethnic group. Individuals for whom poverty status is determined, for each major racial/ethnic group.
Nativity: Proportion U.S. Born Proportion Foreign Born Denominator:	Refers to the individuals who indicate that they were born in U.S. state, Puerto Rico, a U.S. Island area, or abroad of at least one U.S. citizen parent are U.S. citizens, as a proportion of the census tract total population, for each major racial/ethnic group. Refers to individuals who are not U.S citizens at birth. This includes naturalized U.S. citizens, permanent residents, temporary migrants, humanitarian migrants and individuals who are illegally residing in the U.S., as a proportion of the census tract total population, for each major racial/ethnic group. Total population, for each major racial ethnic/group.
Homeownership: Proportion Homeowners Proportion Renters Denominator:	A housing unit is owner occupied if the owner or co-owner lives in the unit even if it is mortgaged or not fully paid, as a proportion of housing units that are occupied, for each major racial/ethnic group. All occupied units which are not owner occupied, whether they are rented for cash rent or occupied without payment of cash rent, are classified as renter-occupied, as a proportion of housing units that are occupied, for each major racial/ethnic group. Total occupied housing units, for each major racial ethnic/group.
Educational Attainment: Proportion High School or Higher Proportion Less than High School	Educational grade level of high school diploma/equivalent or higher, as a proportion of the census tract population 25 years and over, for each major racial/ethnic group. Educational grade level of less than high school, as a proportion of the census tract population 25

Denominator:	years and over, for each major racial/ethnic group. Total population aged 25 years and over, for each major racial ethnic/group.
Language Proficiency: Proportion English Proficient Proportion Limited English Proficiency Denominator:	Individuals who speak a language other than English at home, this refers to their assessment of their ability to speak and write English, "very well", as a proportion of the census tract population five years and over, for each major racial/ethnic group. Individuals who speak a language other than English at home, this refers to their assessment of their inability to speak and write English, "not well" or "not at all" as a proportion of the census tract population five years and over, for each major racial/ethnic group. Total population five years and over, for each major racial ethnic/group.
Age: Proportion Age Below 65 Proportion Age Above 65 Denominator:	Individuals whose age is below 64 as the length of time in completed years that a person has lived. For the most recent decennial census, as a proportion of the census tract total population, for each major racial/ethnic group. Individuals whose age is above 64 as the length of time in completed years that a person has lived. For the most recent decennial census, as a proportion of the census tract total population, for each major racial/ethnic group. Total population, for each major racial ethnic/group.

3.4 Statistical Methodology

In order to assess distributive EJ for cancer risks from on road and stationary sources of HAPs in Harris County, this thesis project implements two stages of statistical analysis. First, the

linear association between the dependents and each explanatory variable is measured using Pearson's correlation coefficient at the census tract level. Bivariate correlations provide an initial indication of the relationships that exist between cancer risk from HAP emissions and the various socio-demographic and control variables utilized in this study. Second, multivariate statistical analysis was used to analyze cancer risks associated with two emission sources (on road mobile and point stationary) as a function of all the explanatory variables described previously, in a single model.

Multivariate models in this study based on generalized estimating equations (GEEs), a statistical technique suitable for dealing with clustered data. GEEs are particularly appropriate for this study because they relax several assumptions of traditional regression models and impose no strict distributional assumptions for the variables analyzed, while accounting for geographic clustering of neighborhoods (tracts) in the study area (Collins et al., 2015). To fit a GEE model, clusters of observations must be defined based on the assumption that observations from within a cluster are correlated, while observations from different clusters are independent. For this study, the cluster definition was based on the median decade of housing construction (2009-2013 ACS) for tracts in Harris County. Specifically, clusters of tracts were defined using the median decade of housing construction which ranged from “2000 to 2010” to “1930 to 1939” (8 clusters). This cluster definition was selected because the median year of home construction can be expected to closely match the urban developmental context within which tracts are nested (Collins et al., 2015; Grineski et al., 2017). A similar approach has been used in recent studies conducted in the Houston area that utilized the GEE approach for EJ analysis (Collins et al., 2015; Maldonado et al., 2016; Chakraborty et al., 2017b). A GEE also requires the specification of an intra-cluster dependency correlation matrix, referred to as the working correlation matrix (Zeger and Liang, 1986). For this

purpose, all GEEs were modeled with different correlation structure specifications available in IBM SPSS Statistics software, using the quasi-likelihood under the independence criterion (QIC) goodness-of-fit coefficient to determine the best working correlation specification (Collins et al., 2015). The QIC tests indicated that the ‘exchangeable’ specification performed better than all other specifications of the working correlation matrix for only two GEE models, while the ‘unstructured’ specification performed best for all remaining GEEs. These specifications were thus used for the results reported in this thesis.

To select the most appropriate GEE model, several model specifications were explored. Since both dependent variables were continuous, the distributions examined include the normal, gamma, and inverse Gaussian distributions. For each of these distributions, GEEs based on both log and identity link functions were examined. An identity link function assumes the dependent variable is predicted directly and not transformed, while a log link function implies that the natural logarithm of the dependent variable is predicted. The inverse gaussian distribution with the log link function was finally selected for all GEEs, since this specification yielded the lowest value of the QIC, indicating the best statistical fit. All independent variables were standardized and standardized coefficients are provided in the results tables. To check for multicollinearity, the multicollinearity condition index (MCI) was calculated for the combination of the independent variables included in the GEE models. The MCIs for all models were found to range from 3.0 to 7.0, indicating the absence of serious collinearity problems among the standardized explanatory variables.

The first phase of the study follows a conventional approach based on most previous EJ studies where each major racial/ethnic category was treated as a single group. These initial GEE models included the five racial/ethnic variables (i.e., Hispanic, non-Hispanic White, non-Hispanic

Black, non-Hispanic Asian, and non-Hispanic other race), as well as population density and median household income as control variables.

In the second phase of the study, three different sets of models were used to separately disaggregate each of the major racial/ethnic groups (i.e., Hispanics, non-Hispanic Whites, and non-Hispanic Blacks) based on six characteristics: poverty (proportion above and below federal poverty level), nativity (proportion U.S. born and foreign-born), homeownership (proportion owners and renters), educational attainment (proportion high school or higher and proportion less than high school), language (proportion proficient in English and limited English proficient), and age (proportion age below 65 years and age 65 or more years). For each racial/ethnic category, six GEE models were thus needed to examine and compare each disaggregated subgroup to its counterpart subgroup (reference variable). In each of these models, the socially advantaged subgroup (i.e., above poverty, U.S. born, homeowners, high school or higher, English proficient and, age below 65) was treated as the reference category, to allow direct comparison with the subgroup expected to be socially disadvantaged (i.e., below poverty, foreign born, renters, less than high school diploma, limited English proficient, aged 65 or more years). All multivariate models include population density and median household income as control variables, as well as the two other major racial/ethnic categories that are not disaggregated.

Chapter 4: Environmental Justice Analysis of Cancer Risk from On Road and Stationary Sources Using Conventional Explanatory Variables

This chapter focuses on analyzing the environmental justice (EJ) implications of estimated cancer risk from ambient exposure to hazardous air pollutants (HAPs) from on road mobile and stationary point sources in Harris County, Texas, based on traditional racial/ethnic variables that are commonly used in distributive EJ research. First, maps and descriptive statistics are used to explore the distribution of the dependent variables at the census tract level. Second, bivariate correlations are used to examine the statistical association between each independent variable and each of the two dependent variables (i.e., cancer risk from on road mobile and stationary point sources). Finally, multivariate statistical analysis based on generalized estimating equations (GEEs) is utilized to estimate the relationship between each dependent variable and the entire set of independent variables.

