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# The Disproportionate Burden Of Asthma By Race, Sex, Income And Education

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**THE DISPROPORTIONATE BURDEN OF ASTHMA BY RACE, SEX, INCOME AND EDUCATION**

by

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# CHAPTER 1 – INTRODUCTION

***Aim***

Detrimental environmental exposures are not distributed evenly among households in the United States, neither by spatial nor social lines (Maantay 2007). Racial minorities and low-income households bear a large portion of the pollution burden compared to non-Hispanic White individuals and higher-income households (Evans and Kantrowitz 2002). Despite increases in disease knowledge and population health over the last century, disparities in disease risk have persisted along social and disproportionate environmental lines. Using an environmental justice framework, I seek to explore the relationship of county level median air quality and adult asthma risk, as well as the differential exposure and sensitivity of air quality by sex, race, income and education, controlling for individual and county effects.

Despite developing a better understanding of the disease, asthma prevalence increased from 7.3% in 2001 to 8.4% in 2010, with an estimated 26 million individuals in the United States having asthma in 2010 (Akinbami 2012). Asthma is responsible for substantial direct and indirect costs to society consisting of pharmaceutical, hospital admission and non-emergency department ambulatory visit costs, as well as employer expenditures and loss in productivity due to asthma morbidity and mortality (Cisternas et al. 2003, Birnbaum et al. 2002, Barnett and Nurmagambetov 2011). More importantly, asthma rates are not distributed evenly among all sociodemographic groups. More specifically, there are persistent differences in asthma burden by income and race. Asthma rates are consistently higher among the poor and non-Hispanic Black individuals compared to the non-poor and non-Black individuals (Rosenbaum 2008, Rhodes et al 2003, Grant et al. 2000, and Miller 2000).

This paper seeks to understand relationship of county level median air quality with adult asthma risk, and the disproportional adult asthma risk by sex, race, income and education, controlling for individual and county effects. Sex, race, income, education and environment (air quality) related to asthma have been chosen as dimensions of inequality to be operationalized based on health inequality and environmental justice literature (Andersen et al. 2002, Toren and Hermansson 1999, Thomson et al. 2004, Cagney and Browning 2004, Curtis et al. 2012, Li and Newcomb 2009, Li and Lin 2014). Three sources of data were used: the Behavioral Risk Factor Surveillance System 2011 (BRFSS), EPA's Air Quality System (AQS) database 2010, and the 2010 US Census.

To examine how air quality is associated with the disproportional adult individual risk of asthma by race, sex, education and income in the United States, individual characteristics (having a health plan, race, smoking behavior, sex, education, income and age) and presence of current, adult asthma will be measured using the behavioral risk factor surveillance system (BRFSS) from 2011. The BRFSS is a telephone-based (land-line and cellular) collection of state health surveys of the non-institutionalized adult population age 18 years and older living in households in all 50 states. Additional details for the BRFSS can be found in chapter 3.

Air quality (median county level Air Quality Index [AQI]) will be measured at the county level from the EPA's Air Quality System (AQS) database from 2010. County level variables (proportion urban, proportion vacant, proportion persons 25 years and over with a bachelor's degree or higher, and proportion people of all ages in poverty) will be measured with data from the 2010 US Census. Additional details for the county level data (Census and AQS) can be found in chapter 3.

The specific objectives of this work are to answer the following questions: 1) What is the difference in exposure of the median AQI by race, controlling for county and individual effects? 2) What is the difference in exposure of the median AQI by sex, controlling for county and individual effects? 3) What is the difference in exposure of the median AQI by education, controlling for county and individual effects? 4) What is the difference in exposure of the median AQI by income, controlling for county and individual effects? 5) Is the variation in asthma prevalence associated with county level median air quality? 6) Does the relationship between asthma prevalence and county level air quality vary by race, sex, education or income?

***Significance***

This research is significant in applied and analytical ways. Practically, asthma is an enormous health concern for adults in the U.S., but even more so for non-White and low income, low education individuals. Uncontrolled asthma results in ambulatory care, emergency room visits, hospitalizations, and even death in severe cases. As asthma prevalence continues to rise, so do the social and monetary costs of asthma in the U.S.. Analytically, this research utilizes both individual and county level characteristics, allowing the examination of the degree of variation in asthma prevalence using multiple levels of variables. Most significantly, this paper examines the disproportionate variation of individual risk of adult asthma among non-White and poor individuals and how their environments and access to resources are linked to this risk. Each of the above justifications regarding the value of this research will be discussed in greater detail below.

Asthma is responsible for substantial direct and indirect costs to society. The CDC estimated asthma costs to be $63.1 billion (2013 dollars) in 2007. Direct per-person annual costs of asthma in 2002 averaged $4,128 (2013 dollars), with the largest components of direct costs consisting of pharmaceuticals, hospital admissions and non-emergency department ambulatory visits. In addition to these costs are the indirect per-person annual costs averaging $1,378 (Cisternas et al. 2003). Annual per capita employer expenditures for asthmatic patients are approximately 2.5 times more than non-asthmatic patients (Birnbaum et al. 2002) and an estimated $4.1billion and $2.3billion (2013 dollars) was lost in productivity in 2007 due to asthma morbidity and mortality, respectively (Barnett and Nurmagambetov 2011).

The increase in asthma prevalence is not occurring evenly across various racial and socioeconomic status groups. Asthma prevalence disparities exist between racial groups, with Black individuals consistently faring worse than non-Black individuals (Rhodes et al. 2004, Weitzman et al. 1990, Schwartz et al. 1990, Crain et al. 1994). Similar racial disparities exist for hospitalization rates (Wissow, et al. 1988, De Palo et al. 1994, Carr et al. 1992, Gergen and Weiss 1990) and mortality rates as well (Carr et al. 1992, Evans 1992, Marder et al. 1992). Comparable disparities in asthma prevalence have been observed between different household income level groups, area/neighborhood average income levels and education level groups (Litonjua et al. 1999, Weitzman et al. 1990, Schwartz et al. 1990).

From 2008-2010 the average annual asthma prevalence rates for Black individuals and persons of multiple races (11.2% and 14.1%, respectively) were significantly higher than prevalence rates for White or Asian persons (7.7% and 5.2%, respectively). Income disparities were just as pronounced. Asthma prevalence was much higher for groups with incomes less than 100% of the poverty level (11.2%), compared to 200% or more of the poverty level (7.3% asthma prevalence) (Akinbami et al. 2012). Considering the previously discussed differences in asthma risk, in addition to the improvement of technology and knowledge of asthma risk over time, it is apparent that these risk reducing resources have not been distributed evenly across individuals in society, nor are environmental risks evenly distributed. The disproportionate exposure to environmental risk factors due to individual social characteristics points to the need for policy implementation that provides the right to a safe, healthy and sustainable environment. More specifically, policy should acknowledge key players who affect the built and natural environment, as well as those in the community who are affected by changes to the built and natural environment. One effective way of doing so is using an environmental justice framework, which includes the following (Gray et al. 2013, Rainey-Brown & Johnson, 2011):

1. The right of all people to be protected from environmental degradation.
2. Adopts the public health model of prevention
3. Environmental Justice uses the effect test as opposed to the intent test when determining injustice inferring discrimination
4. Places the burden of proof on the polluters
5. Redresses disproportionate impact through target actions and resources

The associations between disproportionate exposure to environmental risk factors due to individual social characteristics and numerous negative health outcomes are outlined in detail in chapter 2. Numerous other asthma studies focus on children, specific asthma related issues (such as emergency room visits), lack air quality data, or only focus on indoor pollutants, and focus on only one specific geographic area. This study is different, as it focuses on adults, overall asthma risk, is comprised of a national sample, but most importantly – examines group differences by sex, race, education and income.

***Analysis Level and Variables Operationalized***

To examine the association of social-spatial inequalities and adult asthma risk, several types of statistical analyses were employed for the purpose of hypothesis testing. Logistic regression comparisons and linear regression were utilized for variable inclusion, county inclusion, and sampling methodology robustness checks. The examination of median AQI quartiles by group, t-tests, and confidence intervals served to address differential exposure, while logistic regression (coefficients) was performed to address differential sensitivity. Several multivariate logistic models were used: The first analysis included sex, race, education and income in the overall model to determine overall associations. Next, the data set was stratified by men/women, Black/non-Black, non-college/college graduates, and low income/high income

Variables from the BRFSS are described as level 1, indicating individual level variables include: currently has asthma, health plan, race, smoking behavior, sex, education, income, and age. Variables from the Census or AQS are described as level 2, indicating county level variables include: median air quality index (AQI), proportion urban, proportion vacant, proportion educated, and proportion in poverty. A full description of the variables can be found in chapter three.

***Scope and Limitations***

The main limitations of this study relate to issues of measurement and using cross-sectional and secondary data. This study is limited by its cross-sectional data; only representing the variables at one point in time. This means there is no way of measuring whether or not a respondent's asthma was a result of living in the county in which they were surveyed. The measurement of the outcome variable is limited to respondents that have ever been told by a doctor they have asthma. This measurement does not take into account individuals that had limited or no medical care that may have had asthma. Next, parameters of multilevel analysis for binary data can be severely downwardly biased if observations in clusters are highly correlated, or if there is a single observation in a cluster. Although readily available, the utilization of secondary data limits the formulation of problems and concepts because measurement can only be based on existing data. It should be noted that this does not reduce the validity of importance of this research, and secondary data sources can be used to yield significant research as long as the limitations are understood. Finally, county level measures are likely to be too large grained to have a significant effect on individual asthma risk due to the lack of exposure data. Due to the data of the subjects, county level data is the finest grain geographic location available. Additional, detailed discussions of study limitations can be found in chapter 3 and chapter 5. In the following chapter, I describe the conceptual foundations and rationale for this study through a literature review of asthma, individual and county level effects on adult asthma, as well as an environmental justice framework.

# CHAPTER 2 - LITERATURE REVIEW

## *Description of Search*

Studies were reviewed related to asthma risk, contributing social, behavioral and environmental factors, as well as environmental justice and social selection. Social, behavioral and environmental factors were narrowed down to: health plan, race, sex, income, education, age, smoking behaviors and air quality factors. Additional neighborhood and county level effects were examined as well. This literature review uses peer-reviewed journals from 1999-2018. The literature was compiled using libraries from Wayne State University from the following databases: ProQuest Multisearch, PLoS medicine, PubMed Central, and JSTOR, as well as the open source: google scholar.

The following search terms and combinations have been used: *asthma, asthma+social determinants, asthma+behavioral determinants, asthma+air quality, asthma+health plan, health plan+health care access, asthma+sex, asthma+gender, asthma+race, asthma+age, asthma+smoking, asthma+education, asthma+income, asthma+socioeconomic status, asthma+county effects, asthma+neighborhood effects.* The majority of the studies are U.S. based, and all are in English.

## *Asthma*

Asthma is a chronic lung disease that inflames and narrows one's airways. Asthma causes recurring periods of wheezing (a whistling sound when one breathes), chest tightness, shortness of breath, coughing and the possibility of death with severe and/or untreated symptoms. Possible triggers of asthma may include: infections, exercise, allergens (pollen, food additives, and animals), smoke, dust, mold, and air pollution. Typically asthma is diagnosed by confirming one or several of the following: a family history of asthma and allergies, a physical exam that includes signs and symptoms of asthma (wheezing, swollen nasal passages), a spirometry test for lung function, a spirometry bronchoprovocation to test sensitivity of airways, and a chest xray or electrocardiogram test (CDC 2007). Factors that are associated with increasing individual asthma risk include: having a blood relative with asthma, having another allergic condition, being overweight, being a smoker, exposure to secondhand smoke, exposure to pollution, and exposure to occupational triggers (Martinez et al. 2013).

The National Health Interview Survey (CDCNCHS 2012) estimates 12.6% Americans have ever been diagnosed with asthma and 8.1% still have asthma as of 2011. The disparities among racial, education level and income groups for 2011 mirror the 2008-2010 data. As of 2011: 15.2% of Black individuals and 12.3% of White individuals, 11.5% of persons with bachelor's degree or higher and 12% with less than a high school diploma, 11.9% of families with incomes of $35,000 or higher and 14.5% of families with incomes less than $35,000 have ever had asthma.

***Individual-level***

*Health Plan, Age, and Smoking Behavior*

Having health insurance coverage is a strong predictor of health care access, and is serving as a proxy for this study (Andersen et al. 2002). In a retrospective cohort study, Lynch et al. (2010) point to the association of health insurance and health care access and the possible cyclical nature of a delay in diagnosis of asthma, resulting additional suboptimal health care services. The literature also overwhelmingly shows associations between younger age and predictive asthma incidence into adulthood. In a longitudinal study, childhood allergic rhinitis was found to increase the likelihood of new-onset asthma after childhood and the likelihood of having persisting asthma from childhood into middle age (Burgess et al. 2007). Toren &

Hermansson (1999) found that the incident rates of adult-onset asthma were higher among those aged 16-20 (2.2) compared to older age groupings. Individual behavioral factors, primarily smoking, have a significant effect on the prevalence of asthma. The association between smoking and asthma prevalence is well documented, as is the association with severity of symptoms (Thomson et al. 2004, Strine et al. 2007). Cagney and Browning (2004) found that individuals that are female, overweight and smoke are at a greater risk of vulnerability to having asthma. In a prospective cohort study Dockery et al. (1993) found that mortality rates were strongly associated with cigarette smoking.

*Race*

The most prominent disparity that is commonly found with the effect of race and asthma is the prevalence and mortality of asthma among Black and non-Black individuals. In their multilevel study of the contribution of neighborhood social context, Cagney and Browning (2004) found that Black individuals are at a greater risk of vulnerability to having asthma compared to other racial groups. Using the metropolitan Chicago information center metro survey and the project on human development in Chicago neighborhoods community survey, they also found that Latino individuals are at a reduced risk of vulnerability to having asthma. Rosenbaum (2008) used multilevel logistic regression models of the New York city housing and vacancy survey to find Black households were at a 1.57 higher odds of having asthma compared to White households. A cross sectional study of children 5-18 in primary care clinics in Indiana (Saha et al 2005) found asthma prevalence lowest in White girls (14.5%) and highest in Black boys (27.4%). Subramanian et al (2009) found similar results using multilevel models of data from the project on human development in Chicago neighborhoods, with Black children having an increased odds of asthma (1.6) compared to White children. Rhodes et al (2004) examined

2002 BRFSS data from 19 areas with the adult asthma history module. They found that there is a disparate prevalence of overall asthma prevalence by race (Black 9.3%, White 7.6%, and Asian 2.9%). This disparity is even more pronounced for emergency department visits (Black 37.2%, White 14.5%). Asthma mortality ratios follow the same pattern of racial disparities with higher standardized mortality ratios for Black individuals compared to White individuals (3.34 and 0.65, respectively). These ratios were found using the data from the National Center for Health Statistics 1991-1996 among individuals aged 5-34 by Grant et al (2000). Some studies suggest that the effect of race on asthma risk isn't as large in magnitude once income and education are considered. Curtis et al (2012) found that although African American adults were at a higher asthma risk, had poorer asthma control and higher hospitalization rates compared to White participants, these risks were reduced when income and education were taken into consideration.

*Income and Education*

Low income and low education are consistently associated with higher asthma rates, as well as asthma control, and emergency health service use, within the literature. Grant et al. (2000). used multiple regression to find higher standardized mortality ratios for low education individuals compared to high education individuals (1.51 and 0.69, respectively), as well as higher standardized mortality ratios for low income individuals compared to high income individuals (1.46 and 0.71, respectively). Kanervisto et al. (2011) used a population-based cohort study design and multivariate logistic regression to find that low socioeconomic status were both risk factors for asthma among adults aged 30 years and older. Among Rochester, Minnesota learning disability study participants 1976-1979, Juhn et al (2005) found that the relative risk of developing asthma is 2.4 among individuals with mothers with less than a high school education. Logistic regression analyses of 781 patients revealed higher rates of asthma related emergency health services, higher risk for asthma morbidity, specifically related to worse asthma control in individuals with less than 12 years of education (non-high school graduate) (Bacon et al. 2009). Using a community cohort study of 2,819 subjects between 1985-1997, Eagan et al. (2004) found that the incidence of asthma and respiratory symptoms decreased with increasing educational levels (non-high school graduate, high school graduate and college graduate). The higher risk of developing asthma and respiratory symptoms associated with a lower educational level persisted even after adjusting for sex, age, hay fever, smoking and occupational exposure. Hosseinpoor et al. (2012) found that a large portion of asthma inequality risk between men and women can be explained through employment, education and marital status. Using a longitudinal cohort study (Chicago Initiative to Raise Asthma Health Equity – CHIRAH), Curtis et al. (2012) found that race had an effect on asthma outcomes, but this effect was drastically reduced after controlling for the socioeconomic status (income and education) of the participants.

*Sex*

The literature consistently shows that women are more prone to developing asthma, and asthma related issues than men. Several studies point to biological factors of increased prevalence: smaller pulmonary capacity as a contributing factor to asthma (Harms 2006), and reduced lung function associated with hormone levels, regardless of capacity (Real et al. 2008). Support of the effect on hormones in regard to asthma risk among women can be found in the study by Farha et al. (2009). A control-based study of 23 women found that women with asthma experience changes in airflow and gas transfer during menstrual cycles. Incidence rates of adult-onset asthma among females was found to be 1.3 cases/1000 person years compared to 1.0/1000 for males in a 1999 Swedish population-based study (Toren,  & Hermansson 1999). This coincides with findings from Cagney and Browning (2004), showing an increased risk for female householders (1.3). Surprisingly, Juhn et al. (2005) found an increased relative risk of developing asthma among males (2.2) compared to females in a multilevel survival model. The varying results in these studies in asthma risk by sex could possibly be explained by a study by Chen et al (2003). While examining sex differences in hospitalization due to asthma among the Canadian population, the authors found that not only is sex an important determinant for asthma, but the sex effect itself varied over a life span. Hosseinpoor et al. (2012) used data from the World Health Survey 2002-2004 from individuals from 57 countries to find that women's health was significantly lower than men's, including an increased asthma risk. The authors note that a large portion of this inequality between sexes can be explained through employment, education and marital status, reiterating the complexity and multifaceted nature of asthma risk.

***County Level***

*Air Quality*

Air quality (in addition to tobacco smoke, dust mites, mold, cockroach allergens) is a significant asthma trigger. Outdoor air quality is considered poor when high concentrations of ozone ($O_3$), sulfur dioxide ($SO_2$), carbon monoxide (CO), and particulate matter ($PM_{2.5}$, $PM_{10}$) are present. Ambient measurements (ozone (O3), sulfur dioxide (SO2), carbon monoxide (CO), and particulate matter (PM2.5, PM10)) are collected from a network of national, state and local air monitoring stations from the EPA's Air Quality System (AQS) and used to create the Air Quality Index (AQI). AQI will be used as a county level variable in this study. Described below are the four major types of air pollutants that are included in calculating the AQI:

**Ozone ($O_3$) -** Ground-level $O_3$ is a harmful pollutant that is formed when oxides of nitrogen ($NO_x$) and volatile organic compounds (VOCs) react in the presence of sunlight. Pollutants emitted by cars, power plants, industrial boilers, refineries, and chemical plants are major sources of $NO_x$ and VOCs that form $O_3$. Peak $O_3$ levels usually occur during the summer months during hot, dry weather conditions that promote $O_3$ formation. $O_3$ can result in a variety of adverse health effects, even at low levels.