4.1 Descriptive Mapping and Statistics

Classified choropleth maps depicting the distribution of cancer risk for on road mobile and stationary point sources at the tract level are provided in Figures 2 and 3, respectively. On these two maps, the lightest shading is used to display tracts in the lowest quartile (bottom 25%) of estimated cancer risk and darkest shading is used for tracts in highest quartile (top 25%) of cancer risk, for both on road mobile and stationary point sources.

For on road cancer risk, tracts with highest values are located mainly in central Harris County, including the city of Houston. In contrast, tracts with the lowest risk are located in the peripheral areas of the county. Cancer risk values tend to decrease as the distance from downtown Houston increases.

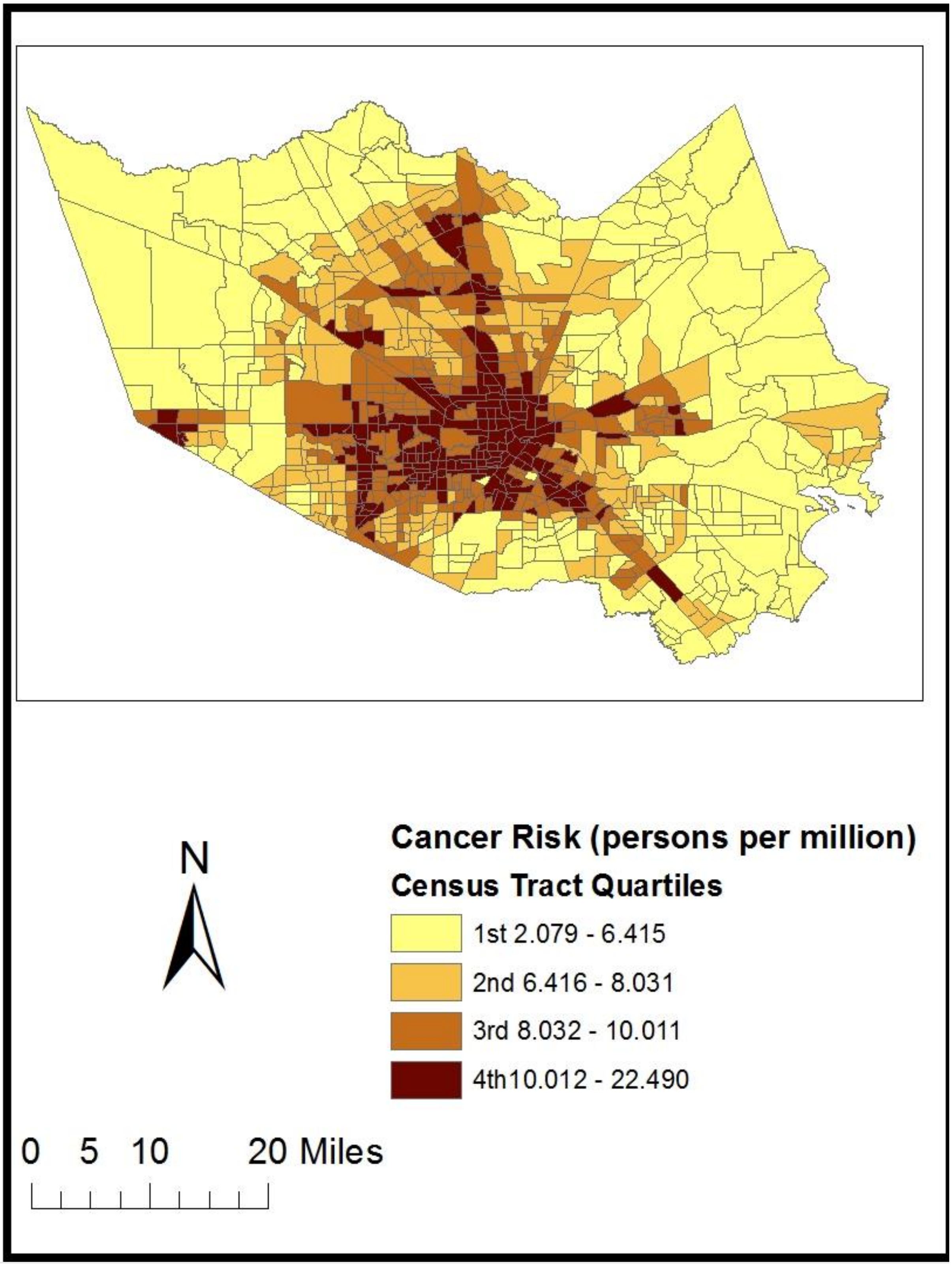

Figure 2. Distribution of On Road Mobile Cancer Risk in Harris County, Texas (2011).

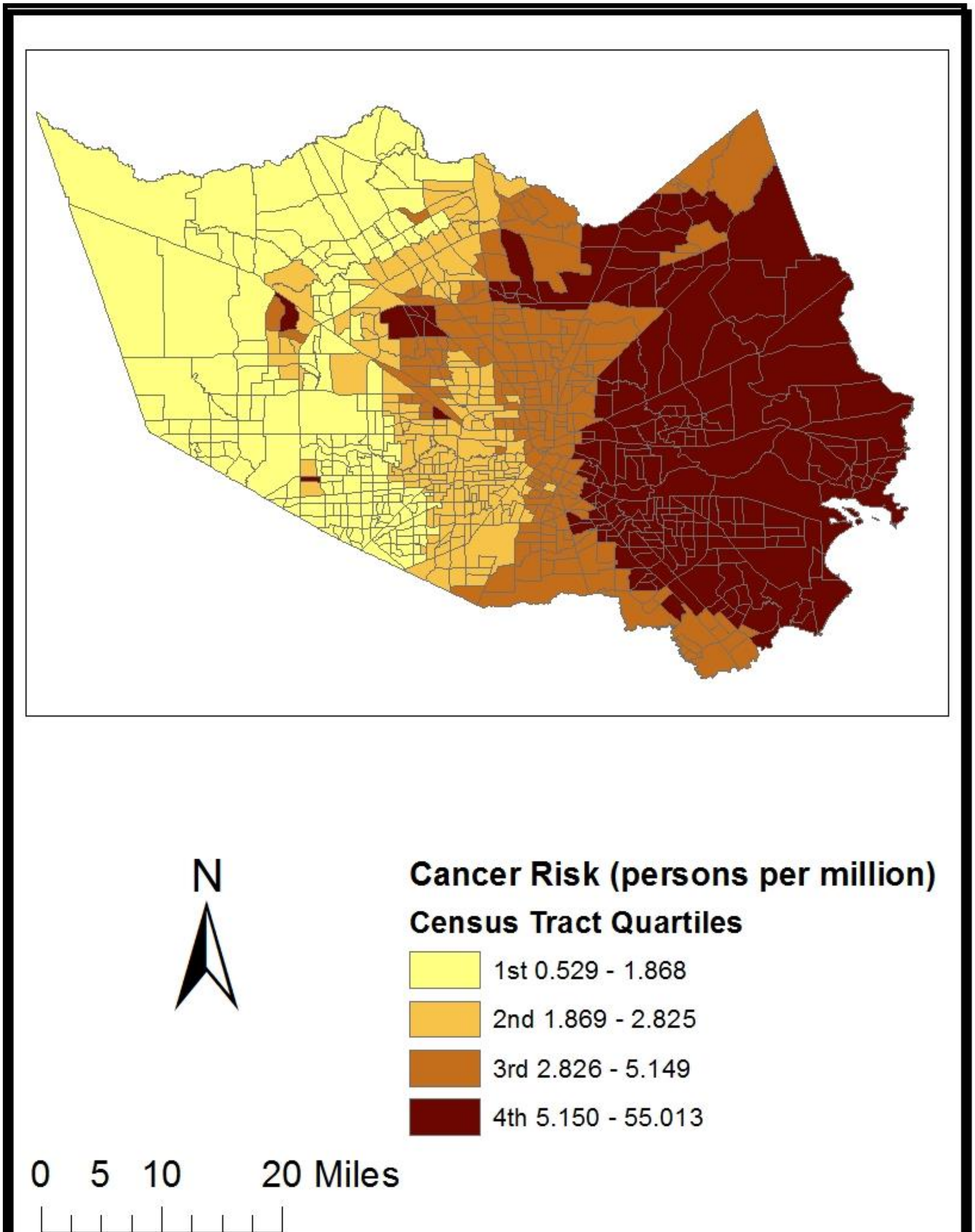

Figure 3. Distribution of Stationary Point Cancer Risk in Harris County, Texas (2011).

With regard to cancer risk from stationary point sources, tracts with the highest values are concentrated in eastern Harris County, which includes areas adjacent to the shipping channel and the corridor close to the petrochemical complex. These cancer risk values appear to decline gradually from the eastern to the western sections of the county. Tracts with lowest quartile for stationary point source cancer risk are located mainly in the western suburbs of Harris County.

Summary statistics for the two dependent variables (cancer risk from on road mobile and stationary point sources) and the major racial/ethnic groups (Hispanic, non-Hispanic Black, non-Hispanic White, Asian and non-Hispanic other race) are provided in Table 4.1. The average excess on road lifetime cancer risk is 8.36 persons per million, and ranges from 2.07 to 22.49. The average for lifetime cancer risk from stationary point sources is relatively smaller (4.72 persons per million), but its range is much larger (0.52 to 55.01). All racial/ethnic variables indicate high variability in their values across tracts in Harris County. The average proportion for Hispanics equals 0.40, but ranges from 0.00 to 0.97. Similarly, average proportion for non-Hispanic Blacks is 0.19, with a range of 0.00 to 0.95. The average proportion for non-Hispanic Whites is 0.32, and ranges from 0.00 to 0.94. The average proportion for non-Hispanic Asian and non-Hispanic other race, in contrast, indicate a much lower mean at 0.060 and 0.001, respectively.

Table 4.1 Descriptive Statistics for Variables Analyzed (N=784 tracts)

Descriptive Statistics	**Minimum**	**Maximum**	**Mean**	**Std. Deviation**
Cancer Risk: On Road Mobile	2.078	22.490	8.368	2.862
Cancer Risk: Stationary Point	0.528	55.013	4.721	5.765
Prop Hispanic	0.001	0.973	0.407	0.256
Prop NH Black	0.000	0.953	0.191	0.218
Prop NH White	0.000	0.940	0.326	0.267
Prop NH Asian	0.000	0.461	0.060	0.071
Prop NH Other Race	0.000	0.055	0.001	0.005

4.2 Bivariate Correlation Analysis of Cancer Risk

Pearson's correlation coefficients, presented in Table 4.2, indicate the strength and significance of the linear relationship between each independent variable and cancer risk from on road mobile and stationary point sources, respectively. The table indicates that on road cancer risk is significantly and positively correlated with the Hispanic proportion and population density, and negatively correlated with the non-Hispanic White proportion and median household income. The proportions for non-Hispanic Black, non-Hispanic Asian and non-Hispanic other race, however, are not significantly correlated with on road cancer risk.

With regard to cancer risk from stationary point sources the Hispanic proportion shows a significant and a positive association. The non-Hispanic Black proportion, non-Hispanic Asian proportion, median household income, and population density are negatively correlated with stationary point cancer risk. The non-Hispanic White and non-Hispanic other race are not significantly correlated.

Table 4.2 Bivariate Correlations with Cancer Risk from On Road and Stationary Sources

Variable	**On Road Mobile Cancer Risk**	**Stationary Point Cancer Risk**
Population density	0.372*	-0.177*
Median household income	-0.107*	-0.096*
Prop Hispanic	0.137**	0.182*
Prop NH Black	0.006	-0.098*
Prop NH White	-0.137*	-0.027
Prop NH Asian	0.032	-0.251*
Prop NH Other race	-0.040	0.009

*p<.05; **p<.01; N=784

Overall, the bivariate analysis of on road cancer risk provides some evidence of environmental injustice based on significantly negative associations with median income and non-Hispanic White proportion, as well as positive association with the Hispanic proportion. Although the Hispanic

proportion and median income indicate similar significant associations with stationary point cancer risk as observed for on road cancer risk, the non-Hispanic Black proportion shows a significantly negative relationship with this variable.

4.3 Multivariate Statistical Analysis Using GEEs

In order to assess the simultaneous effects of all independent variables on each of the two dependent variables, multivariate GEE models are used. The results of the GEE analysis for on road mobile cancer risk is summarized in Table 4.3. In all three models, on road cancer risk is significantly and positively related to population density and median household income (p>.05). Model 1 indicates significantly lower proportions of non-Hispanic Blacks and non-Hispanic Whites, respectively, compared to the Hispanic proportion (reference variable) in tracts with greater on road cancer risk. Model 2 indicates a significantly higher proportion of Hispanics and lower proportion of non-Hispanic Whites, respectively, compared to the non-Hispanic Black proportion (reference variable) in tracts with greater on road cancer risk. Finally, model 3 indicates a significantly higher proportion of both Hispanics, and non-Hispanic Blacks, compared to the non-Hispanic White proportion (reference variable) in tracts with greater on road cancer risk. The proportion for non-Hispanic Asians is significant and positive in all three GEE models, which suggests that this group is facing higher on road cancer risk than each of the three major racial/ethnic groups in Harris County.

Table 4.3 Multivariate GEE Analysis of On Road Mobile Cancer Risk

Variable	**Model 1**		**Model 2**		**Model 3**	
Population density	0.254	429.253**	0.253	433.309**	0.250	435.716**
Median HH income	0.046	8.767*	0.046	8.728*	0.048	9.795*

Prop Hispanic	Ref		0.035	7.689**	0.153	59.347**
Prop NH Black	-0.027	7.048*	Ref		0.103	82.031**
Prop NH White	-0.158	57.196**	-0.122	73.045**	Ref	
Prop NH Asian	0.103	43.440**	0.113	39.022**	0.148	55.532**
Prop NH other Race	-0.017	6.664	-0.016	6.188	-0.014	4.597*
Intercept	2.129	20238.623**	2.128	20654.294**	2.126	21217.816**
Scale	0.017		0.017		0.017	
Model fit (QIC)	24.953		24.965		24.699	
MCI	3.419		3.631		3.349	

**p*<.05; ***p*<.01; N=784

The results of the GEE analysis for stationary point cancer risk is summarized in Table 4.4. Population density is negatively related to cancer risk in all three models, but shows a significant association in only model 2. Median household income is not significant (*p*>.05) in any of the models. Model 1 indicates significantly lower proportions of both non-Hispanics and Whites, compared to the Hispanic proportion (reference variable) in tracts with greater stationary cancer risk. Model 2 indicates a higher proportion of Hispanics and non-Hispanic Whites compared to the non-Hispanic Black proportion (reference variable) in tracts with greater stationary point cancer risk. However, the proportion of Hispanics or non-Hispanic Blacks are not significantly different from the non-Hispanic White proportion in model 3. Finally, the proportion of non-Hispanic Asians is significant and positive in models 2 and 3, which suggests that this group is facing higher on road cancer risk than both non-Hispanic Blacks and Whites.