**Sulfur dioxide ($SO_2$) -** $SO_2$ is a colorless, reactive gas produced during the burning of sulfur-containing fuels such as coal and oil (e.g., when gasoline is extracted from oil or metals are extracted from ore). Fuel combustion at electrical and industrial facilities is the major source of $SO_2$ and levels are usually highest near large industrial sources. $SO_2$ dissolves in water vapor to form acid and interacts with other gases and particles in the air to form products that can contribute to respiratory illness, particularly in children and the elderly, and aggravate existing heart and lung diseases.

**Carbon monoxide (CO) -** CO is an odorless, colorless gas that is formed when the carbon in fuels does not completely burn. Vehicle exhaust contributes approximately 60 percent of all CO emissions nationwide and between 85 and 95 percent of emissions in cities. Other sources of CO emissions include fuel combustion in industrial processes and wildfires. CO concentrations typically peak during cold weather because cold temperatures make combustion less complete, and inversions that trap pollutants low to the ground are more frequent. CO can cause harmful health effects by reducing oxygen delivery to the body's organs and tissues. CO is poisonous even to healthy people at high levels in the air; it can also damage the central nervous system and affect people with heart disease.

**Particulate matter ($PM_{2.5}$, $PM_{10}$) -** Dust, dirt, soot, smoke, and liquid droplets found in the air are known as PM. PM may be directly emitted or formed when pollutants react in the atmosphere. Particles less than 2.5 micrometers in diameter ($PM_{2.5}$) are produced during combustion (e.g., in motor vehicles, power plants, wood burning) and industrial processes.

Particles with diameters between 2.5 and 10 micrometers originate from crushing or grinding operations and dust from paved or unpaved roads. PM has been linked to a series of health problems, including aggravated asthma, chronic bronchitis, decreased lung function, and premature death.

The health consequences of air pollution are numerous. High ozone levels are associated with higher incidence and severity of asthma, emergency room visits and hospitalizations, prescription use, absenteeism from school and work. Particulate matter is also associated the previous effects, in addition to increased mortality (Dockery et al. 1993, Goldsmith and Kobzik 1999). Neidell (2004) asserts that the decline in pollution levels during the 1990s decreased asthma rates by between 5% and 14% in California. The author estimates a savings of $5.2 million in hospital asthma admissions in 1998. McCubbin and Delucchi (1995) estimated in 1991 alone 852 million headaches, 20,000-46,000 cases of chronic respiratory illness and 40,000 premature deaths resulted from motor vehicle pollution. Exposure to ambient air pollution increased the risk of emergency department visits for asthma according to Szyszkowicz and Kousha (2014). Li & Lin (2014) explored the association between ozone and PM2.5 exposure and asthma risk using the BRFSS through multilevel logistic regressions. They found that ambient air pollution increased asthma risk, but the risk varied depending on the population density of the respondent – urban areas were considered high risk. Gilmour et al. (2006) reviewed five studies, showing an increase in asthma risk in relation to air pollution, but they highlight the methodological difficulty in distinguishing selection or causation (new incidence of asthma) in asthma risk. Guarnieri and Balmes' (2014) review of epidemiological and experimental studies from 2009-2014 underscore the evidence of air pollution on increasing asthma risk, but reiterate the lack of understanding of the complexities and methodological difficulties of selection versus causation of new-onset asthma risk, especially at larger grained geography levels. Jacquemin et al. (2015) points to the need for personal-level exposure (versus residential exposure) studies in their longitudinal analysis. They found that asthma incidence was positively, but not significantly associated with air pollution.

*Urban, Vacant, Education and Poverty*

Asthma mortality rates were significantly higher for Black individuals than White individuals in different population densities (urban/rural), suggesting that living in cities may affect the amount that race matters regarding the risk of asthma mortality (Lebak 2007). Similarly, using the National Health Interview Survey, an increased asthma risk was found among children living in urban settings (Aligne et al. 2000), largely due to indoor allergens and outdoor pollution exposure. The stepwise logistic regression suggested that urban residence was strongly associated with asthma risk, reducing the effect of race. Yemaneberhan et al. (1997) compared rates of asthma symptoms in Ethiopia and found that respiratory symptoms were significantly less common in the rural than urban group. Similar findings were presented by Juhn et al. (2005), showing an increased relative risk of developing asthma among children living in census tracts facing intersections with highways or railroads compared to those who lived in census tracts not facing intersections. O'Connor et al. (2008) had similar findings in seven urban communities. They found that poor air quality was associated with significantly lower pulmonary function and asthma related missed school days and asthma symptoms in children. Li & Lin (2014) explored the association between ozone and PM2.5 exposure and asthma risk using the BRFSS through multilevel logistic regressions. They found that ambient air pollution increased asthma risk, but the risk varied depending on the population density of the respondent. That is, urban areas were considered high risk. O'Conner et al (2008) found short-term increases in air pollutant concentrations below the National Ambient Air Quality Standards (NAAQS) were associated with poor respiratory health effects among inner-city children. Higher concentrations of pollutants were associated with asthma-related missed school days and asthma symptoms in their study of 861 children over a 2 year period. Using multilevel survival models, Juhn et al. (2005) found that there is an increased relative risk of developing asthma if an individual lived in a census tract facing intersections with highways/rail ways (1.6), compared to less congested areas. A retrospective cohort study in 29 states using individual and county-level factors by Baltrus et al. 2016 found percent children living in poverty (county level), as well as county level racial segregation to be predictive of asthma emergency department visits in individual models, but not in the final model. In a hierarchical multivariate model, Trupin et al (2010) environmental factors such as air quality and urban/built environment were associated with poor lung function. Li & Newcomb (2009) use a finer grain scale, census block groups, to examine contextual effects of asthma hospitalizations using logistic models. Asthma hospitalizations were associated with poor neighborhoods (low education, poverty, low median housing value), but not all contextual factors remained significant in all models.

***Environmental Risk and Health***

Black individuals, low education level individuals and low-income households endure a greater portion of the pollution burden compared to non-Hispanic White individuals, higher education level individuals and higher-income households (Evans and Kantrowitz 2002). Disparities in disease risk have persisted along social and disproportionate environmental lines despite increases in population health. The disproportionate exposure to environmental risk factors due to individual social characteristics points to the need for policy implementation that provides the right to a safe, healthy and sustainable environment. More specifically, policy should acknowledge key players who affect the built and natural environment, as well as those in the community who are affected by changes to the built and natural environment. One effective way of doing so is using an environmental justice framework, which includes the following (Gray et al. 2013, Rainey-Brown & Johnson, 2011):

1. The right of all people to be protected from environmental degradation.
2. Adopts the public health model of prevention
3. Environmental Justice uses the effect test as opposed to the intent test when determining injustice inferring discrimination
4. Places the burden of proof on the polluters
5. Redresses disproportionate impact through target actions and resources

The following section describes the relationship between the disproportionate exposure to environmental risk factors due to individual and household characteristics and various negative disease outcomes, including asthma.

*Hazardous Toxins*

Black individuals and low income individuals are more likely to be exposed to toxic wastes compared to White individuals and higher income individuals (Institute of Medicine 1999 & White 1998). Pirkle et al. (1994) found that urban residents and low income individuals are more likely to have elevated blood lead levels compared to rural / suburban and higher income counterparts. The previously discussed disproportionate hazardous toxins are associated with several negative health effects. Hazardous toxins are associated with an increased risk for various cancers, respiratory issues, and neurological issues (Scott 1990). Even at low levels, toxin exposure in pregnant mothers is associated with impulse control issues and aggression, as well as poor academic achievement in offspring (Riley & Vorhees 1991).

*Air Pollution*

Both indoor and outdoor air pollution contribute to negative health effects in individuals. The World Bank (1992) compared the differences in city air pollution among low, middle and wealthy income countries from 1970-1990. They found suspended particulate matter increased in low income countries, and the levels were above healthy respiratory limits. During the same time period suspended particulate matter decreased in middle income countries, and decreased to even lower levels in wealthy income countries. The National Center for Health Statistics (1991) found that the majority of preschool children living in poverty in the United States have been exposed to cigarette smoke at home, compared to children not living in poverty. Low income mothers are more likely to smoke and less likely to quite compared to higher-income mothers (Groner et al. 1998). Mothers who did not graduate from high school are more likely to smoke during pregnancy compared to mothers who have a high school diploma. Women with college degrees have the lowest risk for smoking during pregnancy (National Center for Health Statistics 1998). Nitrogen Dioxide and Carbon Monoxide were found in much higher levels among low-income, urban households compared to higher income households according to Goldstein et al. (1988) and Schwab (1990). The previously discussed disproportionate air quality risks are associated with several negative health effects. Holgate et al. (1999) discuss the links between ambient pollutants lung cancer and respiratory infections, exposure to Carbon Monoxide and heart disease. The Institute of Medicine (2000) published similar findings, also including environmental indoor cigarette smoking.

*Neighborhood quality*

Poor neighborhoods are disproportionately at risk for numerous environmental risks. Low income areas are more likely to have inadequate municipal services and high levels of residential mobility due to lack of homeownership (Leventhal & Brooks-Gunn 2000). Spencer et al. (1997) found that low socioeconomic status was associated with increased neighborhood traffic, pollution, noise and lack of green space. Low income households were also associated with higher rates of exposure to crime and aggression (Sampson et al. 1997). The previously discussed disproportionate neighborhood quality risks are associated with several negative health effects. Leventhal & Brooks-Gunn (2000) discuss the effect of low socioeconomic status neighborhoods on poor academic readiness, aggressive behaviors and an increased risk for early sexual activity on children and teens. Low socioeconomic status neighborhoods are also associated with an increased risk for heart disease, injury mortality all-cause mortality (Davey Smith et al. 1998).

***Literature Gaps***

This paper serves to fill several gaps in the asthma and air quality literature. Numerous other asthma studies focus on children, specific asthma related issues (such as emergency room visits), lack air quality data, or only focus on indoor pollutants, and focus on only one specific geographic area. This study is different, as it focuses on adults, overall asthma risk, is comprised of a national sample, highlights methodological issues while studying asthma, but most importantly – examines group differences by sex, race, education and income. In the following chapter I outline the three data sources utilized, details about the variables used, the statistical approach employed, descriptive statistics and human subjects details.

# CHAPTER 3 - METHODS

## ***Data Source***

This paper utilized data from three sources: the 2011 Behavioral Risk Factor Surveillance System (BRFSS), the 2010 United States Census Summary File 1 (Census), and the 2010 Air Quality System (AQS). Descriptions of the data sets and the level of data they contribute can be found below.

### *Level 1 Data (Individual Level)*

Data on asthma and the individual covariates is from the 2011 BRFSS. The BRFSS is a telephone-based (land-line and cellular) survey initiated by the CDC for the first time in 1984. It is a collection of state health surveys of the non-institutionalized adult population age 18 years and older living in households in all 50 states. The objective of the BRFSS is to collect uniform data on preventative and risk behaviors linked to disease. A new post stratification weighting method was introduced in 2011 (iterative proportional fitting) to adjust the data so that underrepresented groups can be accurately represented in the final data set. Specifically, this method helps reduce nonresponse bias and reduce error within estimates. This weighting method has been taken into account during data analysis for this project (see SVY in the Statistical Approach section below for additional details).

### *Level 2 Data (County Level)*

County level data was obtained from the 2010 U.S. Census Summary File 1. Air quality data is from the EPA's Air Quality System (AQS) database from 2010. Ambient measurements (ozone (O3), sulfur dioxide (SO2), carbon monoxide (CO), and particulate matter (PM2.5, PM10)) are collected from a network of national, state and local air monitoring stations and used to create the Air Quality Index (AQI). Generally, an index value of 100 is equal to the primary, or health based, National Ambient Air Quality Standards (NAAQS) for each pollutant. This allows for a direct comparison of each of the pollutants used. Metropolitan Statistical Areas (MSAs) with a population of more than 350,000 are required to report the AQI daily (defined as at least five days a week to allow for personnel/equipment failures). Smaller population areas may also voluntarily report the daily AQI. The required reporting criteria include: the reporting area and period, the critical pollutant, the AQI, the category and sensitive groups. Additional voluntary reporting criteria may include: forecast/current AQI, Health effects, possible causes of AQI, sub area reporting, pollutant concentrations, and additional pollutants. The AQI approximates the level of pollution at the county level. Individuals within a county may have substantially higher or lower pollution exposures due to a number of factors, including variations in individual activity patterns and physical location within a county. Monitors record concentrations of the previously listed pollutants each day. These raw measurements are converted into separate AQI values for each pollutant using standardized formulas.

For example, the daily ozone AQI is calculated by taking the maximum 8 hour concentration from 07:00-23:00 LST, and then converting to AQI. Each 8-hour average concentration is truncated to .001ppm/1ppb. There are 17 8-hour averages considered in each day. Each 8-hour average requires 6 of 8 hours (75%) for a valid calculation. In addition, 75% or 13/17 of the 8-hour averages are needed for a valid daily ozone AQI calculation. The current formulas for calculating AQI for each pollutant can be found at EPA.gov. The highest of these AQI values is reported as the AQI value for that day. The Quality standards are evaluated and if necessary, revised each year. AQI is typically higher in larger cities compared to smaller cities. In general, AQI values are usually below 100. AQI greater than 200 are not frequent and rare over 300. AQI values can vary depending on the weather and the time of day. For example, in colder climates CO may be high because of ineffective car emissions, or CO may peak during rush hour (For additional information see EPA.gov: EPA 2010 & 2014 Air Quality Index: A guide to air quality and your health).

The AQI has a scale of 0 to 500 and is broken down into six groups:

| | | |
|---|---|---|
| 0-50 | Good | No health effects for the general population. |
| 51–100 | Moderate | Few or no health effects for the general population. |
| 101–150 | Unhealthy for Sensitive Groups | Some health effects may be experienced by sensitive people (e.g., children and adults who are active outdoors or have respiratory disease). |
| 151–200 | Unhealthy | Mild health effects among susceptible people, with irritation symptoms in the healthy population. |
| 201–300 | Very Unhealthy | Significant health effect symptoms and decreased exercise tolerance in persons with heart or lung disease; widespread symptoms in the healthy population. |
| 301–500 | Hazardous | Early onset of health effects for certain diseases in addition to significant aggravation of symptoms and decreased exercise tolerance in healthy persons. At AQI levels above 400, premature death of ill and elderly persons may occur. Healthy people experience adverse symptoms that affect normal activity. |

Individual level respondents were matched to federal information processing standards (FIPS) state/county codes within the census and AQS data sets. A state/county location code was created for each respondent by combining the two digit state FIPS code ('What state do you live in?) from the BRFSS and the three digit county code ('What county do you live in?) form the BRFSS to create a five digit state/county location code.

***Variables***

Variables from the BRFSS are described as level 1, indicating individual level variables. Variables from the Census or AQS are described as level 2, indicating county level variables.

*Dependent Variable – Level 1 (BRFSS)*

Currently Has Asthma - Individual level adult asthma status (dichotomous) is measured using the answer to, "did a doctor ever tell you that you had asthma?" and the follow up question, "do you still have asthma?" from the BRFSS 2011. For this study, the respondent was coded 1 for currently having asthma if the respondent answered 'yes' to both of the previous questions. Additional asthma BRFSS questionnaire variable options included:

-During the past 12 months, have you had an episode of asthma or an asthma attack? [asattack]

-During the past 12 months, how many times did you visit an emergency room or urgent care center because of your asthma? [aservist]

-During the past 12 months, how many times did you see a doctor, nurse or other health professional for urgent treatment of worsening asthma symptoms? [asdrvist]

-During the past 12 months, how many times did you see a doctor, nurse, or other health professional for a routine checkup for your asthma? [asrchkup]

-During the past 12 months, how many days were you unable to work or carry out your usual activities because of your asthma? [asactlim]

-Symptoms of asthma include cough, wheezing, shortness of breath, chest tightness and phlegm production when you don´t have a cold or respiratory infection. During the past 30 days, how often did you have any symptoms of asthma? [asymptom]

-During the past 30 days, how many days did symptoms of asthma make it difficult for you to stay asleep? [asnoslep]

-During the past 30 days, how many days did you take a prescription asthma medication to PREVENT an asthma attack from occurring? [asthmed3]

-During the past 30 days, how often did you use a prescription asthma inhaler DURING AN ASTHMA ATTACK to stop it? [asinhalr]

Currently has asthma was chosen as the dependent variable based on the abundant response rate in comparison to the other asthma questionnaire options. "Ever told…" had a post data cleansing response total of 35,483, and "Still have…" had a post data cleansing response total of 24,498, while the additional asthma questionnaire responses each totaled less than 300 responses.

*Independent Variables - Level 1 (BRFSS)*

Health Plan – Individual level health plan status (dichotomous) is measured using the answer to, "Do you have any kind of health care coverage, including health insurance, prepaid plans such as HMOs, or government plans such as Medicare, or Indian Health Service?". For this study, the respondent was coded 1 if the respondent answered 'yes' to the previous question.

Race – Individual level race (dichotomous) is measured using the respondent's self-identified race. The respondent could choose, 'White', 'Black or African American', 'Asian', 'Native Hawaiian or Other Pacific Islander', American Indian, Alaska Native', 'Other', 'Multiracial', 'I don't know/refused' when asked "Which of these groups would you say best represents your race?". This variable was reduced to a dichotomous variable, coded 1 for Black or African American (Black), and coded 0 for 'White', 'Asian', 'Native Hawaiian or Other Pacific Islander', American Indian, Alaska Native', 'Other', or 'Multiracial' (non-Black).

Smoking Behavior – Individual level smoking behavior (dichotomous) is measured using the answer to, "Have you smoked at least 100 cigarettes in your entire life", and the follow up question, "Do you now smoke cigarettes every day, some days, or not at all?". For this study, the respondent was coded 1 for smoking if the respondent answered 'yes' to smoking at least 100 cigarettes and either smoke every day or some days.

Sex – Individual level sex (dichotomous) is measured using the respondent's answer to, "Indicate sex of respondent". The variable is coded 0 for 'female', and 1 for 'male' in this study.