Table 4.4 Multivariate GEE Analysis of Stationary Point Cancer Risk

Variable	**Model 1**		**Model 2**		**Model 3**	
Population density	-0.023	0.044	-0.163	118.987**	-0.243	1.953
Median HH income	-0.392	4.828	-0.293	2.505	-0.113	1.835

Prop Hispanic	Ref		0.202	53.255**	0.078	0.323
Prop NH Black	-0.182	10.558**	Ref		-0.180	3.157
Prop NH White	0.366	2.944	0.467	5.158*	Ref	
Prop NH Asian	0.145	1.052	0.407	19.343**	-0.271	4.960*
Prop NH other Race	0.131	17.497**	0.088	3.957	0.009	0.091
Intercept	2.231	355.989**	2.333	222.371**	1.453	1001.009**
Scale	0.057		0.114		1.106	
Model fit (QIC)	413.989		366.949		574.702	
MCI	3.419		3.631		3.349	

*p<.05; **p<.01; N=784

In summary, the multivariate GEE analysis indicates significantly higher population density, median household income, and a higher proportion of non-Hispanic Asian residents in tracts with greater on road cancer risk in Harris County, Texas. With regard to the three major categories of race/ethnicity, the GEE results demonstrate that EJ analyses based on traditional or broadly defined racial/ethnic categories provide strong evidence of distributive injustices for on road cancer risk. With respect to non-Hispanic Whites, both Hispanics and non-Hispanics Blacks are exposed to significantly greater cancer risks from vehicular HAP sources. For stationary sources, these racial/ethnic differences are not statistically significant. These findings do not necessarily imply, however, that all specific subgroups within these broader categories are equally exposed to cancer risk from on road mobile sources, or if certain subgroups within these categories are facing significantly greater cancer risk from stationary point sources. Therefore, it is necessary to disaggregate these broadly defined racial/ethnic categories and examine whether specific subgroups within each category are facing disproportionately higher cancer risk. The next chapter thus focuses on the subdivision of the three major racial/ethnic variables using six specific characteristics to incorporate racial/ethnic heterogeneity in the EJ

analysis of estimated cancer risk from on road mobile and stationary point sources of HAPs in Harris County.

Chapter 5: Intra-Categorical Environmental Justice Analysis of Cancer Risk from On Road and Stationary Sources: Exploring Racial/Ethnic Heterogeneity

This chapter focuses on analyzing the environmental justice (EJ) implications of estimated cancer risk from exposure to HAPs from both on road mobile and stationary point sources, based on disaggregating each major racial/ethnic group (i.e., Hispanics, non-Hispanic Whites and non-Hispanic Blacks) using six specific characteristics: poverty status, nativity, homeownership, educational attainment, English language proficiency, and age. First, descriptive statistics are used to examine the distribution of the independent variables that subdivide these racial/ethnic groups based on the six characteristics mentioned above. Second, bivariate correlations are used to examine the statistical association between these independent variables and the two dependent variables. Finally, multivariate generalized estimating equations (GEEs) are utilized to examine the EJ implications of cancer risk based on models that compare specific racial/ethnic subgroups to their counterpart subgroups.

Summary statistics for the six variables associated with Hispanics, non-Hispanic Blacks, and non-Hispanic Whites, respectively, are provided in Table 5.1.

Table 5.1 Descriptive Statistics: Variables for Intra-Categorical Analysis

Variable	Minimum	Maximum	Iean	Std. Deviation
Hispanic				
Prop Above poverty	0.044	1.000	0.571	0.249
Prop Below poverty	0.000	0.955	0.428	0.249
Prop US born	0.000	1.000	0.604	0.138
Prop Foreign born	0.000	1.000	0.395	0.138
Prop Homeowners	0.000	1.000	0.522	0.295
Prop Renters	0.000	1.000	0.477	0.295
Prop High school or higher	0.000	1.000	0.623	0.217
Prop Less than high school	0.000	1.000	0.376	0.217
Prop English proficient	0.166	1.000	0.636	0.178
Prop Limited English proficient	0.000	0.833	0.363	0.178
Prop Age below 65	0.676	1.000	0.954	0.045

Prop Age above 65	0.000	0.478	0.050	0.057
Non-Hispanic Black				
Prop Above poverty	0.000	1.000	0.762	0.242
Prop Below poverty	0.000	1.000	0.237	0.242
Prop US born	0.000	1.000	0.921	0.127
Prop Foreign born	0.000	1.000	0.078	0.127
Prop Homeowners	0.000	1.000	0.410	0.337
Prop Renters	0.000	1.000	0.589	0.337
Prop High school or higher	0.000	1.000	0.877	0.163
Prop Less than high school	0.000	1.000	0.122	0.163
Prop English proficient	0.000	1.000	0.974	0.082
Prop Limited English proficient	0.000	1.000	0.025	0.082
Prop Age below 65	0.000	1.000	0.916	0.137
Prop Age above 65	0.000	1.000	0.083	0.137
Non-Hispanic White				
Prop Above poverty	0.000	1.000	0.809	0.157
Prop Below poverty	0.000	1.000	0.190	0.157
Prop US born	0.000	1.000	0.929	0.094
Prop Foreign born	0.000	1.000	0.070	0.094
Prop Homeowners	0.000	1.000	0.649	0.265
Prop Renters	0.000	1.000	0.350	0.265
Prop High school or higher	0.000	1.000	0.896	0.135
Prop Less than high school	0.000	1.000	0.103	0.135
Prop English proficient	0.160	1.000	0.763	0.192
Prop Limited English proficient	0.000	0.839	0.236	0.192
Prop Age below 65	0.000	1.000	0.813	0.141
Prop Age above 65	0.000	1.000	0.186	0.141

5.1 Bivariate Correlation Analysis of Racial/Ethnic Intra-Categorical Variables

Pearson's correlation coefficients, presented in Table 5.2, indicate the strength and significance of the relationship between each dependent variable and the intra-categorical explanatory variables based on the disaggregation of the three major racial/ethnic groups. For the Hispanic category, on road cancer risk is significantly and positively related to subgroups that can be expected to be socially disadvantaged. This includes the proportion below poverty, foreign born, renters, those who have less than a high school diploma, limited English proficiency. Similarly, Table 5.2 indicates that cancer risk from stationary point sources is significantly and positively correlated with the proportion of Hispanics who are homeowners and have less than high school education. Cancer risk from stationary sources is significantly and negatively

correlated with the proportion of Hispanics who are foreign born and renters. In contrast to the socially disadvantaged, variables representing the more socially advantaged Hispanics indicate lower, negative, or non-significant correlations with both types of cancer risk.

For the non-Hispanic Black category, on road cancer risk is significantly and positively related to subgroups that can be expected to be socially disadvantaged. This includes the proportion of those below poverty, renters, and those with less than high school education. Cancer risk from stationary point sources is significantly and positively correlated with the proportion of non-Hispanic Blacks without a high school diploma, but negatively correlated with the proportion of non-Hispanics Blacks who are renters. Compared to the socially disadvantaged, variables representing the more socially advantaged non-Hispanic Blacks indicate lower or non-significant correlations with both types of cancer risk.

For the non-Hispanic White category, on road cancer risk is again significantly and positively related to subgroups that can be expected to be socially disadvantaged. This includes the proportion below poverty, foreign born, renters, and those who have limited English proficiency. All non-Hispanic White subgroups associated with social advantage, in contrast, indicate a significantly negative correlation with on road cancer risk. Cancer risk from stationary point sources is significantly and positively correlated with the proportion of non-Hispanic Whites who without a high school education, but negatively correlated with those who are foreign born.

Table 5.2 Bivariate Correlations with Cancer Risk from On Road and Stationary Sources

Variable	**On Road Cancer Risk**	**Stationary Cancer Risk**
Hispanic		
Prop Above poverty	-0.166**	-0.063
Prop Below poverty	0.166**	0.063
Prop US born	-0.257**	0.195**
Prop Foreign born	0.257**	-0.195**
Prop Homeowners	-0.446**	0.151**
Prop Renters	0.446**	-0.151**

Prop High school or higher	-0.105**	-0.097**
Prop Less than high school	0.105**	0.097**
Prop English proficient	-0.168**	-0.008
Prop Limited English proficient	0.168**	0.008
Prop Age below 65	-0.06	0.029
Prop Age above 65	0.067	-0.037
Non-Hispanic Black		
Prop Above poverty	-0.171**	-0.054
Prop Below poverty	0.159**	0.057
Prop US born	-0.080*	0.033
Prop Foreign born	0.055	-0.032
Prop Homeowners	-0.388**	0.084*
Prop Renters	0.376**	-0.084*
Prop High school or higher	-0.075*	-0.090*
Prop Less than high school	0.075*	0.090*
Prop English proficient	-0.041	0.03
Prop Limited English proficient	0.041	-0.03
Prop Age below 65	-0.024	-0.071
Prop Age above 65	0.024	0.071
Non-Hispanic White		
Prop Above poverty	-0.196**	-0.036
Prop Below poverty	0.196**	0.036
Prop US born	-0.221**	0.207**
Prop Foreign born	0.221**	-0.207**
Prop Homeowners	-0.369**	0.041
Prop Renters	0.369**	-0.041
Prop High school or higher	-0.018	-0.134**
Prop Less than high school	0.018	0.134**
Prop English proficient	-0.230**	0.005
Prop Limited English proficient	0.230**	-0.005
Prop Age below 65	-0.045	-0.038
Prop Age above 65	0.045	0.038

*p<.05; **p<.01; N=784

5.2 Multivariate Intra-categorical Analysis Using GEEs

The results of the multivariate GEE analysis for on road cancer and stationary cancer risk respectively, for specific subgroups associated with each major racial/ethnic category, are summarized in Tables 5.3 to 5.8. Standardized coefficients are provided in these tables to compare the relative contribution of each explanatory variable. In each GEE model or table column, the subgroup expected to be more socially disadvantaged is directly compared to its counterpart

subgroup, which is treated as the reference variable. The results are discussed separately for each racial/ethnic group, in the following sections of this chapter.

5.2.1 Intra-categorical Analysis of Hispanics

Table 5.3 presents results for GEEs with on road cancer risk as the dependent variable and disaggregates the Hispanic category in six different ways (models 1 to 6). Model 1 indicates significantly higher on road cancer risk for Hispanics below poverty compared to those above poverty (reference variable), after controlling for the effects of other independent variables. Similar results can be observed in models 2 to 6, where the proportion of the census tract population who are Hispanic and (separately) Hispanics who are foreign born, renters, less educated, less proficient in English, and above 65 years of age, respectively, show significantly higher cancer risks compared to their counterpart or reference subgroups. The coefficients for the overall non-Hispanic Black and non-Hispanic White proportions, respectively, are significantly smaller when compared to those of socially advantaged Hispanic subgroups (except for Hispanics above poverty). Lastly, the coefficients for the non-Hispanic Asian proportions are significantly higher when compared to those of socially advantaged Hispanic subgroups.

Table 5.3 Hispanic GEEs: On Road Cancer Risk

Variables	**Model 1**	**Model 2**	**Model 3**	**Model 4**	**Model 5**	**Model 6**
Population density	0.268**	0.235**	0.210**	0.265**	0.248**	0.258**
Median household income	0.061**	0.029	0.087**	0.051*	0.046*	0.030*
Prop NH Black	-0.004	-0.027*	-0.045**	-0.022*	-0.018*	-0.021*
Prop NH White	-0.116**	-0.125**	-0.164**	-0.116**	-0.112**	-0.148**
Prop NH Asian	0.108**	0.106**	0.062**	0.119**	0.128**	0.096**
Prop NH other race	-0.013*	-0.021*	-0.013*	-0.015*	-0.015*	-0.016*
Prop Hispanic: Above poverty	Ref					

Prop Hispanic: Below poverty	0.065**					
Prop Hispanic: U.S.born		Ref				
Prop Hispanic: Foreign born		0.058**				
Prop Hispanic: Homeowners			Ref			
Prop Hispanic: Renters			0.134**			
Prop Hispanic: High school or higher				Ref		
Prop Hispanic: Less than high school				0.061**		
Prop Hispanic: English proficient					Ref	
Prop Hispanic: Limited English proficient					0.068**	
Prop Hispanic: Age below 65						Ref
Prop Hispanic: Age above 65						0.042**
Intercept	2.140**	2.123**	2.143**	2.136**	2.136**	2.124**
Scale	0.016	0.016	0.013	0.016	0.016	0.016
Model Fit (QIC)	26.181	24.976	27.257	24.395	26.042	22.354
MCI	4.105	3.602	3.853	4.287	4.107	3.510

*p<.05; **p<.01; N=784

The results of the corresponding GEE analysis for stationary point source cancer risk are summarized in Table 5.4. Model 4 indicates significantly higher stationary cancer risk for Hispanics without a high school diploma compared to those who have a high school diploma (reference variable), after controlling for the effects of other independent variables. However, four of the five other GEE models indicate significantly lower stationary cancer risk for socially disadvantaged Hispanics (those who are below poverty line, foreign born, renters, and 65 years or more) compared to their reference subgroups. With the exception of the proportion of Hispanics who are homeowners, the coefficients for all socially advantaged Hispanic subgroups are not significantly different from those associated with the non-Hispanic White proportion, suggesting

similar levels of cancer risk. The coefficients for the overall non-Hispanic Black proportion are smaller than those of socially advantaged Hispanic subgroups, suggesting relatively higher levels of cancer risk for socially advantaged Hispanics in Harris County, at the census tract level.

Table 5.4 Hispanic GEEs: Stationary Cancer Risk

Variables	**Model 1**	**Model 2**	**Model 3**	**Model 4**	**Model 5**	**Model 6**
Population density	-0.067	-0.136**	-0.152**	-0.163**	-0.161**	-0.162*
Median household income	0.067	-0.299	-0.445**	-0.239**	-0.327*	-0.263*
Prop NH Black	-0.241**	-0.204**	-0.238**	-0.159**	-0.217**	-0.212**
Prop NH White	-0.355	0.098	0.218*	0.320	0.209	0.153
Prop NH Asian	0.090	0.078	0.063	0.037	0.046	0.013
Prop NH other race	0.099**	0.133*	0.135**	0.036	0.126**	0.134**
Prop Hispanic: Above poverty	Ref					
Prop Hispanic: Below poverty	-0.355*					
Prop Hispanic: U.S.born		Ref				
Prop Hispanic: Foreign born		-0.141**				
Prop Hispanic: Homeowners			Ref			
Prop Hispanic: Renters			-0.169**			
Prop Hispanic: High school or higher				Ref		
Prop Hispanic: Less than high school				0.355*		
Prop Hispanic: English proficient					Ref	
Prop Hispanic: Limited English proficient					0.029	
Prop Hispanic: Age below 65						Ref
Prop Hispanic: Age above 65						-0.092**
Intercept	2.114**	2.023**	1.990**	1.902**	2.012**	1.975**

Scale	0.250	0.093	0.085	0.113	0.095	0.094
Model Fit (QIC)	571.954	427.743	266.891	233.849	281.222	285.128
MCI	4.105	3.602	3.853	4.287	4.107	3.510