Education – Individual level race (categorical) is measured using the respondent's answer to, "What is the highest grade or year of school you completed?". The options included: 'Never attended school or only kindergarten', 'Grades 1 through 8 (Elementary)', 'Grades 9 through 11 (Some high school)', 'Grade 12 or GED (High school graduate)', 'College 1 year to 3 years (Some college or technical school)', 'College 4 years or more (College graduate)', 'refused'. This variable was reduced to a combined categorical variable coded 1 for 'Never attended school or only kindergarten', 'Grades 1 through 8 (Elementary)', and 'Grades 9 through 11 (Some high school)' [no high school diploma], coded 2 for 'Grade 12 or GED (High school graduate)' [high school diploma], coded 3 for 'College 1 year to 3 years (Some college or technical school)' [some college], and coded 4 for 'College 4 years or more (College graduate)' [college graduate]. No high school diploma (coded 1) is used as the reference group.

Income – Individual level income (categorical) is measured using the respondent's answer to, "Is your annual household income from all sources (in US dollars): (interviewer lists income categories)". The options included: coded 1 'Less than $10,000', coded 2 '$10,000-$14,999', coded 3 '$15,000-$19,999', coded 4 '$20,000-24,999', coded 5 '$25,000-$34,999', coded 6 '$35,000-$49,999', coded 7 '$50,000-$74,999', and coded 8 '$75,000+'. The categories have not been changed for this study. Less than $10,000 (coded 1) is used as the reference group.

Age – Age is measured in years (continuous) using the response to, "What is your age?".

StateCounty – A state/county location code was created for each respondent by combining the two digit state FIPS code ('What state do you live in?) from the BRFSS and the three digit county code ('What county do you live in?) form the BRFSS to create a five digit state/county location code.

*Independent Variable - Level 2 (AQS)*

Median Air Quality Index – County level Air quality (continuous) is measured using the median AQI, or half of daily AQI values during the year were less than or equal to the median value, and half equaled or exceeded it. Additional AQI variables were considered:

| | |
|---|---|
| Good AQI | Number of days in the year having an AQI value 0 through 50 |
| Moderate AQI | Number of days in the year having and AQI value 51 through 100 |
| Unhealthy for Sensitive Groups AQI | Number of days in the year having an AQI value 101 through 150 |
| Unhealthy AQI | Number of days in the year having an AQI value 151 through 200 |
| Very Unhealthy AQI | Number of days in the year having an AQI value 201 or higher |
| AQI maximum | The highest daily AQI value in the year |
| Unhealthy for Sensitive Groups AQI percent | Percent of days having an AQI 101-150 (uhsg/totalnumdays)*100 |
| Unhealthy AQI percent | Percent of days having an AQI 151-200 (uh/totalnumdays)*100 |

| | |
|---|---|
| Very unhealthy AQI percent | Percent of days having an AQI 200+ (vuh/totalnumdays)*100 |
| Good AQI percent | Percent of days having an AQI 0-50 (good/totalnumdays)*100 |
| Moderate AQI percent | Percent of days having an AQI 51-100 (mod/totalnumdays)*100 |

Good AQI, moderate AQI, unhealthy for sensitive groups AQI, unhealthy AQI and very unhealthy AQI were not used as variables because the total days monitored for each were not included in the data set. AQI maximum was not used as a variable because the values were consistently high (above 300), which is rare for AQI measurements. Unhealthy for sensitive groups AQI percent, unhealthy AQI percent and very unhealthy AQI percent were not used as variables because a limited number of counties were included in the data set (597, 96, and 10, respectively). The variable to be included in this study was narrowed down to: good AQI percent, moderate AQI percent and median AQI. Median AQI was chosen based on the high number of counties included (956), but a logistic regression variable comparison check was made to determine if a different AQI variable would have made a significant difference in model results. These results are discussed in chapter 4 under robustness tests.

*Independent Variables - Level 2 (Census)*

Proportion Urban – County level proportion urban (continuous) is the share of the county that is designated urban (non-rural), as a proportion.

Proportion Vacant – County level proportion vacant (continuous) is the share of the county housing that is designated vacant (non-owner occupied, non-renter occupied), as a proportion.

Proportion Educated – County level proportion educated (continuous) is the share of persons 25 years of age and older with a bachelor’s degree or higher, as a proportion.

Proportion in Poverty – County level proportion in poverty (continuous) is the share of people of all ages in poverty, as a proportion.

***Statistical Approach***

*Data Screening and Approach*

The statistical software STATA, version 13.1 was used for all data screening and analysis for this study. The production of frequency distributions, mean, minimum, maximum and standard deviation for each dependent and independent variable have been created (See Chapter 4). Missing data was examined for patterns using dummy coding for the variable(s) in question and also running an independent samples *t*-test to determine if there are significant mean differences between the two groups. There was not a significant difference between the groups, thus missing values were not included in the analysis. Possible outliers were examined through a box plot of the data. If outliers were detected, subsequent analyses occurred, both including and excluding the outliers to determine the influence of such outliers. If no differences were found, they remained remain in the dataset. If differences were found, those cases were deleted. Three counties were removed because of Maximum AQI outliers: Inyo, CA #6027 (19 observations), Mono, CA #6051 (8 observations), and Pinal, AZ #4021 (433 observations). One county was removed because of extreme (right) skew: Hawaii, HI #15001 (1289 observations) median AQI=200. Comparisons of including and not including Hawaii in the full sample can be found in chapter 4 under robustness checks.

Skewness and kurtosis were also calculated for each non categorical variable to assess normality. If the values for skewness and kurtosis were close to zero, and if the null hypothesis of the Kolmogorov-Smirnov statistic was not rejected, normality is assumed and no transformations are necessary. No transformations were made. Linearity was tested by examination of residuals plots. If standardized residual values are plotted against the predicted values and values cluster around the zero line, linearity is assumed. If the values created a curved pattern, the variable is nonlinear and transformations may be necessary. No transformations were made. Homogeneity of variances was assessed using Levene's test. Failure to reject the null hypothesis assumes equal variances. No small or empty cells were found upon examining crosstabulations. Bivariate analyses, as well as posttest VIFs were examined to test multicolliniearity. This step was also used to test each of the independent variables against the depending variables to confirm inclusion in regression models. No variables were removed due to high VIFs.

The clustering of individuals within counties, and the binary dependent variable suggests the need for logistic regression analysis with clustered standard errors, or a multilevel analysis. While there may be some advantages of utilizing multilevel analysis when data clustering is present (compared to using clustered standard errors), these advantages diminish when the number of clusters is large. Due to the scope of this project, multilevel analysis was not utilized (Guo and Zhao 2000, Primo et al. 2007).

Due to the nature of the data of the BRFSS, the individual (level 1) variables were weighted. In STATA, a SVY set was created to allow for variable weights. This weighting methodology (iterative proportional fitting, also known as raking) helps adjust the data to allow for more accurate representation of underrepresented groups, as well as the incorporation of cell phone data and non-telephone coverage. 2011 was the first year the BRFSS began using raking to weight the survey data. This weighting method adjusts the sampling weights of the sample data based on known population characteristics. Prior to 2011, post stratification was used. This adjusted non-coverage and nonresponse rates, but limited the demographic variables that were adjusted. The weighting methodology was updated to allow for more demographic variables as well as reducing the potential for bias and increasing the representativeness of estimates. Age, sex, categories of ethnicity, geographic regions within states, marital status, education level, home ownership and type of phone ownership are currently used to weight BRFSS data. To achieve this weighting method, the population distribution of previously listed set of variables (age, sex, etc.) are used to adjust the weight for each case until the sample distribution fits with the population. The CDC, Pew Research Center and several other organizations commonly use this method of weighting. Comparisons of the weighted and unweighted models can be found in chapter 4 under robustness checks.

Several types of statistical analyses were employed for the purpose of hypothesis testing in this study. Logistic regression comparisons and linear regression were utilized for variable inclusion, county inclusion, and sampling methodology robustness checks. The examination of median AQI quartiles by group, t-tests, and confidence intervals served to address differential exposure, while logistic regression (coefficients) was performed to address differential sensitivity. Several multivariate logistic models were used: The first analysis included sex, race, education and income in the overall model to determine overall associations. Next, the data set was stratified by men/women, Black/non-Black, non-college/college graduates, and low income/high income. Examining AQI quartile group differences, t-tests, confidence intervals and full sample logistic regression will be used to address the first five research questions, which address differential exposure to air quality: 1) What is the difference in exposure of the median AQI by race, controlling for county and individual effects? 2) What is the difference in exposure of the median AQI by sex, controlling for county and individual effects? 3) What is the difference in exposure of the median AQI by education, controlling for county and individual effects? 4) What is the difference in exposure of the median AQI by income, controlling for county and individual effects? 5) Is the variation in asthma prevalence associated with county level median air quality? As individual health sensitivity data is not available directly, examining the results from the stratified logistic regression will be used to address the fifth and sixth research questions, which address differential sensitivity to air quality: 5) Is the variation in asthma prevalence associated with county level median air quality? 6) Does the relationship between asthma prevalence and county level air quality vary by race, sex, education or income?

***Descriptive Statistics***

**Table 1 Categorical Descriptive Statistics**

| Categorical Variable | Coded | Frequency (Total 270,964 individuals) | Percent (100% cumulative) |
|---|---|---|---|
| Asthma | Yes | 25,358 | 9.36 |
| | No | 245,606 | 90.64 |
| Respondent has ever and still has asthma | | | |
| Health Plan | Yes | 242,192 | 89.38 |
| | No | 28,772 | 10.62 |
| Respondent has a health plan (“Do you have any kind of health care coverage, including health insurance, prepaid plans such as HMOs, or government plans such as Medicare, or Indian Health Service?”) | | | |
| Race | Black | 24,685 | 9.11 |
| | Non-Black | 246,279 | 90.89 |
| Respondent’s self-identified race | | | |
| Smoke | Yes | 45,659 | 16.85 |
| | No | 225,305 | 83.15 |
| Respondent smokes some days or everyday | | | |
| Sex | Male | 112,732 | 41.60 |
| | Female | 158,232 | 58.40 |
| Respondent’s sex | | | |
| Education | 1 | 18,607 | 6.87 |
| | 2 | 71,769 | 26.49 |
| | 3 | 74,505 | 27.50 |
| | 4 | 106,083 | 39.15 |
| Respondent’s level of education (1(reference)=No High School Diploma, 2=High School Diploma, 3=Some College, 4=College Graduate) | | | |
| Income | 1 | 14,309 | 5.28 |
| | 2 | 16,019 | 5.91 |
| | 3 | 20,328 | 7.50 |
| | 4 | 25,499 | 9.41 |
| | 5 | 30,958 | 11.43 |
| | 6 | 39,452 | 14.56 |
| | 7 | 43,565 | 16.08 |
| | 8 | 80,834 | 29.83 |
| Respondent’s annual household income in US Dollars (1(reference)=Less than $10,000, 2=$10,000-$14,999, 3=$15,000-$19,999, 4=$20,000-24,999, 5=$25,000-$34,999, 6=$35,000-$49,999, 7=$50,000-$74,999, 8=$75,000+) | | | |

**Table 2 Continuous Descriptive Statistics**

| Continuous Variable | Observations | Mean | Std. Deviation | Minimum | Maximum | Skew | Kurtosis |
|---|---|---|---|---|---|---|---|
| Age | 270,964 | 54.53 | 16.75 | 18 | 99 | -0.09 | 2.32 |
| Respondent's age in years | | | | | | | |
| Median AQI | 270,964 | 40.24 | 10.86 | 1 | 81 | 0.14 | 4.64 |
| (Collapsed by county) | 956 | 37.53 | 10.10 | 1 | 81 | -0.54 | 4.36 |
| Half of daily AQI values during the year were less than or equal to the median value, and half equaled or exceeded it. | | | | | | | |
| Urban | 270,964 | 0.72 | 0.34 | 0 | 1 | -1.29 | 3.14 |
| (Collapsed by county) | 956 | 0.48 | 0.40 | 0 | 1 | -0.16 | 1.30 |
| Share of the county that is designated urban (non-rural) as a proportion | | | | | | | |
| Vacant | 270,964 | 0.11 | 0.07 | 0.04 | 0.62 | 2.77 | 12.69 |
| (Collapsed by county) | 956 | 0.13 | 0.08 | 0.04 | 0.62 | 2.50 | 10.69 |
| Share of the county housing that is designated vacant (non-owner occupied, non-renter occupied) as a proportion | | | | | | | |
| Educated | 270,964 | 0.29 | 0.10 | 0.07 | 0.69 | 0.50 | 2.95 |
| (Collapsed by county) | 956 | 0.24 | 0.10 | 0.07 | 0.69 | 1.04 | 4.20 |
| Share of persons 25 years of age and older with a bachelor's degree of higher as a proportion | | | | | | | |
| Poverty | 270,964 | 0.14 | 0.05 | 0.03 | 0.36 | 0.64 | 4.08 |
| (Collapsed by county) | 956 | 0.15 | 0.05 | 0.03 | 0.36 | 0.71 | 4.16 |
| Share of people all ages in poverty as a proportion | | | | | | | |

The final sample of BRFSS individuals consisted of 270,964 respondents (see table 1). Nine percent of the respondents included in the final sample currently have asthma, and have a mean age of 55 years old (see table 1). The majority of individuals have a health plan (89%), and are female (58%). Nine percent of the sample population is Black, and 39% are college graduates. Less than a quarter of the sample are smokers (17%), and 30% have an annual household income of $75,000 or greater. The final Census sample of counties consisted of 956 counties (see table 2). The average median AQI is 38, which is considered 'good'. The average proportion urban is 48%, 13% proportion vacant, 24% proportion educated and 15% proportion in poverty.

**Table 3 Median AQI Quartiles (Individual Level and County Level)**

| Respondent | Freq. | Percent | Cum. |
|---|---|---|---|
| 1 | 77,075 | 28.44 | 28.44 |
| 2 | 70,276 | 25.94 | 54.38 |
| 3 | 61,557 | 22.72 | 77.10 |
| 4 | 62,056 | 22.90 | 100.00 |
| Total | 270,964 | 100.00 | |
| County | Freq. | Percent | Cum. |
| 1 | 239 | 25.00 | 25.00 |
| 2 | 259 | 27.09 | 52.09 |
| 3 | 248 | 25.94 | 78.03 |
| 4 | 210 | 21.97 | 100.00 |
| Total | 956 | 100.00 | |

To begin to examine the differences in exposure of the median AQI by race, sex, education, and income, median AQI was broken up into quartiles (see Table 3). Quartile 1 consisted of median AQIs from 1-35, quartile 2 consisted of median AQIs from 36-40, quartile 3 consisted of median AQIs from 41-46, and quartile 4 consisted of median AQIs from 47-81. Quartiles 1-3 were comprised of 'good' AQI, and quartile 4 consists of AQIs considered 'sensitive' by the EPA. The majority of the respondents are in quartile 1, and the majority of counties are in quartile 2. Although the variables were chosen based on the available data and (see robustness checks in chapter 4), there are several shortcomings to using some of these variables. Currently having asthma does not have a longitudinal basis, such as date of onset, and only comprises 9% of the sample. Measuring AQI is difficult considering the location and amount of monitoring stations are not consistent within each county. Monitoring stations may or may not be near areas of high pollution and lower median AQIs could be a result. Using county level data could also be an issue in assuming any type of exposure, particularly in the west/southwest, where counties are extremely large. Finally, the overall county level AQI distribution is skewed, with very few counties having fair/poor median AQI.

***Human Subjects***

This dissertation research is exempt from review by the Human Investigation Committee at Wayne State University under Exemption Category 4 as detailed on the Division of Research website at Wayne State University as:

> *Research involving the collection or study of existing data, documents, records, pathological specimens, or diagnostic specimens, if these sources are publicly available or if the information is recorded by the investigator in such a manner that subjects cannot be identified, directly or through identifiers linked to the subjects.* ***To qualify for this exemption the data, documents, records, or specimens must be in existence before the project begins.***

The data used in this study existed before the project began, and all data is de-identified. Concurrence of exemption by the Human Investigation Committee at Wayne State University occurred on December 21, 2016. IRB#122416B3X Protocol# 1612000139.

In the following chapter I complete an overview of the analysis, state the six alternative hypotheses, provide AQI quartiles by groups, t-tests, confidence intervals, logistic regression (coefficient) results, and robustness checks, summarize the hypothesis tests results and discuss caveats.

# CHAPTER 4 - ANALYSIS

In this chapter, I examine the following specific questions: 1) What is the difference in exposure of the median AQI by race, controlling for county and individual effects? 2) What is the difference in exposure of the median AQI by sex, controlling for county and individual effects? 3) What is the difference in exposure of the median AQI by education, controlling for county and individual effects? 4) What is the difference in exposure of the median AQI by income, controlling for county and individual effects? 5) Is the variation in asthma prevalence associated with county level median air quality? 6) Does the relationship between asthma prevalence and county level air quality vary by race, sex, education or income?

Sex, race, income, education and environment (air quality) related to asthma have been chosen as dimensions of inequality to be operationalized based on health inequality and environmental justice literature (Andersen et al. 2002, Toren and Hermansson 1999, Thomson et al. 2004, Cagney and Browning 2004, Curtis et al. 2012, Li and Newcomb 2009, Li and Lin 2014). Three sources of data were used: the Behavioral Risk Factor Surveillance System 2011 (BRFSS), EPA's Air Quality System (AQS) database 2010, and the 2010 US Census.

As discussed in chapter three, to examine the association of social-spatial inequalities and adult asthma risk, several types of statistical analyses were employed for the purpose of hypothesis testing. Logistic regression comparisons and linear regression were utilized for variable inclusion, county inclusion, and sampling methodology robustness checks. The examination of median AQI quartiles by group, t-tests, and confidence intervals served to address differential exposure, while logistic regression (coefficients) was performed to address differential sensitivity. Several multivariate logistic models were used: The first analysis included sex, race, education and income in the overall model to determine overall associations.

Next, the data set was stratified by men/women, Black/non-Black, non-college/college graduates, and low income/high income.

***Hypotheses***

$H_{a1}$: Black individuals have a higher median AQI exposure level compared to non-black individuals

$H_{a2}$: Females have a higher median AQI exposure level compared to males

$H_{a3}$: Non-College graduates have a higher median AQI exposure level compared to College graduates

$H_{a4}$: Low annual household income individuals have a higher median AQI exposure level compared to high annual household income individuals

$H_{a5}$: Asthma prevalence will be positively associated with median AQI

$H_{a6}$: Differential sensitivity will not found by race, sex, education or income

All individual and county level variables are controlled in hypothesis testing.

***Results***

*AQI Quartiles*

**Table 4 Median AQI Quartiles by Sex**

| | Female | Male | Total |
|---|---|---|---|
| 1 | 44,495 | 32,580 | 77,075 |
| 2 | 40,729 | 29,547 | 70,276 |
| 3 | 36,197 | 25,360 | 61,557 |
| 4 | 36,811 | 25,245 | 62,056 |
| Total | 158,232 | 112,732 | 270,964 |
| Females | Freq. | Percent | Cum. |
| 1 | 44,495 | 28.12 | 28.12 |
| 2 | 40,729 | 25.74 | 53.86 |
| 3 | 36,197 | 22.88 | 76.74 |
| 4 | 36,811 | 23.26 | 100.00 |
| Total | 158,232 | 100.00 | |
| Males | Freq. | Percent | Cum. |
| 1 | 32,580 | 28.90 | 28.90 |
| 2 | 29,547 | 26.21 | 55.11 |
| 3 | 25,360 | 22.50 | 77.61 |
| 4 | 25,245 | 22.39 | 100.00 |
| Total | 112,732 | 100.00 | |

As previously discussed in chapter three, median AQI was broken up into quartiles (see Table 3). This serves to examine differential exposure of AQI. To recap: Quartile 1 consisted of median AQIs from 1-35, quartile 2 consisted of median AQIs from 36-40, quartile 3 consisted of median AQIs from 41-46, and quartile 4 consisted of median AQIs from 47-81. Quartiles 1-3 were comprised of 'good' AQI, and quartile 4 consists of AQIs considered 'sensitive' by the EPA. The majority of the respondents are in quartile 1, and the majority of counties are in quartile 2. The largest percentage of women and men reside in the first quartile (see Table 4).

**Table 5 Median AQI Quartiles by Race**

| | Non-black | black | Total |
|---|---|---|---|
| 1 | 74,814 | 2,261 | 77,075 |
| 2 | 65,287 | 4,989 | 70,276 |
| 3 | 54,859 | 6,698 | 61,557 |
| 4 | 51,319 | 10,737 | 62,056 |
| Total | 246,279 | 24,685 | 270,964 |
| Non-black | Freq. | Percent | Cum. |
| 1 | 74,814 | 30.38 | 30.38 |
| 2 | 65,287 | 26.51 | 56.89 |
| 3 | 54,859 | 22.28 | 79.16 |
| 4 | 51,319 | 20.84 | 100.00 |
| Total | 246,279 | 100.00 | |
| Black | Freq. | Percent | Cum. |
| 1 | 2,261 | 9.16 | 9.16 |
| 2 | 4,989 | 20.21 | 29.37 |
| 3 | 6,698 | 27.13 | 56.50 |
| 4 | 10,737 | 43.50 | 100.00 |
| Total | 24,685 | 100.00 | |

**Table 6 Median AQI Quartiles by Education**

| | College | Non-College | Total |
|---|---|---|---|
| 1 | 29,776 | 47,299 | 77,075 |
| 2 | 28,260 | 42,016 | 70,276 |
| 3 | 23,694 | 37,863 | 61,557 |
| 4 | 24,353 | 37,703 | 62,056 |
| Total | 106,083 | 164,881 | 270,964 |
| College Graduate | Freq. | Percent | Cum. |
| 1 | 29,776 | 28.07 | 28.07 |
| 2 | 28,260 | 26.64 | 54.71 |
| 3 | 23,694 | 22.34 | 77.04 |
| 4 | 24,353 | 22.96 | 100.00 |
| Total | 106,083 | 100.00 | |
| Non-College Graduate | Freq. | Percent | Cum. |
| 1 | 47,299 | 28.69 | 28.69 |
| 2 | 42,016 | 25.48 | 54.17 |
| 3 | 37,863 | 22.96 | 77.13 |
| 4 | 37,703 | 22.87 | 100.00 |
| Total | 164,881 | 100.00 | |

The most striking difference in exposure between groups is between black respondents and non-black respondents (see Table 5). The largest percentage of non-black respondents reside in the first quartile, while the largest percentage of black respondents reside in the fourth (worst air quality) quartile. The largest percentage of college educated and non-college educated respondents reside in the first quartile (see Table 6).

**Table 7 Median AQI Quartiles by Annual Household Income**

| | <50k | 50k+ | Total |
|---|---|---|---|
| 1 | 41,922 | 35,153 | 77,075 |
| 2 | 37,313 | 32,963 | 70,276 |
| 3 | 32,544 | 29,013 | 61,557 |
| 4 | 34,786 | 27,270 | 62,056 |
| Total | 146,565 | 124,399 | 270,964 |
| Annual HH Income <50k | Freq. | Percent | Cum. |
| 1 | 41,922 | 28.60 | 28.60 |
| 2 | 37,313 | 25.46 | 54.06 |
| 3 | 32,544 | 22.20 | 76.27 |
| 4 | 34,786 | 23.73 | 100.00 |
| Total | 146,565 | 100.00 | |
| Annual HH Income ≥50k | Freq. | Percent | Cum. |
| 1 | 35,153 | 28.26 | 28.26 |
| 2 | 32,963 | 26.50 | 54.76 |
| 3 | 29,013 | 23.32 | 78.08 |
| 4 | 27,270 | 21.92 | 100.00 |
| Total | 124,399 | 100.00 | |

**Table 8 Median AQI Quartiles by Smoking Behavior**

| | Non-Smoker | Smoke | Total |
|---|---|---|---|
| 1 | 64,382 | 12,693 | 77,075 |
| 2 | 58,580 | 11,696 | 70,276 |
| 3 | 51,060 | 10,497 | 61,557 |
| 4 | 51,283 | 10,773 | 62,056 |
| Total | 225,305 | 45,659 | 270,964 |
| Smoker | Freq. | Percent | Cum. |
| 1 | 12,693 | 27.80 | 27.80 |
| 2 | 11,696 | 25.62 | 53.42 |
| 3 | 10,497 | 22.99 | 76.41 |
| 4 | 10,773 | 23.59 | 100.00 |
| Total | 45,659 | 100.00 | |
| Non-Smoker | Freq. | Percent | Cum. |
| 1 | 64,382 | 28.58 | 28.58 |
| 2 | 58,580 | 26.00 | 54.58 |
| 3 | 51,060 | 22.66 | 77.24 |
| 4 | 51,283 | 22.76 | 100.00 |
| Total | 225,305 | 100.00 | |

The largest percentage of low and high income respondents reside in the first quartile (see Table 7). The largest percentage of smokers and non-smokers live in the first quartile (see Table 8), and the largest percentage of respondents with asthma and without asthma reside in the first quartile (see Table 9).

**Table 9 Median AQI Quartile by Asthma**

| | No Asthma | Asthma | Total |
|---|---|---|---|
| 1 | 69,560 | 7,515 | 77,075 |
| 2 | 63,678 | 6,598 | 70,276 |
| 3 | 55,888 | 5,669 | 61,557 |
| 4 | 56,480 | 5,576 | 62,056 |
| Total | 245,606 | 25,358 | 270,964 |
| Asthma | Freq. | Percent | Cum. |
| 1 | 7,515 | 29.64 | 29.64 |
| 2 | 6,598 | 26.02 | 55.66 |
| 3 | 5,669 | 22.36 | 78.01 |
| 4 | 5,576 | 21.99 | 100.00 |
| Total | 25,358 | 100.00 | |
| No Asthma | Freq. | Percent | Cum. |
| 1 | 69,560 | 28.32 | 28.32 |
| 2 | 63,678 | 25.93 | 54.25 |
| 3 | 55,888 | 22.76 | 77.00 |
| 4 | 56,480 | 23.00 | 100.00 |
| Total | 245,606 | 100.00 | |

*T-tests*

**Table 10 Two-sample t-test with Equal Variances (Median AQI by Sex)**

| Female | Male | Mean Female | Mean Male | dif | St_Err | t_value | p_value |
|---|---|---|---|---|---|---|---|
| 158232 | 112732 | 40.346 | 40.079 | .268 | .043 | 6.3 | 0 |

**Table 11 Two-sample t-test with Unequal Variances (Median AQI by Race, Education & Income)**

| Non-Black | Black | Mean Non-Black | Mean Black | Dif | Std Error | t value | p value |
|---|---|---|---|---|---|---|---|
| 246279 | 24685 | 39.693 | 45.653 | -5.96 | .071 | -83.25 | 0 |
| College | Non-College | Mean College | Mean Non-College | Dif | Std Error | t value | p value |
| 106083 | 164881 | 40.327 | 40.176 | -.15 | .043 | -3.5 | .001 |
| Low Income | High Income | Mean Low Income | Mean High Income | Dif | Std Error | t value | p value |
| 146565 | 124399 | 40.272 | 40.193 | .08 | .042 | 1.9 | .058 |

*Confidence Intervals*

**Table 12 Median AQI Confidence Intervals**

| Variable | Obs | Mean | Std Error | [95% Confidence | Interval) |
|---|---|---|---|---|---|
| Male | 112732 | 40.08 | 0.03 | 40.02 | 40.14 |
| Female | 158232 | 40.35 | 0.03 | 40.29 | 40.40 |
| Black | 24685 | 45.65 | 0.06 | 45.54 | 45.76 |
| Non-Black | 246279 | 39.70 | 0.02 | 39.65 | 39.74 |
| Non-College | 164881 | 40.18 | 0.03 | 40.12 | 40.23 |
| College | 106083 | 40.33 | 0.03 | 40.26 | 40.39 |
| High Income | 124399 | 40.19 | 0.03 | 40.13 | 40.25 |
| Low Income | 146565 | 40.27 | 0.03 | 40.21 | 40.33 |

The results of the quartiles showed that there is a difference in exposure between groups is between black respondents and non-black respondents, but no difference in exposure between groups was found between males and females, college educated and non-college educated respondents, or low and high income respondents. Next, t-tests and confidence intervals will be examined to see if these patterns continue.

The results of the variance ratio tests and Levene's test of equal variances for sex, race, education, and income determined that a two-sample t-test with equal variances was appropriate for median AQI by sex (see Table 10), and a two-sample t-test with unequal variances was appropriate for median AQI by race, education and income (see Table 11). The mean difference between males and females was statistically, significantly different from zero. This suggests that males and females have differential AQI exposure levels, with females having higher AQI exposure levels compared to males. The mean difference between non-blacks and blacks was statistically, significantly different from zero. This suggests that non-blacks and blacks have differential AQI exposure levels, with black individuals having higher AQI exposure levels compared to non-black individuals. The mean difference between college graduates and non-college graduates was statistically, significantly different from zero. This suggests that college graduates and non-college graduates have differential AQI exposure levels, with college graduates having higher AQI exposure levels compared to non-college graduates. The mean difference between low and high income individuals was not statistically, significantly different from zero. It cannot be ascertained whether low and high income individuals have differential AQI exposure levels based on mean differences. The median AQI confidence intervals for each of the stratified groupings reinforce these results (see Table 12). The confidence intervals for males and females do not overlap, suggesting that males and females have differential AQI exposure levels, with females having higher AQI exposure levels compared to males. The confidence intervals for black individuals and non-black individuals do not overlap, suggesting that black individuals and non-black individuals have differential AQI exposure levels, with black individuals having notably higher AQI exposure levels compared to non-black individuals. The confidence intervals for college graduates and non-college graduates do not overlap, suggesting that college graduates and non-college graduates have differential AQI exposure levels, with college graduates having higher AQI exposure levels compared to non-college graduates. The confidence intervals for high and low income individuals overlap, suggesting that high and low income individuals may not have differential AQI exposure levels.

*Logistic Regression*

**Table 13 Full Model Logistic Regression**

| DV Asthma | Coef. | St.Err | t-value | p-value | Sig. |
|---|---|---|---|---|---|
| County Median AQI | -0.006 | 0.001 | -4.33 | 0.000 | *** |
| Health Plan (Yes) | 0.313 | 0.046 | 6.76 | 0.000 | *** |
| Smoker (Yes) | 0.275 | 0.034 | 8.03 | 0.000 | *** |
| Race (Black) | 0.135 | 0.045 | 2.98 | 0.003 | *** |
| Sex (Male) | -0.553 | 0.029 | -19.05 | 0.000 | *** |
| Age | -0.005 | 0.001 | -6.49 | 0.000 | *** |
| 1b. No HS Diploma | 0.000 | . | . | . | |
| 2. HS Diploma | -0.068 | 0.051 | -1.31 | 0.189 | |
| 3. Some College | 0.072 | 0.051 | 1.42 | 0.156 | |
| 4. College Grad | -0.054 | 0.054 | -1.01 | 0.314 | |
| 1b. <10k | 0.000 | . | . | . | |
| 2.10k-14,999k | -0.166 | 0.067 | -2.48 | 0.013 | ** |
| 3.15k-19,999k | -0.382 | 0.066 | -5.80 | 0.000 | *** |
| 4.20k-24,999k | -0.461 | 0.066 | -6.97 | 0.000 | *** |
| 5.25k-34,999k | -0.576 | 0.066 | -8.76 | 0.000 | *** |
| 6.35k-49,999k | -0.674 | 0.063 | -10.74 | 0.000 | *** |
| 7.50k-74,999k | -0.740 | 0.064 | -11.51 | 0.000 | *** |
| 8.75k+ | -0.816 | 0.062 | -13.22 | 0.000 | *** |
| County Proportion Urban | 0.008 | 0.057 | 0.14 | 0.889 | |
| County Proportion Vacant | -0.045 | 0.250 | -0.18 | 0.856 | |
| County Proportion Educated | -0.235 | 0.189 | -1.24 | 0.214 | |
| County Proportion Poverty | 0.025 | 0.331 | 0.08 | 0.939 | |
| _cons | -1.248 | 0.125 | -9.97 | 0.000 | *** |
| Mean dependent var | 0.094 | SD dependent var | | | 0.291 |
| Number of obs | 270964.000 | F-test | | | 48.921 |

*** p<0.01, ** p<0.05

To investigate research questions five and six, full sample and stratified logistic regression was performed. The full model (see Table 13) did not produce any significant results for the county level variables proportion urban, proportion vacant, proportion educated or proportion in poverty. The full model did not produce any significant results for the individual level variable education (categories 2 [high school diploma], 3 [some college] and 4 [college graduate]), either. Only one county level variable is significant (negative coefficient), median AQI. That is, counties with a higher median AQI have lower rates of asthma compared to counties with a lower median AQI. Three individual level variables have positive, significant coefficients: health plan, race and smoking. Individuals who have a health plan have higher rates of asthma than individuals who do not have a health plan. Black respondents have higher rates of asthma than non-Black respondents. Individuals who smoke have higher rates of asthma than individuals who do not smoke. Several individual level variables have negative, significant coefficients: sex, age and each income category. Men have lower rates of asthma compared to women, and older individuals have lower rates of asthma compared to younger individuals. Compared to omitted income category 1 (annual household income level less than $10,000), individuals in income level 2 (annual household income level between $10,000-$14,999), individuals in income level 3 (annual household income level $15,000-$19,999), individuals in income level 4 (annual household income level $20,000-$24,999), individuals in income level 5 (annual household income level $25,000-$34,999), individuals in income level 6 (annual household income level $35,000-$49,999), individuals in income level 7 (annual household income level $50,000-74,999), and individuals in income level 8 (annual household income level greater or equal to $75,000) are each significantly less likely to have asthma.

**Table 14 Logistic Regression Stratified by Sex (Male)**

| DV Asthma | Coef. | St.Err | t-value | p-value | Sig. |
|---|---|---|---|---|---|
| County Median AQI | -0.006 | 0.002 | -2.36 | 0.018 | ** |
| Health Plan (Yes) | 0.328 | 0.080 | 4.10 | 0.000 | *** |
| Smoker (Yes) | 0.214 | 0.059 | 3.64 | 0.000 | *** |
| Race (Black) | 0.230 | 0.084 | 2.75 | 0.006 | *** |
| Age | -0.006 | 0.001 | -4.51 | 0.000 | *** |
| 1b. No HS Diploma | 0.000 | . | . | . | |
| 2. HS Diploma | -0.025 | 0.087 | -0.28 | 0.776 | |
| 3. Some College | 0.116 | 0.086 | 1.35 | 0.176 | |
| 4. College Grad | -0.066 | 0.090 | -0.72 | 0.468 | |
| 1b. <10k | 0.000 | . | . | . | |
| 2.10k-14,999k | -0.151 | 0.127 | -1.19 | 0.234 | |
| 3.15k-19,999k | -0.362 | 0.125 | -2.90 | 0.004 | *** |
| 4.20k-24,999k | -0.484 | 0.125 | -3.86 | 0.000 | *** |
| 5.25k-34,999k | -0.459 | 0.123 | -3.73 | 0.000 | *** |
| 6.35k-49,999k | -0.636 | 0.118 | -5.39 | 0.000 | *** |
| 7.50k-74,999k | -0.729 | 0.122 | -5.99 | 0.000 | *** |
| 8.75k+ | -0.723 | 0.116 | -6.25 | 0.000 | *** |
| County Proportion Urban | -0.021 | 0.100 | -0.21 | 0.832 | |
| County Proportion Vacant | 0.147 | 0.441 | 0.33 | 0.739 | |
| County Proportion Educated | -0.160 | 0.327 | -0.49 | 0.625 | |
| County Proportion Poverty | 0.417 | 0.600 | 0.69 | 0.488 | |
| _cons | -1.915 | 0.226 | -8.47 | 0.000 | *** |
| Mean dependent var | 0.067 | SD dependent var | | | 0.251 |
| Number of obs | 112732.000 | F-test | | | 9.461 |

*** p<0.01, ** p<0.05

The stratified sex model [male] (see Table 14) did not produce any significant results for the county level variables proportion urban, proportion vacant, proportion educated or proportion in poverty. The stratified sex model [men] did not produce any significant results for neither the individual level variable education (categories 2[high school diploma], 3 [some college] and 4 [college graduate]), nor the individual level variable income (category 2 [annual household income $10,000-$14,999]). Only one county level variable is significant (negative coefficient), median AQI. That is, counties with a higher median AQI have lower rates of asthma compared to counties with a lower median AQI. Three individual level variables have positive, significant coefficients: health plan, race and smoking. Individuals who have a health plan have higher rates of asthma than individuals who do not have a health plan. Black respondents have higher rates of asthma than non-Black respondents. Individuals who smoke have higher rates of asthma than individuals who do not smoke. Several individual level variables have negative, significant coefficients: age and income categories 3-8. Older individuals have lower rates of asthma compared to younger individuals. Compared to omitted income category 1 (annual household income level less than $10,000), individuals in income level 3 (annual household income level $15,000-$19,999), individuals in income level 4 (annual household income level $20,000-$24,999), individuals in income level 5 (annual household income level $25,000-$34,999), individuals in income level 6 (annual household income level $35,000-$49,999), individuals in income level 7 (annual household income level $50,000-74,999), and individuals in income level 8 (annual household income level greater or equal to $75,000) are each significantly less likely to have asthma.