*p<.05; **p<.01; N=784

5.2.2 Intra-categorical Analysis of Non-Hispanic Blacks

Table 5.5 presents results from GEEs with on road cancer risk as the dependent variable and disaggregates the non-Hispanic Black category in six different ways (models 1 to 6). Model 1 indicates significantly higher on road cancer risk for non-Hispanic Blacks below poverty compared to those above poverty (reference variable), after controlling for the effects of other independent variables. Similar results can be observed in models 3, 4 and 6, where the proportion of non-Hispanic Blacks who are renters, less educated, and are 65 years of age, show significantly higher cancer risks compared to their counterpart subgroups. Models 2 and 5, however, indicate significantly lower on road cancer risk for the proportions of non-Hispanic Blacks who are foreign born proportion compared to those who are U.S. born (reference variable) and those who are less proficient in English compared to those who are English proficient (reference variable), after controlling for the other independent variables. The coefficients for the overall Hispanic proportion are significantly higher when compared to those of socially advantaged non-Hispanic Black subgroups who live above the poverty line, are U.S. born, and own homes. In all six models, the coefficients for the overall non-Hispanic White proportion are negative and significant, which suggests higher cancer risk for socially advantaged non-Hispanics Blacks compared to the non-Hispanics White population. Lastly, the coefficients for all socially advantaged non-Hispanic Black subgroups are significantly lower than those associated with the non-Hispanic Asian proportion.

Table 5.5 Non-Hispanic Blacks GEEs: On Road Cancer Risk

Variables	Model 1	Model 2	Model 3	Model 4	Model 5	Model 6
Population density	0.215**	0.256**	0.186**	0.260**	0.252**	0.249**
Median household income	0.047**	0.037*	0.082**	0.037*	0.041*	0.038*
Prop Hispanic	0.023*	0.032*	0.040*	0.025	0.027	0.024
Prop NH White	-0.430**	-0.454**	-0.482**	-0.431**	-0.470**	-0.451**
Prop NH Asian	1.950**	1.687**	2.184**	1.650**	1.599**	1.562**
Prop NH other race	-3.970*	-2.208	-2.690*	-4.216*	-2.766*	-2.873*
Prop NH Black: Above poverty	Ref					
Prop NH Black: Below poverty	0.266**					
Prop NH Black: U.S. born		Ref				
Prop NH Black: Foreign born		-0.192*				
Prop NH Black: Homeowners			Ref			
Prop NH Black: Renters			0.232**			
Prop NH Black: High school or higher				Ref		
Prop NH Black: Less than high school				0.202**		
Prop NH Black: English proficient					Ref	
Prop NH Black: Limited English proficient					-0.154*	
Prop NH Black: Age below 65						Ref
Prop NH Black: Age above 65						0.132*
Intercept	2.068**	2.187**	1.997**	2.144**	2.187**	2.166**
Scale	0.017	0.017	0.017	0.017	0.017	0.017
Model fit (QIC)	24.486	27.348	31.967	25.683	26.161	25.202
MCI	3.752	3.649	3.943	3.706	3.608	3.599

**p*<.05; ***p*<.01; N=784

The results of the corresponding GEE analysis for stationary point source cancer risk are summarized in Table 5.6. Models 1,2,5, and 6 indicate significantly lower stationary cancer risk for the non-Hispanic Black below poverty proportion compared to those above poverty,

those who are foreign born compared to U.S. born, those who are less proficient in English compared to the English proficient, and those who are aged 65 years or above compared to below 65, respectively, after controlling for other independent variables. For those who are renters and do not have a high school diploma, there was no significant difference suggesting similar levels of cancer risks when compared to their reference subgroup. In all six models, the coefficients for the overall Hispanic and non-Hispanic White proportions are significantly higher when compared to those of socially advantaged non-Hispanic Black subgroups. Lastly, the coefficients for the overall non-Hispanic Asian proportion are not significantly different when compared to those of socially advantaged non-Hispanic Black subgroups (except for U.S. born and homeowners).

Table 5.6 Non-Hispanic Blacks GEEs: Stationary Cancer Risk

Variable	**Model 1**	**Model 2**	**Model 3**	**Model 4**	**Model 5**	**Model 6**
Population density	-0.155**	-0.100*	-0.196	-0.155**	-0.161**	-0.154**
Median household income	-0.304*	-0.205**	-0.255	-0.293*	-0.285*	-0.213
Prop Hispanic	0.257**	0.275**	0.184**	0.216**	0.249**	0.227**
Prop NH White	0.411*	0.425**	0.419*	0.438**	0.438*	0.349*
Prop NH Asian	0.086	-0.147**	0.115*	0.070	0.085	0.043
Prop NH other race	0.124**	0.073*	0.127**	0.101**	0.106*	0.104*
Prop NH Black: Above poverty	Ref					
Prop NH Black: Below poverty	-0.099**					
Prop NH Black: U.S. born		Ref				
Prop NH Black: Foreign born		-0.124*				
Prop NH Black: Homeowners			Ref			
Prop NH Black: Renters			0.033			
Prop NH Black: High school or higher				Ref		

Prop NH Black: Less than high school				0.052		
Prop NH Black: English proficient					Ref	
Prop NH Black: Limited English proficient					-0.079*	
Prop NH Black: Age below 65						Ref
Prop NH Black: Age above 65						-0.059*
Intercept	1.963**	1.806**	2.039**	1.923**	1.951**	1.912**
Scale	0.094	0.120	0.093	0.101	0.099	0.101
Model fit (QIC)	238.240	176.899	334.745	227.330	35.349	68.551
MCI	3.752	3.649	3.943	3.706	3.608	3.599

**p*<.05; ***p*<.01; N=784

5.2.3 Intra-categorical Analysis of Non-Hispanic Whites

Table 5.7 presents GEEs with on road cancer risk as the dependent variable and disaggregates the non-Hispanic White category in six different ways (models 1 to 6). With the exception of model 4, all GEEs indicate significantly higher on road cancer risk for socially disadvantaged non-Hispanic Whites (i.e., who are below poverty, foreign born, renters, less proficient in English, and age above 65 years, respectively), when compared to their counterpart subgroups. In all six models, the coefficients for the overall Hispanic and non-Hispanic Black proportions are significant and positive, which suggests higher cancer risk for these racial/ethnic minority groups compared to the socially advantaged White residents of Harris County. The coefficients for the non-Hispanic Asian proportion are also significantly higher when compared to those of socially advantaged non-Hispanic White subgroups.

Table 5.7 Non-Hispanic Whites GEEs: On Road Cancer Risk

Variable	**Model 1**	**Model 2**	**Model 3**	**Model 4**	**Model 5**	**Model 6**
Population density	0.244**	0.221**	0.254**	0.238**	0.213**	0.237**
Median household income	0.058**	0.047**	0.072**	0.048**	0.042**	0.048**

Prop Hispanic	0.137**	00.132**	0.119**	0.149**	0.060*	0.138**
Prop NH Black	0.085**	0.099**	0.072**	0.116**	0.052**	0.112**
Prop NH Asian	0.150**	0.086**	0.056**	0.137**	0.166**	0.143**
Prop NH other race	-0.014*	-0.017*	-0.023**	-0.016*	-0.012	-0.016*
Prop NH White: Above poverty	Ref					
Prop NH White: Below poverty	0.042**					
Prop NH White: U.S. born		Ref				
Prop NH White: Foreign born		0.119**				
Prop NH White: Homeowners			Ref			
Prop NH White: Renters			0.097**			
Prop NH White: High school or higher				Ref		
Prop NH White: Less than high school				-0.015		
Prop NH White: English proficient					Ref	
Prop NH White: Limited English proficient					0.120**	
Prop NH White: Age below 65						Ref
Prop NH White: Age above 65						0.016*
Intercept	2.120**	2.137**	2.141**	2.125**	2.120**	2.122**
Scale	0.017	0.015	0.013	0.016	0.017	0.017
Model fit (QIC)	24.274	23.168	21.535	24.470	25.348	23.834
MCI	3.901	3.339	4.003	3.701	6.770	3.502

*p<.05; **p<.01; N=784

The results of the corresponding GEE analysis for stationary point cancer risk are summarized in Table 5.8. Models 3 and 4 indicate significantly higher stationary point cancer risk for non-Hispanic Whites who are renters and less educated, compared to their counterpart subgroups. In contrast, models 2 and 5 indicate significantly lower stationary cancer risk for those who are foreign born and are less proficient in English, compared to their counterpart subgroups. The coefficient for the overall Hispanic proportion is significantly smaller compared to those of non-Hispanic Whites who are proficient in English, while the coefficient for the overall non-

Hispanic Black proportion is significantly higher compared to non-Hispanic Whites who are in poverty. The coefficients for the non-Hispanic Asian proportion indicate significantly lower risk for this group than socially advantaged non-Hispanic Whites in all models, except for non-Hispanic Blacks above poverty in model 1.