**Table 15 Logistic Regression Stratified by Sex (Female)**

| DV Asthma | Coef. | St.Err | t-value | p-value | Sig. |
|---|---|---|---|---|---|
| County Median AQI | -0.006 | 0.002 | -3.73 | 0.000 | *** |
| Health Plan (Yes) | 0.299 | 0.055 | 5.46 | 0.000 | *** |
| Smoker (Yes) | 0.318 | 0.041 | 7.70 | 0.000 | *** |
| Race (Black) | 0.079 | 0.051 | 1.53 | 0.125 | |
| Age | -0.005 | 0.001 | -4.71 | 0.000 | *** |
| 1b. No HS Diploma | 0.000 | . | . | . | |
| 2. HS Diploma | -0.102 | 0.063 | -1.62 | 0.105 | |
| 3. Some College | 0.040 | 0.063 | 0.65 | 0.518 | |
| 4. College Grad | -0.048 | 0.067 | -0.72 | 0.474 | |
| 1b. <10k | 0.000 | . | . | . | |
| 2.10k-14,999k | -0.174 | 0.078 | -2.24 | 0.025 | ** |
| 3.15k-19,999k | -0.391 | 0.077 | -5.11 | 0.000 | *** |
| 4.20k-24,999k | -0.446 | 0.077 | -5.82 | 0.000 | *** |
| 5.25k-34,999k | -0.647 | 0.076 | -8.52 | 0.000 | *** |
| 6.35k-49,999k | -0.696 | 0.073 | -9.53 | 0.000 | *** |
| 7.50k-74,999k | -0.745 | 0.074 | -10.09 | 0.000 | *** |
| 8.75k+ | -0.878 | 0.072 | -12.27 | 0.000 | *** |
| County Proportion Urban | 0.027 | 0.069 | 0.39 | 0.698 | |
| County Proportion Vacant | -0.170 | 0.293 | -0.58 | 0.561 | |
| County Proportion Educated | -0.271 | 0.228 | -1.19 | 0.234 | |
| County Proportion Poverty | -0.196 | 0.377 | -0.52 | 0.604 | |
| _cons | -1.173 | 0.144 | -8.14 | 0.000 | *** |
| Mean dependent var | 0.112 | SD dependent var | | | 0.316 |
| Number of obs | 158232.000 | F-test | | | 23.075 |

*** p<0.01, ** p<0.05

The stratified sex model [female] (see Table 15) did not produce any significant results for the county level variables proportion urban, proportion vacant, proportion educated or proportion in poverty. The stratified sex model [women] did not produce any significant results for neither the individual level variable education (categories 2 [high school diploma], 3 [some college] and 4 [college graduate]), nor the race variable. Only one county level variable is significant (negative coefficient), median AQI. That is, counties with a higher median AQI have lower rates of asthma compared to counties with a lower median AQI. Two individual level variables have positive, significant coefficients: health plan and smoking. Individuals who have a health plan have higher rates of asthma than individuals who do not have a health plan, and individuals who smoke have higher rates of asthma than individuals who do not smoke. Several individual level variables have negative, significant coefficients: age and each income category. Older individuals have lower rates of asthma compared to younger individuals. Compared to omitted income category 1 (annual household income level less than $10,000), individuals in income level 2 (annual household income level between $10,000-$14,999), individuals in income level 3 (annual household income level $15,000-$19,999), individuals in income level 4 (annual household income level $20,000-$24,999), individuals in income level 5 (annual household income level $25,000-$34,999), individuals in income level 6 (annual household income level $35,000-$49,999), individuals in income level 7 (annual household income level $50,000-74,999), and individuals in income level 8 (annual household income level greater or equal to $75,000) are each significantly less likely to have asthma.

**Table 16 Logistic Regression Stratified by Race (Black)**

| DV Asthma | Coef. | St.Err | t-value | p-value | Sig. |
|---|---|---|---|---|---|
| County Median AQI | -0.001 | 0.005 | -0.22 | 0.825 | |
| Health Plan (Yes) | 0.327 | 0.116 | 2.83 | 0.005 | *** |
| Smoker (Yes) | 0.228 | 0.095 | 2.40 | 0.017 | ** |
| Sex (Male) | -0.425 | 0.090 | -4.74 | 0.000 | *** |
| Age | -0.009 | 0.002 | -3.46 | 0.001 | *** |
| 1b. No HS Diploma | 0.000 | . | . | . | |
| 2. HS Diploma | -0.087 | 0.130 | -0.67 | 0.503 | |
| 3. Some College | -0.024 | 0.135 | -0.17 | 0.861 | |
| 4. College Grad | -0.247 | 0.159 | -1.55 | 0.121 | |
| 1b. <10k | 0.000 | . | . | . | |
| 2.10k-14,999k | -0.162 | 0.150 | -1.08 | 0.280 | |
| 3.15k-19,999k | -0.402 | 0.147 | -2.74 | 0.006 | *** |
| 4.20k-24,999k | -0.388 | 0.161 | -2.41 | 0.016 | ** |
| 5.25k-34,999k | -0.777 | 0.162 | -4.80 | 0.000 | *** |
| 6.35k-49,999k | -0.835 | 0.164 | -5.09 | 0.000 | *** |
| 7.50k-74,999k | -0.772 | 0.196 | -3.95 | 0.000 | *** |
| 8.75k+ | -0.834 | 0.183 | -4.55 | 0.000 | *** |
| County Proportion Urban | 0.370 | 0.238 | 1.55 | 0.120 | |
| County Proportion Vacant | 0.352 | 1.193 | 0.29 | 0.768 | |
| County Proportion Educated | -0.159 | 0.640 | -0.25 | 0.804 | |
| County Proportion Poverty | -0.375 | 1.111 | -0.34 | 0.736 | |
| _cons | -1.462 | 0.428 | -3.42 | 0.001 | *** |
| Mean dependent var | 0.112 | SD dependent var | | | 0.315 |
| Number of obs | 24685.000 | F-test | | | 7.508 |

*** p<0.01, ** p<0.05

The stratified race model [Black] (see Table 16) did not produce any significant results for any of the county level variables (median AQI, proportion urban, proportion vacant, proportion educated or proportion in poverty). The stratified race model [Black] did not produce any significant results for neither the individual level variable education (categories 2 [high school diploma], 3 [some college] and 4 [college graduate]), nor individual level variable income (category 2 [annual household income $10,000-$14,999]). Two individual level variables have positive, significant coefficients: health plan and smoking. Individuals who have a health plan have higher rates of asthma than individuals who do not have a health plan, and individuals who smoke have higher rates of asthma than individuals who do not smoke. Several individual level variables have negative, significant coefficients: sex, age and income categories 3-8. Men have lower rates of asthma compared to women, and older individuals have lower rates of asthma compared to younger individuals. Compared to omitted income category 1 (annual household income level less than $10,000), individuals in income level 3 (annual household income level $15,000-$19,999), individuals in income level 4 (annual household income level $20,000-$24,999), individuals in income level 5 (annual household income level $25,000-$34,999), individuals in income level 6 (annual household income level $35,000-$49,999), individuals in income level 7 (annual household income level $50,000-74,999), and individuals in income level 8 (annual household income level greater or equal to $75,000) are each significantly less likely to have asthma.

**Table 17 Logistic Regression Stratified by Race (Non-Black)**

| DV Asthma | Coef. | St.Err | t-value | p-value | Sig. |
|---|---|---|---|---|---|
| County Median AQI | -0.007 | 0.001 | -4.55 | 0.000 | *** |
| Health Plan (Yes) | 0.310 | 0.050 | 6.22 | 0.000 | *** |
| Smoker (Yes) | 0.281 | 0.037 | 7.69 | 0.000 | *** |
| Sex (Male) | -0.573 | 0.030 | -18.93 | 0.000 | *** |
| Age | -0.005 | 0.001 | -5.64 | 0.000 | *** |
| 1b. No HS Diploma | 0.000 | . | . | . | |
| 2. HS Diploma | -0.071 | 0.056 | -1.27 | 0.205 | |
| 3. Some College | 0.085 | 0.055 | 1.55 | 0.120 | |
| 4. College Grad | -0.029 | 0.058 | -0.50 | 0.617 | |
| 1b. <10k | 0.000 | . | . | . | |
| 2.10k-14,999k | -0.158 | 0.075 | -2.11 | 0.035 | ** |
| 3.15k-19,999k | -0.366 | 0.073 | -5.01 | 0.000 | *** |
| 4.20k-24,999k | -0.470 | 0.072 | -6.55 | 0.000 | *** |
| 5.25k-34,999k | -0.529 | 0.072 | -7.33 | 0.000 | *** |
| 6.35k-49,999k | -0.638 | 0.068 | -9.32 | 0.000 | *** |
| 7.50k-74,999k | -0.721 | 0.069 | -10.48 | 0.000 | *** |
| 8.75k+ | -0.799 | 0.067 | -11.96 | 0.000 | *** |
| County Proportion Urban | -0.017 | 0.059 | -0.28 | 0.777 | |
| County Proportion Vacant | -0.144 | 0.246 | -0.58 | 0.559 | |
| County Proportion Educated | -0.271 | 0.191 | -1.41 | 0.158 | |
| County Proportion Poverty | 0.094 | 0.331 | 0.28 | 0.777 | |
| _cons | -1.236 | 0.128 | -9.69 | 0.000 | *** |
| Mean dependent var | 0.092 | SD dependent var | | | 0.289 |
| Number of obs | 246279.000 | F-test | | | 43.759 |

*** p<0.01, ** p<0.05

The stratified race model [non-Black] (see Table 17) did not produce any significant results for the county level variables proportion urban, proportion vacant, proportion educated or proportion in poverty. The stratified race model [non-Black] did not produce any significant results for the individual level variable education (categories 2 [high school diploma], 3 [some college] and 4 [college graduate]), either. Only one county level variable is significant (negative coefficient), median AQI. That is, counties with a higher median AQI have lower rates of asthma compared to counties with a lower median AQI. Two individual level variables have positive, significant coefficients: health plan and smoking. Individuals who have a health plan have higher rates of asthma than individuals who do not have a health plan and individuals who smoke have higher rates of asthma than individuals who do not smoke. Several individual level variables have negative, significant coefficients: sex, age and each income category. Men have lower rates of asthma compared to women, and older individuals have lower rates of asthma compared to younger individuals. Compared to omitted income category 1 (annual household income level less than $10,000), individuals in income level 2 (annual household income level between $10,000-$14,999), individuals in income level 3 (annual household income level $15,000-$19,999), individuals in income level 4 (annual household income level $20,000-$24,999), individuals in income level 5 (annual household income level $25,000-$34,999), individuals in income level 6 (annual household income level $35,000-$49,999), individuals in income level 7 (annual household income level $50,000-74,999), and individuals in income level 8 (annual household income level greater or equal to $75,000) are each significantly less likely to have asthma.

**Table 18 Logistic Regression Stratified by Education (College Graduate)**

| DV Asthma | Coef. | St.Err | t-value | p-value | Sig. |
|---|---|---|---|---|---|
| County Median AQI | -0.009 | 0.002 | -3.96 | 0.000 | *** |
| Health Plan (Yes) | 0.247 | 0.100 | 2.46 | 0.014 | ** |
| Smoker (Yes) | -0.050 | 0.074 | -0.68 | 0.499 | |
| Race (Black) | 0.001 | 0.088 | 0.02 | 0.987 | |
| Sex (Male) | -0.580 | 0.047 | -12.32 | 0.000 | *** |
| Age | -0.004 | 0.002 | -2.87 | 0.004 | *** |
| 1b. <10k | 0.000 | . | . | . | |
| 2.10k-14,999k | 0.169 | 0.220 | 0.77 | 0.443 | |
| 3.15k-19,999k | -0.061 | 0.185 | -0.33 | 0.740 | |
| 4.20k-24,999k | -0.260 | 0.174 | -1.49 | 0.137 | |
| 5.25k-34,999k | -0.327 | 0.165 | -1.98 | 0.047 | ** |
| 6.35k-49,999k | -0.424 | 0.157 | -2.70 | 0.007 | *** |
| 7.50k-74,999k | -0.467 | 0.155 | -3.02 | 0.003 | *** |
| 8.75k+ | -0.557 | 0.150 | -3.72 | 0.000 | *** |
| County Proportion Urban | 0.050 | 0.098 | 0.51 | 0.613 | |
| County Proportion Vacant | -0.675 | 0.410 | -1.64 | 0.100 | |
| County Proportion Educated | -0.254 | 0.288 | -0.88 | 0.378 | |
| County Proportion Poverty | 0.270 | 0.520 | 0.52 | 0.603 | |
| _cons | -1.339 | 0.227 | -5.91 | 0.000 | *** |
| Mean dependent var | 0.079 | SD dependent var | | | 0.270 |
| Number of obs | 106083.000 | F-test | | | 16.464 |

*** p<0.01, ** p<0.05

The stratified education model [college graduate] (see Table 18) did not produce any significant results for the county level variables proportion urban, proportion vacant, proportion educated or proportion in poverty. The stratified education model [college graduate] did not produce any significant results for neither the individual level variables of race, smoking, nor the income categories 2, 3 and 4. Only one county level variable is significant (negative coefficient), median AQI. That is, counties with a higher median AQI have lower rates of asthma compared to counties with a lower median AQI. One individual level variable has a positive, significant coefficient: health plan. Individuals who have a health plan have higher rates of asthma than individuals who do not have a health plan. Several individual level variables have negative, significant coefficients: sex, age and the income categories 5, 6, 7 and 8. Men have lower rates of asthma compared to women, and older individuals have lower rates of asthma compared to younger individuals. Compared to omitted income category 1 (annual household income level less than $10,000), individuals in income level 5 (annual household income level $25,000-$34,999), individuals in income level 6 (annual household income level $35,000-$49,999), individuals in income level 7 (annual household income level $50,000-74,999), and individuals in income level 8 (annual household income level greater or equal to $75,000) are each significantly less likely to have asthma.

**Table 19 Logistic Regression Stratified by Education (Non-College Graduate)**

| DV Asthma | Coef. | St.Err | t-value | p-value | Sig. |
|---|---|---|---|---|---|
| County Median AQI | -0.005 | 0.002 | -3.08 | 0.002 | *** |
| Health Plan (Yes) | 0.326 | 0.050 | 6.48 | 0.000 | *** |
| Smoker (Yes) | 0.312 | 0.038 | 8.20 | 0.000 | *** |
| Race (Black) | 0.158 | 0.052 | 3.05 | 0.002 | *** |
| Sex (Male) | -0.553 | 0.035 | -15.71 | 0.000 | *** |
| Age | -0.006 | 0.001 | -6.05 | 0.000 | *** |
| 1b. <10k | 0.000 | . | . | . | |
| 2.10k-14,999k | -0.184 | 0.070 | -2.64 | 0.008 | *** |
| 3.15k-19,999k | -0.398 | 0.069 | -5.74 | 0.000 | *** |
| 4.20k-24,999k | -0.460 | 0.070 | -6.59 | 0.000 | *** |
| 5.25k-34,999k | -0.576 | 0.070 | -8.25 | 0.000 | *** |
| 6.35k-49,999k | -0.666 | 0.068 | -9.77 | 0.000 | *** |
| 7.50k-74,999k | -0.733 | 0.072 | -10.22 | 0.000 | *** |
| 8.75k+ | -0.808 | 0.071 | -11.40 | 0.000 | *** |
| County Proportion Urban | 0.001 | 0.067 | 0.01 | 0.989 | |
| County Proportion Vacant | 0.133 | 0.293 | 0.45 | 0.651 | |
| County Proportion Educated | -0.220 | 0.241 | -0.91 | 0.361 | |
| County Proportion Poverty | -0.001 | 0.405 | -0.00 | 0.998 | |
| _cons | -1.305 | 0.145 | -9.01 | 0.000 | *** |
| Mean dependent var | 0.103 | SD dependent var | | | 0.304 |
| Number of obs | 164881.000 | F-test | | | 36.924 |

*** p<0.01, ** p<0.05

The stratified education model [non-college graduate] (see Table 19) did not produce any significant results for the county level variables proportion urban, proportion vacant, proportion educated or proportion in poverty. Only one county level variable is significant (negative coefficient), median AQI. That is, counties with a higher median AQI have lower rates of asthma compared to counties with a lower median AQI. Three individual level variables have positive, significant coefficients: health plan, race and smoking. Individuals who have a health plan have higher rates of asthma than individuals who do not have a health plan. Black respondents have higher rates of asthma than non-Black respondents. Individuals who smoke have higher rates of asthma than individuals who do not smoke. Several individual level variables have negative, significant coefficients: sex, age and each income category. Men have lower rates of asthma compared to women, and older individuals have lower rates of asthma compared to younger individuals. Compared to omitted income category 1 (annual household income level less than $10,000), individuals in income level 2 (annual household income level between $10,000-$14,999), individuals in income level 3 (annual household income level $15,000-$19,999), individuals in income level 4 (annual household income level $20,000-$24,999), individuals in income level 5 (annual household income level $25,000-$34,999), individuals in income level 6 (annual household income level $35,000-$49,999), individuals in income level 7 (annual household income level $50,000-74,999), and individuals in income level 8 (annual household income level greater or equal to $75,000) are each significantly less likely to have asthma.

**Table 20 Logistic Regression Stratified by Income (Annual Household Income $50,000 or greater)**

| DV Asthma | Coef. | St.Err | t-value | p-value | Sig. |
|---|---|---|---|---|---|
| County Median AQI | -0.004 | 0.002 | -1.48 | 0.138 | |
| Health Plan (Yes) | -0.030 | 0.131 | -0.23 | 0.819 | |
| Smoker (Yes) | 0.014 | 0.070 | 0.20 | 0.844 | |
| Race (Black) | 0.102 | 0.097 | 1.05 | 0.293 | |
| Sex (Male) | -0.535 | 0.044 | -12.14 | 0.000 | *** |
| Age | -0.005 | 0.002 | -3.52 | 0.000 | *** |
| 1b. No HS Diploma | 0.000 | . | . | . | |
| 2. HS Diploma | -0.418 | 0.156 | -2.68 | 0.007 | *** |
| 3. Some College | -0.237 | 0.152 | -1.56 | 0.119 | |
| 4. College Grad | -0.369 | 0.149 | -2.48 | 0.013 | ** |
| County Proportion Urban | 0.015 | 0.096 | 0.16 | 0.874 | |
| County Proportion Vacant | -0.293 | 0.425 | -0.69 | 0.491 | |
| County Proportion Educated | -0.018 | 0.269 | -0.07 | 0.946 | |
| County Proportion Poverty | 0.573 | 0.513 | 1.12 | 0.264 | |
| _cons | -1.587 | 0.253 | -6.28 | 0.000 | *** |
| Mean dependent var | | 0.074 | SD dependent var | | 0.261 |
| Number of obs | | 124399.000 | F-test | | 15.436 |

*** p<0.01, ** p<0.05

The stratified income model [annual household income $50,000 or greater] (see Table 20) did not produce any significant results for the county level variables: median AQI, proportion urban, proportion vacant, proportion educated or proportion in poverty. The stratified income model [annual household income $35,000 or greater] did not produce any significant results for the individual level variables: health plan, race, smoking or education category 3 [some college]. Zero individual level variables have positive, significant coefficients. Several individual level variables have negative, significant coefficients: sex, age and education categories 2 [high school diploma] and 4 [college graduate]. Men have lower rates of asthma compared to women, and older individuals have lower rates of asthma compared to younger individuals. Compared to omitted education category 1 (no high school diploma), individuals in education category 2 (high school diploma) and individuals in education category 4 (college graduate), are both significantly less likely to have asthma.

**Table 21 Logistic Regression Stratified by Income (Annual Household Income Annual Household income less than $50,000)**

| DV Asthma | Coef. | St.Err | t-value | p-value | Sig. |
|---|---|---|---|---|---|
| County Median AQI | -0.006 | 0.002 | -3.69 | 0.000 | *** |
| Health Plan (Yes) | 0.313 | 0.048 | 6.47 | 0.000 | *** |
| Smoker (Yes) | 0.398 | 0.040 | 9.88 | 0.000 | *** |
| Race (Black) | 0.198 | 0.052 | 3.83 | 0.000 | *** |
| Sex (Male) | -0.610 | 0.038 | -15.92 | 0.000 | *** |
| Age | -0.006 | 0.001 | -6.01 | 0.000 | *** |
| 1b. No HS Diploma | 0.000 | . | . | . | |
| 2. HS Diploma | -0.115 | 0.054 | -2.14 | 0.032 | ** |
| 3. Some College | -0.020 | 0.053 | -0.38 | 0.703 | |
| 4. College Grad | -0.227 | 0.060 | -3.78 | 0.000 | *** |
| County Proportion Urban | -0.001 | 0.072 | -0.02 | 0.984 | |
| County Proportion Vacant | 0.014 | 0.309 | 0.04 | 0.965 | |
| County Proportion Educated | -0.304 | 0.259 | -1.18 | 0.240 | |
| County Proportion Poverty | 0.109 | 0.426 | 0.26 | 0.797 | |
| _cons | -1.577 | 0.146 | -10.83 | 0.000 | *** |
| Mean dependent var | 0.110 | SD dependent var | | | 0.313 |
| Number of obs | 146565.000 | F-test | | | 39.137 |

*** p<0.01, ** p<0.05

The stratified income model [annual household income less than $50,000] (see Table 21) did not produce any significant results for the county level variables proportion urban, proportion vacant, proportion educated or proportion in poverty. The stratified income model [annual household income less than $35,000] did not produce any significant results for the individual level variable education category 3 [some college]. Only one county level variable is significant (negative coefficient), median AQI. That is, counties with a higher median AQI have lower rates of asthma compared to counties with a lower median AQI. Three individual level variables have positive, significant coefficients: health plan, race and smoking. Individuals who have a health plan have higher rates of asthma than individuals who do not have a health plan. Black respondents have higher rates of asthma than non-Black respondents. Individuals who smoke have higher rates of asthma than individuals who do not smoke. Several individual level variables have negative, significant coefficients: sex, age and education categories 2 (high school diploma) and 4 (college graduate). Men have lower rates of asthma compared to women, and older individuals have lower rates of asthma compared to younger individuals. Compared to omitted education category 1 (no high school diploma), individuals in education category 2 (high school diploma) and education category 4 (college graduate) are both significantly less likely to have asthma.

*Summary of Stratified Logistic Regression*

**Table 22 Logistic Regression Summary**

| | | Sex | | Race | | Education | | Income | |
|---|---|---|---|---|---|---|---|---|---|
| | **Entire Sample** | **Men** | **Women** | **Black** | **Non Black** | **College** | **Non College** | **Low** | **High** |
| **Predictor** | | | | | | | | | |
| Median AQI | - | - | - | NS | - | - | - | - | NS |
| Health Plan (yes) | + | + | + | + | + | + | + | + | NS |
| Race (Black) | + | + | NS | NA | NA | NS | + | + | NS |
| Smoke (yes) | + | + | + | + | + | NS | + | + | NS |
| Sex (Male) | - | NA | NA | - | - | - | - | - | - |
| AGE | - | - | - | - | - | - | - | - | - |
| Education 2 (HS diploma) | NS | NS | NS | NS | NS | NA | NA | - | - |
| Education 3 (Some College) | NS | NS | NS | NS | NS | NA | NA | NS | NS |
| Education 4 (College Grad) | NS | NS | NS | NS | NS | NA | NA | - | - |
| Income 2 (<15k) | - | NS | - | NS | - | NS | - | NA | NA |
| Income 3 (<20k) | - | - | - | - | - | NS | - | NA | NA |
| Income 4 (<25k) | - | - | - | - | - | NS | - | NA | NA |
| Income 5 (<35k) | - | - | - | - | - | - | - | NA | NA |
| Income 6 (<50k) | - | - | - | - | - | - | - | NA | NA |
| Income 7 (<75k) | - | - | - | - | - | - | - | NA | NA |
| Income 8 (75k+) | - | - | - | - | - | - | - | NA | NA |
| Proportion Urban | NS | NS | NS | NS | NS | NS | NS | NS | NS |
| Proportion Vacant | NS | NS | NS | NS | NS | NS | NS | NS | NS |
| Proportion Educated | NS | NS | NS | NS | NS | NS | NS | NS | NS |
| Propoption Poverty | NS | NS | NS | NS | NS | NS | NS | NS | NS |

Overall, variable significance and direction remain mostly consistent throughout the different logistic runs. The summary table (table 22) shows specific patterns of variable significance among the original and stratified logistic runs. Non-significant outcomes have been checked for small cell issues and none were found. County level median AQI is consistently significant (with the exception of stratified race-Black and stratified income-high), all with negative coefficients. The negative results are interesting, as one would intuitively expect lower (better) county level median AQI to be associated with lower asthma rates. Although it is beyond the scope of this study to determine the cause of the direction of the coefficients, several contributing factors are plausible. First, the temporal sequence of residence and incidence of asthma isn't available, nor is exposure status. Individuals may have developed asthma while living or working (exposure) in a high (worse) median AQI county, but do not reside in this county at the time of data collection. It is also possible that selection, rather than causation is at play. That is, individuals of higher socioeconomic status and have asthma purposefully move to better air quality areas to alleviate symptoms. Li & Newcomb (2009) discuss this possible selection and contextual effect when they found that higher road density was associated with a lower likelihood of having children hospital asthma admissions in neighborhood, all else being equal. Measurement of AQI is another possible reason. Location and amount of monitoring stations are not consistent within each county. Monitoring stations may or may not be near areas of high pollution and lower median AQIs could be a result. Using county level data could also be an issue in assuming any type of exposure, particularly in the west/southwest, where counties are extremely large. Finally, the overall county level AQI distribution is skewed, with very few counties having fair/poor median AQI. None of the other county level variables (proportion urban, proportion vacant, proportion educated, proportion in poverty) are significant for any of the logistic runs.

The individual level variables have specific patterns of significance as well. Having a health plan is consistently significant (with the exception of stratified income-high), all with positive coefficients. This is consistent with the literature and makes sense intuitively. One would need a health plan/doctor to be diagnosed with asthma, thus higher rates of asthma among individuals with health plans. Race (Black) was only significant (positive coefficients) for the original model and stratified sex-men, stratified education-non-college and stratified income-low. Smoking was consistently significant (with the exception of stratified education-college graduate and stratified income-high), all with positive coefficients. Sex of the respondent is consistently significant, all with negative coefficients. Age of the respondent is consistently significant, all with negative coefficients. Education was surprisingly not significant (with the exception of stratified income-low and stratified income-high). Category 2 (high school diploma) and category 4 (college graduate) both have negative coefficients. Income 2 ($10,000-$14,999) is significant with the exception of stratified sex-men, stratified race-Black and stratified education-college graduate, all with negative coefficients. Income 3 ($15,000-$19,999) is significant with the exception of stratified education-college graduate, all with negative coefficients. Income 4 ($20,000-$24,999) is significant with the exception of stratified education-college graduate, all with negative coefficients. Income 5 ($25,000-$34,999), income 6 ($35,000-$49,999), income 7 ($50,000-$74,999) and income 8 ($75,000+) are all significant through each logistic run, and all have negative coefficients. It is important to note that although there are changes in significance (versus non-significance) for some of the variables in some of the runs, there are no coefficient directional changes.

Intra-stratification differences are also noted. Within the sex stratification run, each of the variables has the same level and direction of significance with the exception of race and income category 2. For men in the stratified sample, race (Black) is a significant, positive predictor of asthma. For women in the stratified sample, income category 2 ($10,000-$14,999) is a significant, negative predictor of asthma. Within the race stratification run, each of the variables has the same level and direction of significance with the exception of median AQI and income category 2. For non-Black respondents in the stratified sample, median AQI and income category 2 ($10,000-$14,999) are both significant, negative predictors of asthma. For non-college graduates in the education stratification sample, race (Black) and smoking are both significant, positive predictors of asthma. For non-college graduates in the stratified sample, income category 2 ($10,000-$14,999), income category 3 ($15,000-$19,999), and income category 4 ($20,000-$24,999) are all significant, negative predictors of asthma. Within the income stratification run, each of the variables has the same level and direction of significance with the exception of median AQI, health plan, race and smoking. For low income individuals in the stratified sample, median AQI is a significant, negative predictor of asthma. For low income individuals in the stratified sample, health plan, race (Black) and smoking are all significant, positive predictor of asthma.

***Robustness Checks***

**Table 23 Logistic Regression (AQI variable comparison)**

| DV Asthma | (Median AQI) | (good AQI percent) | (moderate AQI percent) |
|---|---|---|---|
| AQI (see columns) | -0.00607*** | 0.00316*** | -0.00385*** |
| Health Plan (Yes) | 0.313*** | 0.313*** | 0.311*** |
| Smoker (Yes) | 0.275*** | 0.276*** | 0.279*** |
| Race (Black) | 0.135*** | 0.137*** | 0.138*** |
| Sex (Male) | -0.553*** | -0.553*** | -0.552*** |
| Age | -0.00522*** | -0.00521*** | -0.00515*** |
| 2. HS Diploma | -0.0676 | -0.0668 | -0.0618 |
| 3. Some College | 0.0720 | 0.0725 | 0.0762 |
| 4. College Grad | -0.0542 | -0.0533 | -0.0493 |
| 2.10k-14,999k | -0.166** | -0.166** | -0.166** |
| 3.15k-19,999k | -0.382*** | -0.381*** | -0.379*** |
| 4.20k-24,999k | -0.461*** | -0.459*** | -0.461*** |
| 5.25k-34,999k | -0.576*** | -0.575*** | -0.575*** |
| 6.35k-49,999k | -0.674*** | -0.673*** | -0.673*** |
| 7.50k-74,999k | -0.740*** | -0.739*** | -0.739*** |
| 8.75k+ | -0.816*** | -0.815*** | -0.814*** |
| County Proportion Urban | 0.00803 | -0.000390 | -0.00950 |
| County Proportion Vacant | -0.0453 | -0.130 | -0.0627 |
| County Proportion Educated | -0.235 | -0.212 | -0.139 |
| County Proportion Poverty | 0.0254 | 0.102 | 0.187 |
| Constant | -1.248*** | -1.724*** | -1.434*** |
| Observations | 270,964 | 270,964 | 267,697 |

*** p<0.01, ** p<0.05

A logistic regression variable comparison check was used to determine if a different AQI variable would have made a significant difference in model results. As shown in Table 23, the logistic regression results of asthma risk for median AQI, good AQI percent and moderate AQI present are similar, and the choice of median AQI as the AQI variable based on the maximum number of counties included is justified.

**Table 24 Full Model Logistic Regression (Hawaii Included)**

| DV Asthma | Coef. | St.Err | t-value | p-value | Sig. |
|---|---|---|---|---|---|
| County Median AQI | -0.005 | 0.001 | -3.89 | 0.000 | *** |
| Health Plan (Yes) | 0.314 | 0.046 | 6.79 | 0.000 | *** |
| Smoker (Yes) | 0.276 | 0.034 | 8.07 | 0.000 | *** |
| Race (Black) | 0.135 | 0.045 | 2.97 | 0.003 | *** |
| Sex (Male) | -0.553 | 0.029 | -19.07 | 0.000 | *** |
| Age | -0.005 | 0.001 | -6.49 | 0.000 | *** |
| 1b. No HS Diploma | 0.000 | . | . | . | |
| 2. HS Diploma | -0.065 | 0.051 | -1.26 | 0.207 | |
| 3. Some College | 0.075 | 0.051 | 1.47 | 0.141 | |
| 4. College Grad | -0.051 | 0.054 | -0.95 | 0.341 | |
| 1b. <10k | 0.000 | . | . | . | |
| 2.10k-14,999k | -0.165 | 0.067 | -2.47 | 0.013 | ** |
| 3.15k-19,999k | -0.379 | 0.066 | -5.77 | 0.000 | *** |
| 4.20k-24,999k | -0.459 | 0.066 | -6.94 | 0.000 | *** |
| 5.25k-34,999k | -0.574 | 0.066 | -8.74 | 0.000 | *** |
| 6.35k-49,999k | -0.672 | 0.063 | -10.72 | 0.000 | *** |
| 7.50k-74,999k | -0.739 | 0.064 | -11.51 | 0.000 | *** |
| 8.75k+ | -0.815 | 0.062 | -13.22 | 0.000 | *** |
| County Proportion Urban | -0.024 | 0.055 | -0.43 | 0.664 | |
| County Proportion Vacant | -0.029 | 0.249 | -0.12 | 0.907 | |
| County Proportion Educated | -0.199 | 0.188 | -1.06 | 0.290 | |
| County Proportion Poverty | -0.018 | 0.330 | -0.06 | 0.956 | |
| _cons | -1.286 | 0.124 | -10.39 | 0.000 | *** |
| Mean dependent var | 0.094 | SD dependent var | | | 0.291 |
| Number of obs | 272253.000 | F-test | | | 48.860 |

*** p<0.01, ** p<0.05

**Table 25 Summary Statistics (Full Sample – Hawaii Included)**

| | N | Mean | SD | min | max | skewness | kurtosis |
|---|---|---|---|---|---|---|---|
| County Median AQI | 272253 | 40.992 | 15.415 | 1 | 200 | 5.172 | 54.74 |
| Health Plan (Yes) | 272253 | .894 | .308 | 0 | 1 | -2.558 | 7.544 |
| Smoker (Yes) | 272253 | .168 | .374 | 0 | 1 | 1.771 | 4.138 |
| Race (Black) | 272253 | .091 | .287 | 0 | 1 | 2.851 | 9.127 |
| Sex (Male) | 272253 | .416 | .493 | 0 | 1 | .34 | 1.116 |
| Age | 272253 | 54.542 | 16.747 | 18 | 99 | -.089 | 2.324 |
| Education | 272253 | 2.989 | .965 | 1 | 4 | -.437 | 2.005 |
| Income | 272253 | 5.727 | 2.171 | 1 | 8 | -.672 | 2.305 |
| County Proportion Urban | 272253 | .72 | .347 | 0 | 1 | -1.27 | 3.063 |
| County Proportion Vacant | 272253 | .106 | .068 | .04 | .615 | 2.746 | 12.536 |
| County Proportion Educated | 272253 | .291 | .097 | .067 | .688 | .504 | 2.965 |
| County Proportion Poverty | 272253 | .136 | .047 | .031 | .363 | .642 | 4.093 |

**Table 26 Full Model Logistic Regression (Hawaii Dropped)**

| DV Asthma | Coef. | St.Err | t-value | p-value | Sig. |
|---|---|---|---|---|---|
| County Median AQI | -0.006 | 0.001 | -4.33 | 0.000 | *** |
| Health Plan (Yes) | 0.313 | 0.046 | 6.76 | 0.000 | *** |
| Smoker (Yes) | 0.275 | 0.034 | 8.03 | 0.000 | *** |
| Race (Black) | 0.135 | 0.045 | 2.98 | 0.003 | *** |
| Sex (Male) | -0.553 | 0.029 | -19.05 | 0.000 | *** |
| Age | -0.005 | 0.001 | -6.49 | 0.000 | *** |
| 1b. No HS Diploma | 0.000 | . | . | . | |
| 2. HS Diploma | -0.068 | 0.051 | -1.31 | 0.189 | |
| 3. Some College | 0.072 | 0.051 | 1.42 | 0.156 | |
| 4. College Grad | -0.054 | 0.054 | -1.01 | 0.314 | |
| 1b. <10k | 0.000 | . | . | . | |
| 2.10k-14,999k | -0.166 | 0.067 | -2.48 | 0.013 | ** |
| 3.15k-19,999k | -0.382 | 0.066 | -5.80 | 0.000 | *** |
| 4.20k-24,999k | -0.461 | 0.066 | -6.97 | 0.000 | *** |
| 5.25k-34,999k | -0.576 | 0.066 | -8.76 | 0.000 | *** |
| 6.35k-49,999k | -0.674 | 0.063 | -10.74 | 0.000 | *** |
| 7.50k-74,999k | -0.740 | 0.064 | -11.51 | 0.000 | *** |
| 8.75k+ | -0.816 | 0.062 | -13.22 | 0.000 | *** |
| County Proportion Urban | 0.008 | 0.057 | 0.14 | 0.889 | |
| County Proportion Vacant | -0.045 | 0.250 | -0.18 | 0.856 | |
| County Proportion Educated | -0.235 | 0.189 | -1.24 | 0.214 | |
| County Proportion Poverty | 0.025 | 0.331 | 0.08 | 0.939 | |
| _cons | -1.248 | 0.125 | -9.97 | 0.000 | *** |
| Mean dependent var | 0.094 | SD dependent var | | | 0.291 |
| Number of obs | 270964.000 | F-test | | | 48.921 |

*** p<0.01, ** p<0.05

**Table 27 Summary Statistics (Full Sample – Hawaii Dropped)**

| | N | Mean | SD | min | max | skewness | kurtosis |
|---|---|---|---|---|---|---|---|
| County Median AQI | 270964 | 40.235 | 10.858 | 1 | 81 | .14 | 4.644 |
| Health Plan (Yes) | 270964 | .894 | .308 | 0 | 1 | -2.557 | 7.536 |
| Smoker (Yes) | 270964 | .169 | .374 | 0 | 1 | 1.771 | 4.137 |
| Race (Black) | 270964 | .091 | .288 | 0 | 1 | 2.842 | 9.077 |
| Sex (Male) | 270964 | .416 | .493 | 0 | 1 | .341 | 1.116 |
| Age | 270964 | 54.532 | 16.749 | 18 | 99 | -.088 | 2.323 |
| Education | 270964 | 2.989 | .965 | 1 | 4 | -.437 | 2.005 |
| Income | 270964 | 5.729 | 2.171 | 1 | 8 | -.673 | 2.307 |
| County Proportion Urban | 270964 | .723 | .344 | 0 | 1 | -1.293 | 3.138 |
| County Proportion Vacant | 270964 | .106 | .068 | .04 | .615 | 2.775 | 12.69 |
| County Proportion Educated | 270964 | .292 | .097 | .067 | .688 | .499 | 2.95 |
| County Proportion Poverty | 270964 | .136 | .048 | .031 | .363 | .643 | 4.078 |

As discussed in chapter 3, one county was removed because of extreme (right) skew: Hawaii, HI #15001 (1289 observations) median AQI=200. To check the robustness of the removal of Hawaii, a full sample logistic regression was performed with and without including Hawaii, as well as the summary statistics following each regression. As shown in Tables 24 and 26, the logistic regression results have similar coefficients with both including and dropping Hawaii and the same statistical significance for each of the variables, but the kurtosis of county level median AQI was greatly improved by dropping Hawaii, as shown by the summary statistics in Tables 25 and 27.