Table 5.8 Non-Hispanic Whites GEEs: Stationary Cancer Risk

Variable	**Model 1**	**Model 2**	**Model 3**	**Model 4**	**Model 5**	**Model 6**
Population density	-0.162**	-0.216**	-0.257**	-0.255**	-0.091	-0.238**
Median household income	-0.399*	-0.070	-0.024	-0.048	-0.088	-0.051
Prop Hispanic	-0.231	0.126	0.143	0.080	0.245*	0.142
Prop NH Black	-0.365*	-0.094	-0.113	-0.139	-0.049	-0.103
Prop NH Asian	0.003	-0.179*	-0.222*	-0.215*	-0.279*	-0.217*
Prop NH other race	0.116**	0.002	0.001	0.010	0.005	0.006
Prop NH White: Above poverty	Ref					
Prop NH White: Below poverty	-0.030					
Prop NH White: U.S. born		Ref				
Prop NH White: Foreign born		-0.091*				
Prop NH White: Homeowners			Ref			
Prop NH White: Renters			0.052*			
Prop NH White: High school or higher				Ref		
Prop NH White: Less than high school				0.130*		
Prop NH White: English proficient					Ref	
Prop NH White: Limited English proficient					-0.213**	
Prop NH White: Age below 65						Ref
Prop NH White: Age above 65						-0.035
Intercept	2.041**	1.419**	1.427**	1.425**	1.444**	1.429**
Scale	0.086	0.248	0.255	0.253	1.060	0.248
Model fit (QIC)	298.735	155.701	160.627	164.324	520.216	178.870

MCI	3.901	3.339	4.003	3.701	6.770	3.502

*p<.05; **p<.01; N=784

Chapter 6: Concluding Discussion

This thesis project has sought to contribute to distributive environmental justice (EJ) research by analyzing racial/ethnic disparities in inhalation exposure to hazardous air pollutants (HAPs) in Harris County, Texas. Most quantitative EJ studies have not disaggregated traditional racial/ethnic categories, and the few multivariate studies that have done so have only disaggregated the Hispanic category. This thesis thus addresses an important gap by conducting a detailed multivariate analysis of intra-categorical differences in potential cancer risks associated with ambient HAP exposure for multiple racial/ethnic groups and air pollution sources. Specifically, this study has sought to determine how the EJ implications of cancer risk from on road mobile and stationary sources of HAPs differ across and within each major racial/ethnic group (i.e., Hispanics, non-Hispanic Blacks, and non-Hispanics Whites) by subdividing each group based on six relevant socio-demographic characteristics. Since previous EJ studies in the Harris County area have used broad racial/ethnic categories when analyzing the relationship between race/ethnicity and exposure to HAPs, this study also contributes new empirical knowledge regarding the EJ implications of exposure to both mobile and stationary sources of HAPs.

The first research question focused on investigating if estimated cancer risks from inhalation exposure to HAPs from on road mobile and stationary point sources are distributed inequitably with respect to race, ethnicity, and socioeconomic status, when each major racial/ethnic category is treated as a single homogenous group. To answer this question, both bivariate and multivariate analyses were utilized to analyze the distribution of lifetime cancer risk from on road and stationary sources at the census tract level. For on road emission sources, bivariate correlations indicated significantly higher population density, lower median income, higher proportions of Hispanics, and lower proportion of non-Hispanic Whites in tracts with greater cancer risk. These results suggested to distributive environmental injustices that were

confirmed by multivariate GEE analysis which revealed that the proportion of both Hispanics and non-Hispanic Blacks are significantly higher than the non-Hispanic White proportion, in tracts exposed to greater on road mobile cancer risk. Compared to all three major racial/ethnic groups, the proportion of non-Hispanic Asians is significantly higher in tracts with greater on road cancer risk. For stationary point sources, bivariate correlations indicated significantly lower population density, lower median income, higher Hispanic proportion, and lower non-Hispanic Black proportion in tracts with greater cancer risk. Multivariate GEE analysis showed that the proportion of Hispanics or non-Hispanic Blacks are not significantly different from the non-Hispanic White proportion, in terms of their association with stationary point cancer risk. Compared to the non-Hispanic Black proportions, however, the proportion of Hispanics, non-Hispanic Whites and non-Hispanics Asians are significantly higher in tracts with greater stationary cancer risk. Overall, the results suggest that racial/ethnic minorities are disproportionately distributed with respect to cancer risk from vehicular HAPs sources in Harris County. These results are consistent with those reported by other EJ studies in this urban area that have found similar distributive injustices for cumulative cancer risk associated with HAPs (Linder et al., 2008; Chakraborty et al., 2014; Collins et al., 2015; Grineski et al., 2015; Hernandez et al., 2015). However, these previous studies did not focus specifically on transportation-related air pollutants or compare to different HAP emission sources. For stationary cancer risk, no clear patterns of environmental injustice can be observed from the multivariate analysis using the conventional approach of broadly defining the major racial/ethnic categories.

The second research question focused on investigating whether estimated cancer risks from inhalation exposure to HAPs from on road and stationary sources are distributed inequitably when each major racial/ethnic category is subdivided into contextually relevant subgroups. This specific

question was answered by disaggregating each major racial/ethnic group based on six characteristics: poverty status, nativity, homeownership, educational attainment, English language proficiency, and age. The results of both bivariate and multivariate intra-categorical EJ analyses utilized to answer this questions are summarized in Table 6.1, which indicates whether the statistical relationship between cancer risk from on road mobile and stationary point sources and each explanatory variable was positive, negative, or non-significant.

Table 6.1 Statistical Results: Cancer Risk from On Road and Stationary Sources

Variable	**Bivariate: On Road**	**Bivariate: Stationary**	**Multivariate: On Road**	**Multivariate: Stationary**
Hispanic:				
Prop Above poverty	-	NS	Ref	Ref
Prop Below poverty	+	NS	+	-
Prop US born	-	+	Ref	Ref
Prop Foreign born	+	-	+	-
Prop Homeowners	-	+	Ref	Ref
Prop Renters	+	-	+	-
Prop High school or higher	-	-	Ref	Ref
Prop Less than high school	+	+	+	+
Prop English proficient	-	NS	Ref	Ref
Prop Limited English proficient	+	NS	+	-
Prop Age below 65	-	NS	Ref	Ref
Prop Age above 65	NS	NS	+	-
Non-Hispanic Black:				
Prop Above poverty	-	NS	Ref	Ref
Prop Below poverty	+	NS	+	-
Prop US born	-	NS	Ref	Ref
Prop Foreign born	NS	NS	-	-
Prop Homeowners	-	+	Ref	Ref
Prop Renters	+	-	+	NS
Prop High school or higher	-	-	Ref	Ref
Prop Less than high school	+	+	+	NS
Prop English proficient	NS	NS	Ref	Ref
Prop Limited English proficient	NS	NS	-	-
Prop Age below 65	NS	NS	Ref	Ref
Prop Age above 65	NS	NS	+	-
Non-Hispanic White:				
Prop Above poverty	-	NS	Ref	Ref
Prop Below poverty	+	NS	+	-
Prop US born	-	+	Ref	Ref
Prop Foreign born	+	-	+	-

Prop Homeowners	-	NS	Ref	Ref
Prop Renters	+	NS	+	+
Prop High school or higher	-	-	Ref	Ref
Prop Less than high school	NS	+	-	+
Prop English proficient	-	NS	Ref	Ref
Prop Limited English proficient	+	NS	+	-
Prop Age below 65	NS	NS	Ref	Ref
Prop Age above 65	NS	NS	+	-

Note: + = positive (*p*<.05); - = negative (*p*<.05); NS = not significant.