**Table 28 Full Model Logistic Regression (Weighted)**

| DV Asthma | Coef. | St.Err | t-value | p-value | Sig. |
|---|---|---|---|---|---|
| County Median AQI | -0.006 | 0.001 | -4.33 | 0.000 | *** |
| Health Plan (Yes) | 0.313 | 0.046 | 6.76 | 0.000 | *** |
| Smoker (Yes) | 0.275 | 0.034 | 8.03 | 0.000 | *** |
| Race (Black) | 0.135 | 0.045 | 2.98 | 0.003 | *** |
| Sex (Male) | -0.553 | 0.029 | -19.05 | 0.000 | *** |
| Age | -0.005 | 0.001 | -6.49 | 0.000 | *** |
| 1b. No HS Diploma | 0.000 | . | . | . | |
| 2. HS Diploma | -0.068 | 0.051 | -1.31 | 0.189 | |
| 3. Some College | 0.072 | 0.051 | 1.42 | 0.156 | |
| 4. College Grad | -0.054 | 0.054 | -1.01 | 0.314 | |
| 1b. <10k | 0.000 | . | . | . | |
| 2.10k-14,999k | -0.166 | 0.067 | -2.48 | 0.013 | ** |
| 3.15k-19,999k | -0.382 | 0.066 | -5.80 | 0.000 | *** |
| 4.20k-24,999k | -0.461 | 0.066 | -6.97 | 0.000 | *** |
| 5.25k-34,999k | -0.576 | 0.066 | -8.76 | 0.000 | *** |
| 6.35k-49,999k | -0.674 | 0.063 | -10.74 | 0.000 | *** |
| 7.50k-74,999k | -0.740 | 0.064 | -11.51 | 0.000 | *** |
| 8.75k+ | -0.816 | 0.062 | -13.22 | 0.000 | *** |
| County Proportion Urban | 0.008 | 0.057 | 0.14 | 0.889 | |
| County Proportion Vacant | -0.045 | 0.250 | -0.18 | 0.856 | |
| County Proportion Educated | -0.235 | 0.189 | -1.24 | 0.214 | |
| County Proportion Poverty | 0.025 | 0.331 | 0.08 | 0.939 | |
| _cons | -1.248 | 0.125 | -9.97 | 0.000 | *** |
| Mean dependent var | 0.094 | SD dependent var | | | 0.291 |
| Number of obs | 270964.000 | F-test | | | 48.921 |

*** p<0.01, ** p<0.05

**Table 29 Full Model Logistic Regression (Unweighted)**

| DV Asthma | Coef. | St.Err | t-value | p-value | Sig. |
|---|---|---|---|---|---|
| County Median AQI | -0.005 | 0.001 | -7.24 | 0.000 | *** |
| Health Plan (Yes) | 0.290 | 0.023 | 12.74 | 0.000 | *** |
| Smoker (Yes) | 0.152 | 0.017 | 8.78 | 0.000 | *** |
| Race (Black) | 0.030 | 0.023 | 1.33 | 0.185 | |
| Sex (Male) | -0.508 | 0.015 | -35.02 | 0.000 | *** |
| Age | -0.007 | 0.000 | -18.07 | 0.000 | *** |
| 1b. No HS Diploma | 0.000 | . | . | . | |
| 2. HS Diploma | -0.217 | 0.026 | -8.43 | 0.000 | *** |
| 3. Some College | -0.090 | 0.026 | -3.44 | 0.001 | *** |
| 4. College Grad | -0.180 | 0.027 | -6.54 | 0.000 | *** |
| 1b. <10k | 0.000 | . | . | . | |
| 2.10k-14,999k | -0.177 | 0.032 | -5.59 | 0.000 | *** |
| 3.15k-19,999k | -0.372 | 0.031 | -11.99 | 0.000 | *** |
| 4.20k-24,999k | -0.522 | 0.031 | -17.10 | 0.000 | *** |
| 5.25k-34,999k | -0.672 | 0.030 | -22.18 | 0.000 | *** |
| 6.35k-49,999k | -0.772 | 0.030 | -25.94 | 0.000 | *** |
| 7.50k-74,999k | -0.857 | 0.030 | -28.47 | 0.000 | *** |
| 8.75k+ | -0.967 | 0.029 | -33.45 | 0.000 | *** |
| County Proportion Urban | 0.056 | 0.027 | 2.08 | 0.037 | ** |
| County Proportion Vacant | 0.030 | 0.118 | 0.26 | 0.797 | |
| County Proportion Educated | -0.149 | 0.088 | -1.70 | 0.090 | |
| County Proportion Poverty | -0.396 | 0.165 | -2.41 | 0.016 | ** |
| _cons | -0.903 | 0.061 | -14.80 | 0.000 | *** |

| | | | |
|---|---|---|---|
| Mean dependent var | 0.094 | SD dependent var | 0.291 |
| Pseudo r-squared | 0.025 | Number of obs | 270964.000 |
| Chi-square | 4268.111 | Prob > chi2 | 0.000 |

*** p<0.01, ** p<0.05

**Table 30 Logistic Regression (Unweighted v. Weighted)**

| DV Asthma | (Unweighted) | (Weighted) |
|---|---|---|
| County Median AQI | -0.00503*** | -0.00607*** |
| Health Plan (Yes) | 0.290*** | 0.313*** |
| Smoker (Yes) | 0.152*** | 0.275*** |
| Race (Black) | 0.0301 | 0.135*** |
| Sex (Male) | -0.508*** | -0.553*** |
| Age | -0.00742*** | -0.00522*** |
| 2. HS Diploma | -0.217*** | -0.0676 |
| 3. Some College | -0.0900*** | 0.0720 |
| 4. College Grad | -0.180*** | -0.0542 |
| 2.10k-14,999k | -0.177*** | -0.166** |
| 3.15k-19,999k | -0.372*** | -0.382*** |
| 4.20k-24,999k | -0.522*** | -0.461*** |
| 5.25k-34,999k | -0.672*** | -0.576*** |
| 6.35k-49,999k | -0.772*** | -0.674*** |
| 7.50k-74,999k | -0.857*** | -0.740*** |
| 8.75k+ | -0.967*** | -0.816*** |
| County Proportion Urban | 0.0563** | 0.00803 |
| County Proportion Vacant | 0.0304 | -0.0453 |
| County Proportion Educated | -0.149 | -0.235 |
| County Proportion Poverty | -0.396** | 0.0254 |
| Constant | -0.903*** | -1.248*** |
| Observations | 270,964 | 270,964 |

*** $p<0.01$, ** $p<0.05$

Using survey weights changed the significance level effects of several of the level one and level two variables. In the unweighted logistic regression set (Table 29) race was not significant, but became statistically significant (positive coefficient at the 0.01 level) in the weighted set, see Tables 28 and 30. That is, black respondents have higher rates of asthma than non-black respondents. The statistically significant effects of individuals with a high school diploma, individuals with some college and college graduates (compared to omitted education category 1, no high school diploma) in the unweighted sample were not found to be statistically significant in the weighted sample. While statistically significant in the unweighted logistic regression, proportion urban and proportion poverty were not statistically significant in the weighted logistic regression. Compared to omitted income category 1 (annual household income level less than $10,000), individuals in income level 2 (annual household income level between $10,000-$14,999) have negative, significant coefficients in both the unweighted and weighted logistic regression runs, but are significant at the 0.01 level in the unweighted model and significant at the 0.05 level in the weighted model. In both models individuals in income level 2 are significantly less likely to have asthma compared to the omitted income category 1.

**Table 31 Linear Regression Predicting Median AQI**

| | Coef. | St.Err | t-value | p-value | Sig. |
|---|---|---|---|---|---|
| Health Plan (Yes) | -0.140 | 0.155 | -0.90 | 0.369 | |
| Smoker (Yes) | -0.950 | 0.120 | -7.89 | 0.000 | *** |
| Race (Black) | -0.189 | 0.143 | -1.32 | 0.186 | |
| Sex (Male) | 0.126 | 0.089 | 1.41 | 0.159 | |
| Age | -0.019 | 0.003 | -6.60 | 0.000 | *** |
| 1b. No HS Diploma | 0.000 | . | . | . | |
| 2. HS Diploma | -1.883 | 0.202 | -9.33 | 0.000 | *** |
| 3. Some College | -1.787 | 0.201 | -8.90 | 0.000 | *** |
| 4. College Grad | -2.031 | 0.206 | -9.84 | 0.000 | *** |
| 1b. <10k | 0.000 | . | . | . | |
| 2.10k-14,999k | -0.245 | 0.310 | -0.79 | 0.429 | |
| 3.15k-19,999k | -1.302 | 0.277 | -4.69 | 0.000 | *** |
| 4.20k-24,999k | -1.629 | 0.265 | -6.14 | 0.000 | *** |
| 5.25k-34,999k | -1.175 | 0.266 | -4.42 | 0.000 | *** |
| 6.35k-49,999k | -1.444 | 0.255 | -5.66 | 0.000 | *** |
| 7.50k-74,999k | -1.172 | 0.254 | -4.61 | 0.000 | *** |
| 8.75k+ | -1.007 | 0.247 | -4.09 | 0.000 | *** |
| County Proportion Urban | 18.925 | 0.150 | 125.92 | 0.000 | *** |
| County Proportion Vacant | -4.330 | 0.702 | -6.17 | 0.000 | *** |
| County Proportion Educated | -19.085 | 0.479 | -39.84 | 0.000 | *** |
| County Proportion Poverty | 44.488 | 0.913 | 48.71 | 0.000 | *** |
| _cons | 32.606 | 0.378 | 86.25 | 0.000 | *** |
| Mean dependent var | 40.235 | SD dependent var | | | 10.858 |
| R-squared | 0.210 | Number of obs | | | 270964.000 |
| F-test | 1365.865 | Prob > F | | | 0.000 |

*** p<0.01, ** p<0.05

Table 31 shows linear regression results of the independent variables predicting median AQI. Significant results were not found for the individual level variables health plan, race, sex, and income category 2 [$10,000-$14,999]. Each of the county level variables were significant.

County proportion urban and county proportion poverty both had positive coefficients. Higher proportions of share of county that is urban and in poverty were associated with a higher median AQI. County proportion vacant and county proportion educated both had negative coefficients. Higher proportions of share of county with owner vacancies and educated persons were associated with a lower median AQI. Eleven individual level variables have negative, significant coefficients: smoking, age, education categories 2, 3 and 4, income categories 3, 4, 5, 6, 7 and 8.

***Summary of Hypothesis Tests***

A summary of the various analysis results organized by the corresponding alternative hypotheses follow below. Hypothesis number one stated: Black individuals have a higher median AQI exposure level compared to non-black individuals. The results from quartile examination, t-tests and confidence intervals all suggest that there is a notable difference in exposure between black respondents and non-black respondents, with black individuals having higher AQI exposure levels compared to non-black individuals.

Hypothesis number two stated: Females have a higher median AQI exposure level compared to males. Differences in exposure were not found upon quartile examination, but the t-test and confidence intervals suggest that suggesting that males and females have differential AQI exposure levels, with females having higher AQI exposure levels compared to males.

Hypothesis number three stated: Non-College graduates have a higher median AQI exposure level compared to College graduates. Differences in exposure were not found upon quartile examination, but the t-test and confidence intervals suggest that college graduates and non-college graduates have differential AQI exposure levels. The opposite result of the alternative hypothesis was found, with college graduates having higher AQI exposure levels compared to non-college graduates.

Hypothesis number four stated: Low annual household income individuals have a higher median AQI exposure level compared to high annual household income individuals. It was consistently found that there was not a notable difference in exposure between income groups by quartile, t-test or confidence interval examination.

Hypothesis number five and six stated: Asthma prevalence will be positively associated with median AQI, and Differential sensitivity will not found by race, sex, education or income. The results of the logistic regressions indicate that county level median air quality is associated with adult asthma risk, but other county level effects are not significant, controlling for county and individual effects. Overall, variable significance and direction remain mostly consistent throughout the different logistic runs. Specific patterns of variable significance among the full sample and stratified logistic runs have been found. County level median AQI is consistently significant (with the exception of stratified race-Black and stratified income-high), all with negative coefficients. None of the other county level variables (proportion urban, proportion vacant, proportion educated, proportion in poverty) are significant for any of the logistic runs. Having a health plan is consistently significant (with the exception of stratified income-high), all with positive coefficients. Race (Black) was only significant (positive coefficients) for the original model and stratified sex-men, stratified education-non-college and stratified income-low. Smoking was consistently significant (with the exception of stratified education-college graduate and stratified income-high), all with positive coefficients. Sex of the respondent is consistently significant, all with negative coefficients. Age of the respondent is consistently significant, all with negative coefficients. Education was not significant (with the exception of stratified income-low and stratified income-high). Category 2 (high school diploma) and category 4 (college graduate) both have negative coefficients. Income 2 ($10,000-$14,999) is significant with the exception of stratified sex-men, stratified race-Black and stratified education-college graduate, all with negative coefficients. Income 3 ($15,000-$19,999) is significant with the exception of stratified education-college graduate, all with negative coefficients. Income 4 ($20,000-$24,999) is significant with the exception of stratified education-college graduate, all with negative coefficients. Income 5 ($25,000-$34,999), income 6 ($35,000-$49,999), income 7 ($50,000-$74,999) and income 8 ($75,000+) are all significant through each logistic run, and all have negative coefficients. It is important to note that although there are changes in significance (versus non-significance) for some of the variables in some of the runs, there are no coefficient directional changes.

Differential sensitivity differences have also been found upon examining stratification logistic regressions. Within the sex stratification run, each of the variables has the same level and direction of significance with the exception of race and income category 2. For men in the stratified sample, race (Black) is a significant, positive predictor of asthma. For women in the stratified sample, income category 2 ($10,000-$14,999) is a significant, negative predictor of asthma. Within the race stratification run, each of the variables has the same level and direction of significance with the exception of median AQI and income category 2. For non-Black respondents in the stratified sample, median AQI and income category 2 ($10,000-$14,999) are both significant, negative predictors of asthma. For non-college graduates in the education stratification sample, race (Black) and smoking are both significant, positive predictors of asthma. For non-college graduates in the stratified sample, income category 2 ($10,000-$14,999), income category 3 ($15,000-$19,999), and income category 4 ($20,000-$24,999) are all significant, negative predictors of asthma. Within the income stratification run, each of the variables has the same level and direction of significance with the exception of median AQI, health plan, race and smoking. For low income individuals in the stratified sample, median AQI is a significant, negative predictor of asthma. For low income individuals in the stratified sample, health plan, race (Black) and smoking are all significant, positive predictor of asthma.

***Caveats***

There are several key issues that must be addressed while interpreting these results. First, is the question of individual air pollution exposure versus individual air pollution sensitivity. The first possibility is that at risk group members may be exposed to higher levels of pollution. An additional possibility is that at risk group members may have higher sensitivity to pollution. It is beyond the scope of this project to examine sensitivity directly, as additional medical records showing immune/allergy information are not available for the respondents. The stratified logistic regression serves to examine this differential sensitivity. Evidence of group differences in exposure was based on the quartile examination, t-tests and confidence intervals, specifically by race.

Next, with a cross sectional study is it impossible to disentangle the temporal sequence of intra county sorting of households and polluters. There are several possibilities that may occur. At risk households may be sorted into higher pollution areas within a county to live. Industry/polluters may move into at risk neighborhoods and increase pollution. It is beyond the scope of this project to examine these issues directly, but there is a lack of evidence of differential exposure by low and high income based on the quartile examinations, t-tests and confidence intervals.

Finally, there is the temporal/spatial issue of inter county sorting. Without longitudinal tracking of individuals, it is difficult to ascertain whether individuals are moving from one county to another, changing the composition of said counties, or if air quality is affecting the composition of the county. For example, an influx of young adults move to a poor air quality county in which a new university has opened to attend school. This change in demographics would (spuriously) correlate poor air quality with a younger, educated demographic. The temporal sequence of intercounty sorting is beyond the scope of this project. These three examples highlight the methodological issues of studying air quality and asthma, in particularly on a large scale. These methodological issues are discussed in more detail in the final chapter. In the final chapter I summarize the major findings of this study, discuss additional limitations, offer future directions for research and provide a summary statement of implications.

# CHAPTER 5 – CONCLUSION

***Summary of findings***

Using air quality quartiles, t-tests, confidence intervals and logistic regression, this multivariate study includes three sources of data: the Behavioral Risk Factor Surveillance System 2011 (BRFSS), EPA's Air Quality System (AQS) database 2010, and the 2010 US Census. Six specific questions have been probed: 1) What is the difference in exposure of the median AQI by race, controlling for county and individual effects? 2) What is the difference in exposure of the median AQI by sex, controlling for county and individual effects? 3) What is the difference in exposure of the median AQI by education, controlling for county and individual effects? 4) What is the difference in exposure of the median AQI by income, controlling for county and individual effects? 5) Is the variation in asthma prevalence associated with county level median air quality? 6) Does the relationship between asthma prevalence and county level air quality vary by race, sex, education or income?

In order to answer research questions 1-4, regarding differential exposure to air quality, AQI quartile group differences, t-tests, confidence intervals were examined. In regard to question number one, it was found consistently that the most notable difference in exposure between groups is between black respondents and non-black respondents. The largest percentage of non-black respondents reside in the first quartile, while the largest percentage of black respondents reside in the fourth (worst air quality) quartile. The mean difference between non-blacks and blacks was statistically, significantly different from zero, suggesting that non-blacks and blacks have differential AQI exposure levels, with black individuals having higher AQI exposure levels compared to non-black individuals. Finally, the confidence intervals for black individuals and non-black individuals do not overlap, suggesting that black individuals and non-black individuals have differential AQI exposure levels, with black individuals having notably higher AQI exposure levels compared to non-black individuals.

To address question number two, it was found that the largest percentage of women and men both reside in the first quartile, but the mean difference between males and females was statistically, significantly different from zero. This suggests that males and females have differential AQI exposure levels, with females having higher AQI exposure levels compared to males. The confidence intervals for males and females do not overlap, suggesting that males and females have differential AQI exposure levels, with females having higher AQI exposure levels compared to males.