For on road mobile sources, bivariate correlations indicated a significantly positive relationship with cancer risk for the proportion of Hispanics who are below poverty, foreign born, renters, lack high school education, and have limited English proficiency. For non-Hispanic Blacks, on road cancer risk is significantly and positively related to the proportion of those who are below poverty, renters, and are less educated. For non-Hispanic Whites on road cancer risk is significantly and positively related to the proportion of those who are below poverty, foreign born, renters, and have limited English proficiency. Multivariate GEE results for on road mobile sources indicate that Hispanics subgroups that face significantly greater on road cancer risk compared to their counterpart subgroups include those who are below the poverty line, foreign born, renters, lack high school education, have limited English proficiency, and 65 or more years old. Non-Hispanic Blacks exposed to significantly greater on road cancer risk than their counterparts comprise those who are below the poverty line, renters, less educated, and 65 or more years old. Non-Hispanic Whites facing significantly greater on road cancer risk when compared to their counterpart subgroups include those who are below poverty, foreign born, renters, less proficient in English, and above 65 or more years old.

For stationary point sources of HAPs, bivariate correlations indicated a significant and positive relationship with those who do not have a high school diploma, in all three major racial/ethnic categories. Multivariate results for stationary point sources, indicate the only Hispanic subgroups facing significantly higher cancer risk compared to their counterpart groups include

those that do not have a high school diploma, while non-Hispanic Whites facing significantly higher cancer risks include those who are renters and do not have a high school diploma.

In summary, the findings demonstrate that racial/ethnic subgroups that are facing the highest cancer risks differ according to air pollution source and socio-demographic characteristics. For on road emission sources, there is enough evidence to indicate that socially disadvantaged subgroups are disproportionately located in neighborhoods exposed to significantly higher cancer risk, regardless of their broader racial/ethnic designation. Within all three major categories (i.e., Hispanics, non-Hispanic Blacks, and non-Hispanic Whites), the subgroups facing significantly higher risk include individuals in poverty, foreign born persons, renters, and those with limited English proficiency. For these socially disadvantaged subgroups, even their White racial status does not lower the risk burdens associated with on road HAP exposure. For stationary point sources similar injustices in the distribution of cancer risk can be observed only for non-Hispanic Whites who are renters and without high school education, as well as Hispanics without high school education. The socially disadvantaged subgroups exposed to significantly higher cancer risks from both on road and stationary sources include Hispanics without high school education and non-Hispanic White renters.

With regards to the Hispanic category, the results are particularly disturbing, since socially disadvantaged Hispanics who are facing disproportionately higher on road risk are also more likely to lack health insurance and other resources necessary to mitigate the adverse health effects of vehicular air pollution. Previous research suggest that Hispanics have the lowest health insurance rate of any racial/ethnic group in the U.S. and this disparity is significantly higher for Hispanics (Durden & Dean, 2013; Monnat, 2017). The differences in EJ results for on road and stationary sources can be explained, in part, by the disparate spatial distributions of these HAP sources in

this county. On road mobile sources are dispersed throughout Harris County and the highest cancer risk values are observed in central Harris County, including the city of Houston, where the population is more racially and economically diverse. In contrast, the most important contributor to cancer risk from stationary point sources are the chemical plants and industries that are concentrated mainly in eastern Harris County. Compared to central Harris County, this is a sparsely populated region which is not as diverse in terms of race/ethnicity or socioeconomic status.

It is important to recognize some of the limitations of the data and methodology utilized in this study. Even though estimates of on road and stationary cancer risk from the 2011 NATA developed by the EPA are used to represent the dependent variables for this study, there are specific limitations with this dataset (USEPA, 2017c). The 2011 NATA estimates cancer risk only from direct inhalation exposure to outdoor air toxics and does not account for exposure through other pathways such as ingestion or skin contact, as well as exposure to HAPs produced indoors such as emissions from cars in attached garages. The NATA information is also not a substitute for actual health outcomes or cancer incidence data, and only represent modeled estimates of cancer risk based on EPA's risk assessment guidelines. Additionally, the NATA risk estimates only include individual and additive health effects, but synergistic interactions among HAPs could pose additional cancer risks that are not examined in this study (USEPA, 2017c).

Finally, it is important to consider that this thesis focused on evaluating the current patterns of HAP exposure and related distributional injustices, and not the processes that led to the observed racial/ethnic disparities. The results presented here cannot be used to answer the 'which came first' EJ question, or infer the sequence of events that caused increased exposure to on road HAPs in tracts within Harris County that are disproportionately populated by Hispanics or specific socially

disadvantaged subgroups. More research is necessary to identify the historical trajectories of industrial and highway development, changing patterns of racial/ethnic migration, gentrification and urbanization, and other political, socioeconomic, and spatial processes in this metropolitan area that are potentially responsible for the unequal distribution of mobile and stationary air pollution sources. Future research should also consider the disaggregation of the non-Hispanic Asian category, since this group is facing significantly higher exposure to on road cancer risk compared to all other racial/ethnic categories. A recent EJ study disaggregated Asian Americans based on ancestry and found cancer risks from HAP exposure to be significantly higher for Chinese and Korean Americans compared to other Asian subgroups in the U.S. (Grineski et al. 2017). Although this study focused on country-of-origin and was national in scope, it provides an important framework for more detailed intra-categorical analysis that is required to determine which social characteristics are related to the environmental injustices experienced by Asian Americans in Harris County. In order to better understand distributive injustices and contribute to the formulation of policies to that address unequal exposure to air pollution risks in this rapidly growing and diversifying urban area, it is necessary to incorporate intra-ethnic heterogeneity more explicitly in future EJ research.

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Curriculum Vita

Michel G. Loustaunau Garcia was born in Chihuahua, Chih., Mexico, she lived there the first thirteen years of her life for her elementary and middle school. After finishing middle school, Michel immigrated to the United States. During her undergraduate education, Michel worked as an intern at Emergence Health Network in the records department and at Workforce Solutions Borderplex assisting the youth case managers for two years. After completing her Bachelor Degree in Psychology, Michel started working at Workforce Solutions Borderplex as a youth case manager. In 2015, Michel was accepted in the Master of Arts in Sociology program at The University of Texas at El Paso. As a graduate student, she worked as a graduate research assistant under the supervision of Dr. Jayajit Chakraborty Professor in the Department of Sociology and Anthropology at UTEP. As a research assistant Michel acquired expertise and experience with IBM SPSS Statistics and geographic information system (GIS) software, as well as downloading and using American Community Survey (ACS) data. Michel graduated from the M.A. in Sociology in fall 2018.

Contact Information: mgloustaunau@miners.utep.edu

This thesis was typed by Michel G. Loustaunau Garcia