To examine question number three, it was found that the largest percentage of college educated and non-college educated respondents both reside in the first quartile, but the mean difference between college graduates and non-college graduates was statistically, significantly different from zero. This suggests that college graduates and non-college graduates have differential AQI exposure levels, with college graduates having higher AQI exposure levels compared to non-college graduates. The confidence intervals for college graduates and non-college graduates do not overlap, suggesting that college graduates and non-college graduates have differential AQI exposure levels, with college graduates having higher AQI exposure levels compared to non-college graduates.

In regard to answering question number four, it was found consistently that there was not a notable difference in exposure between income groups. It was found the largest percentage of low and high income respondents both reside in the first quartile and the mean difference between low and high income individuals was not statistically, significantly different from zero. It cannot be ascertained whether low and high income individuals have differential AQI exposure levels based on mean differences. The confidence intervals for high and low income individuals overlap, suggesting that high and low income individuals may not have differential AQI exposure levels.

The results from the stratified logistic regression were used to address the fifth and sixth research questions, which address differential sensitivity to air quality. The results indicate that county level median air quality is associated with adult asthma risk, but other county level effects are not significant, controlling for county and individual effects. Overall, variable significance and direction remain mostly consistent throughout the different logistic runs. Specific patterns of variable significance among the full sample and stratified logistic runs have been found. County level median AQI is consistently significant (with the exception of stratified race-Black and stratified income-high), all with negative coefficients. None of the other county level variables (proportion urban, proportion vacant, proportion educated, proportion in poverty) are significant for any of the logistic runs. This consistent finding was not expected, and possible explanations of these results are discussed below in the limitations section.

The individual level variables have specific patterns of significance as well. Having a health plan is consistently significant (with the exception of stratified income-high), all with positive coefficients. Race (Black) was only significant (positive coefficients) for the original model and stratified sex-men, stratified education-non-college and stratified income-low. Smoking was consistently significant (with the exception of stratified education-college graduate and stratified income-high), all with positive coefficients. Sex of the respondent is consistently significant, all with negative coefficients. Age of the respondent is consistently significant, all with negative coefficients. Education was not significant (with the exception of stratified income-low and stratified income-high). Category 2 (high school diploma) and category 4 (college graduate) both have negative coefficients. Income 2 ($10,000-$14,999) is significant with the exception of stratified sex-men, stratified race-Black and stratified education-college graduate, all with negative coefficients. Income 3 ($15,000-$19,999) is significant with the exception of stratified education-college graduate, all with negative coefficients. Income 4 ($20,000-$24,999) is significant with the exception of stratified education-college graduate, all with negative coefficients. Income 5 ($25,000-$34,999), income 6 ($35,000-$49,999), income 7 ($50,000-$74,999) and income 8 ($75,000+) are all significant through each logistic run, and all have negative coefficients. It is important to note that although there are changes in significance (versus non-significance) for some of the variables in some of the runs, there are no coefficient directional changes.

Intra-stratification differences have also been found. Within the sex stratification run, each of the variables has the same level and direction of significance with the exception of race and income category 2. For men in the stratified sample, race (Black) is a significant, positive predictor of asthma. For women in the stratified sample, income category 2 ($10,000-$14,999) is a significant, negative predictor of asthma. Within the race stratification run, each of the variables has the same level and direction of significance with the exception of median AQI and income category 2. For non-Black respondents in the stratified sample, median AQI and income category 2 ($10,000-$14,999) are both significant, negative predictors of asthma. For non-college graduates in the education stratification sample, race (Black) and smoking are both significant, positive predictors of asthma. For non-college graduates in the stratified sample, income category 2 ($10,000-$14,999), income category 3 ($15,000-$19,999), and income category 4 ($20,000-$24,999) are all significant, negative predictors of asthma. Within the income stratification run, each of the variables has the same level and direction of significance with the exception of median AQI, health plan, race and smoking. For low income individuals in the stratified sample, median AQI is a significant, negative predictor of asthma. For low income individuals in the stratified sample, health plan, race (Black) and smoking are all significant, positive predictor of asthma.

***Limitations and Future Research***

This study is not without limitations. The principal limitations relate to issues of measurement and using cross-sectional and secondary data. This study is limited by its cross-sectional data; only representing the variables at one point in time. This means there is no way of measuring whether or not a respondent's asthma was a result of living in the county in which they were surveyed. The measurement of the outcome variable is limited to respondents that have ever been told by a doctor they have asthma. This measurement does not take into account individuals that had limited or no medical care that may have had asthma. Although readily available, the utilization of secondary data limits the formulation of problems and concepts because measurement can only be based on existing data. It should be noted that this does not reduce the validity of importance of this research, and secondary data sources can be used to yield significant research as long as the limitations are understood. The placement of air quality stations could contribute to measurement error. Although the stations are typically placed in high traffic/high population areas, there is not a current, regulated station assignment from the EPA. That is, stations may not necessarily be placed where the pollution or need is greatest. County level measures are likely to be too large grained to have a specific effect on individual asthma risk, as asthma prevalence may vary due to population density (city versus suburbs versus rural) due to pollution emissions (D'amato et al, 2010 & Yip et al., 2011). Due to the data of the subjects, county level data is the finest grain geographic location available. An additional possibility is that the county level variables are actually proxies for air quality. Finally, data for indoor air quality was not available for the respondents in this study, nor are additional health data (immunosensitivity) for respondents. Respondent exposure to poor indoor air quality could serve as an explanation of the positive relationship between median AQI and asthma risk, and it is impossible to rule out individual pollution sensitivity.

This paper highlights the many methodological issues with studying asthma and outdoor air quality, including variable availability, measurement, and selection. Future research is integral to understanding relationships and creating meaningful and effective policy decisions. Additional research would be useful for other respiratory illnesses such as chronic obstructive pulmonary disease (COPD) and lung cancer and the relationship with air quality. Two frameworks would be useful while directing future research: life course and sociocological frameworks. Both frameworks would help solve internal validity methodological issues by addition temporal sequencing and reducing confounding issues. Geotracking monitoring home, school and work air quality would be necessary to reduce confounding issues, as well.

***Summary Statement of Implications***

This project demonstrates the incredibly complex methodological issues while studying asthma. This research has the potential to be a positive contribution to sociology by seeking to understand the possible contributing factors to the disproportional adult individual risk of asthma by race, sex, education and income in United States. There is a growing perspective on social/spatial/environmental determinants of health (Brown et al. 2003). There have been historical federal policies attempting to reduce the amount of environmental risk, such as: Title VI of the Civil Rights act (1964), Executive Order 12898, and the 1970 Clean Air Act (amended in 1990), but disproportionate exposure and health risks still exist (Gray et al. 2013). Evidence of environmental racism is provided by this study, as shown by the significantly different AQI exposure group mean differences between black individuals and non-black individuals. The breadth of literature supports the idea that detrimental environmental exposures are not distributed evenly among individuals in the U.S., by spatial or social lines and the same sorting pattern occurs within counties, but that claim cannot be made at this time without future, finer grained research. Health interventions and air quality policies should focus on using an Environmental Justice Framework at a finer grained level to aid in a more equal distribution of among at risk groups. More specifically, policy should acknowledge key players who affect the built and natural environment, as well as those in the community who will be affected by changes to the built and natural environment. The complex results of these findings underline the multifaceted nature of asthma risk, the importance of individuals having equal access to a healthy environment, and the need for finer-grain, longitudinal studies to determine relationships between individual and county level determinants in order to reduce asthma risk.

# APPENDIX A

## OVERVIEW: BRFSS 2011

### 1. BACKGROUND

The Behavioral Risk Factor Surveillance System (BRFSS) is a collaborative project of the Centers for Disease Control and Prevention (CDC) and U.S. states and territories. The BRFSS, administered and supported by CDC's Behavioral Risk Factor Surveillance Branch, is an ongoing data collection program designed to measure behavioral risk factors for the adult population (18 years of age or older) living in households. The BRFSS was initiated in 1984, with 15 states collecting surveillance data on risk behaviors through monthly telephone interviews. Over time, the number of states participating in the survey increased, so that by 2001, 50 states, the District of Columbia, Puerto Rico, Guam, and the Virgin Islands were participating in the BRFSS. In this document, the term “state” is used to refer to all areas participating in the surveillance system, including the District of Columbia, Guam, the U.S. Virgin Islands, and the Commonwealth of Puerto Rico.

The BRFSS objective is to collect uniform, state-specific data on preventive health practices and risk behaviors that are linked to chronic diseases, injuries, and preventable infectious diseases that affect the adult population. Factors assessed by the BRFSS include tobacco use, health care coverage, HIV/AIDS knowledge and prevention, physical activity, and fruit-and-vegetable consumption. Data are collected from a random sample of adults (one per household) through a telephone survey.

BRFSS field operations are managed by state health departments that follow guidelines provided by the CDC. These health departments participate in developing the survey instrument and conduct the interviews either in-house or by using contractors. The data are transmitted to the CDC's Office of Surveillance, Epidemiology, and Laboratory Services, Behavioral Risk Factor Surveillance Branch for editing, processing, weighting, and analysis. An edited and weighted data file is provided to each participating health department for each year of data collection, and summary reports of state-specific data are prepared by CDC. Health departments use the data for a variety of purposes, including identifying demographic variations in health-related behaviors, targeting services, addressing emergent and critical health issues, proposing legislation for health initiatives, and measuring progress toward state and national health objectives.[1]

The health characteristics estimated from the BRFSS pertain to the adult population, aged 18 years or older, who live in households. In 2011, additional questions were included as optional modules to provide a measure for several childhood indicators including asthma prevalence and influenza immunization for people aged 17 years or younger. As noted above, respondents are identified through telephone-based methods. Overall, an estimated 96.3% of U.S. households had telephone service in 2010.[2] The telephone coverage varies across states and subgroups. The increasing percentage of households that are abandoning their landline telephones for cell phones has significantly eroded the population coverage provided by landline-based surveys to pre-1970s levels. For the first half of 2011, the percentage of cell phone-only households was 31.6 percent.[3] This is an increase of 1.9 percent over the preceding 6-month period. In households where both landline and wireless phone service is available, there is a trend toward increased use of wireless communication. In 2011, BRFSS respondents who received 100 percent of their calls on cell phones were eligible for participation in the cell phone survey. No direct method of compensating for non-telephone coverage is employed by the BRFSS; however, in 2011, a new weighting methodology, iterative proportional fitting (or “raking”), replaced the post stratification weighting method that had been used for the BRFSS for several years. Raking adjusts the data so that groups which are underrepresented in the sample can be more accurately represented in the final dataset. Raking allows for the incorporation of cell phone survey data, permits the introduction of additional demographic characteristics and more accurately matches sample distributions to known demographic characteristics of populations. The use of raking reduces nonresponse bias and has been shown to reduce error within estimates. BRFSS raking includes categories of age by gender, detailed race and ethnicity groups, education levels, marital status, regions within states, gender by race and ethnicity, telephone source, renter/owner status, and age groups by race and ethnicity. In 2011, 50 states, the District of Columbia, Guam, and Puerto Rico collected samples of both landline and cell phone interviews while the Virgin Islands collected a sample of landline-only interviews.

## 2. DESIGN OF THE BRFSS

### A. The BRFSS Questionnaire

The questionnaire has three parts: **i. Core component:** a standard set of questions asked by all states. It includes queries about current health-related perceptions, conditions, and behaviors (e.g., health status, health insurance, diabetes, tobacco use, disability, and HIV/AIDS risks), as well as demographic questions.

**ii. Optional CDC modules:** sets of questions on specific topics (e.g., cardiovascular disease, arthritis, women’s health) that states elect to use on their questionnaires. In 2011, 34 optional modules were supported by CDC. The module questions are generally submitted by CDC programs and have been selected for inclusion in the editing and evaluation process by CDC. For more information, see http://apps.nccd.cdc.gov/BRFSSModules/ModByState.asp?Yr=2011.

**iii. State-added questions:** These are questions developed or acquired by participating states and added to their questionnaires. State-added questions are not edited or evaluated by CDC.

Each year, the states and CDC agree on the content of the core component and optional modules. Many questions are taken from established national surveys, such as the National Health Interview Survey or the National Health and Nutrition Examination Survey. This practice allows the BRFSS to take advantage of questions that may have been tested and allows states to compare their data with those from other surveys. Any new questions proposed as additions to the BRFSS must go through cognitive testing and field testing prior to their inclusion on the survey. BRFSS guidelines specify that all states ask the core component questions without modification; they may choose to add any, all, or none of the optional modules and may add questions of their choosing at the end of the questionnaire.

Although CDC supported 34 modules in 2011, it is not feasible for a state to use them all. States are selective about which modules and state-specific questions they add, to ensure the questionnaire is kept at a reasonable length--but there is wide variation across states in the total number of questions in a given year. New questionnaires are implemented in January and usually remain unchanged throughout the year. However, the flexibility of state-added questions does permit additions, changes, and deletions at any time during the year. The 2011 list of optional modules used on both the landline and cell phone surveys is available at http://apps.nccd.cdc.gov/BRFSSModules/ModByState.asp?Yr=2011.

**B. Annual Questionnaire Development**

The State BRFSS Coordinators Working Group meets three times a year with the Behavioral Risk Factor Surveillance Branch Management. One task of this group is to develop a 5-year, long-term plan for the BRFSS core instrument. The 2011 BRFSS questionnaire was the first year of a 5-year plan.

Before the beginning of the calendar year, CDC provides states with the text of the core component and the optional modules that will be supported for the coming year. States select their optional modules and choose any state-added questions. Each state then constructs its questionnaire. The order of the questioning is always the same: the core component is asked first, optional modules are asked next, and state-added questions last. This ordering ensures comparability across states and follows CDC guidelines. Generally, the only changes allowed are limited insertions of state-added questions on topics related to core questions. Such exceptions are to be agreed upon in consultation with CDC. However, despite this flexibility, not all states have adhered to the guidelines. Known deviations from the guidelines are noted in the Comparability of Data document.

Once the questionnaire content (core, modules, and state-added questions) is determined by a state, a hard-copy or electronic version of the instrument is constructed and sent to CDC. For states with Computer-Assisted Telephone Interview (CATI) systems, this document is used for CATI programming and general reference. The questionnaire is used without changes for one calendar year. The questionnaire is available at http://www.cdc.gov/brfss/questionnaires/questionnaires.htm. If a significant portion of the state population does not speak English, states have the option of translating the questionnaire into other languages. At the present time, CDC also provides a Spanish version of the core questionnaire and optional modules.

**C. Sample Description**

In a telephone survey, such as the BRFSS, a sample record is one telephone number in the list of all telephone numbers selected for dialing. To meet the BRFSS standard for the participating states' sample designs, sample records must be justifiable as a probability sample of all households with telephones in the state. All participating areas met this criterion in 2011. Fifty-one projects used a disproportionate stratified sample (DSS) design. Guam, Puerto Rico, and the U.S. Virgin Islands used a simple random sample design.

In the type of DSS design most commonly used in the BRFSS landline sampling, telephone numbers are divided into two groups, or strata, which are sampled separately. The high-density and medium-density strata contain telephone numbers that are expected to belong mostly to households. Whether a telephone number goes into the high-density or medium-density stratum is determined by the number of listed household numbers in its hundred block, or set of 100 telephone numbers with the same area code, prefix, and first two digits of the suffix and all possible combinations of the last two digits. Numbers that come from hundred blocks with one or more listed household numbers (“1+ blocks,” or “banks”) are put in either the high-density stratum (“listed 1+ blocks”) or medium-density stratum (“unlisted 1 + blocks”). The two strata are sampled to obtain a probability sample of all households with telephones.

Cell phone sampling frames are available from Marketing Systems Group (MSG)--Genesys Sampling Systems--and random samples of cell phone numbers can be called, provided that specific protocols are followed. Their sampling frame is based on the Telecordia database of telephone exchanges (e.g., 617-492-000 to 617-492-9999) and 1,000 banks (e.g., 617-492-0000 to 617-492-0999). MSG uses dedicated cellular 1,000 banks, sorted on the basis of area code and exchange within a state. An interval, K, is formed by dividing the population count of telephone numbers in the frame, N, by the desired sample size, n. The frame of telephone numbers is divided into n intervals of size K telephone numbers. From each interval, one 10-digit telephone number is drawn at random.

The target population for cell phone samples in 2011 consists of persons living in households who have a working cellular telephone, are aged 18 and older, and do not have a landline telephone.

In most cases, each state constitutes a single stratum. However, to provide adequate sample sizes for smaller geographically defined populations of interest, some states sample disproportionately from strata defined to correspond to substate regions. In 2011, the 48 states or territories with disproportionately sampled geographic strata were Alabama, Alaska, Arizona, Arkansas, California, Colorado, Connecticut, Delaware, the District of Columbia, Florida, Georgia, Hawaii, Idaho, Illinois, Indiana, Iowa, Kansas, Kentucky, Louisiana, Maine, Maryland, Massachusetts, Michigan, Minnesota, Mississippi, Missouri, Montana, Nebraska, Nevada, New Hampshire, New Jersey, New Mexico, New York, North Carolina, Ohio, Oklahoma, Pennsylvania, Puerto Rico, Rhode Island, South Carolina, South Dakota, Tennessee, Texas, Utah, Virginia, the Virgin Islands, Washington, and Wisconsin.

Data for a state may be collected directly by the state health department or a contractor. In 2011, 11 state health departments collected their data in-house; 43 contracted data collection to university survey research centers or commercial firms. In 2011, the CDC's Behavioral Risk Factor Surveillance Branch provided samples purchased from MSG to all 54 states or territories.

## 3. DATA COLLECTION

### Interviewing Procedures

In 2011, 54 states or territories used CATI systems. CDC supports CATI programming using the Ci3 WinCATI software package. This support includes programming the core and module questions for data collectors, providing questionnaire scripting of state-added questions for states requiring such assistance, and contracting with a Ci3 consultant to assist states. Following guidelines provided by CDC, state health personnel or contractors conduct interviews. The core portion of the questionnaire lasts an average of 18 minutes. Interview time for modules and state-added questions is dependent upon the number of questions used, but generally add 5 to 10 minutes to the interview.

Interviewer retention is very high among states that conduct the survey in-house. The state coordinator or interviewer supervisor usually conducts the training using materials developed by CDC. These materials cover seven basic areas: overview of the BRFSS, role descriptions for staff involved in the interviewing process, the questionnaire, sampling, codes and dispositions (three-digit codes indicating the outcome of each call attempts), survey follow-up, and practice sessions. Contractors typically use interviewers who have experience conducting telephone surveys, but these interviewers are given additional training on the BRFSS questionnaire and procedures before they are approved to work on BRFSS. Further specifics on interviewer training and procedures are available at http://www.cdc.gov/brfss/training.htm.

CDC expects interviewer performance to be monitored. In 2011, all BRFSS surveillance sites had the capability to monitor their interviewers. The system used for monitoring interviewers varied from listening to the interviewer only at an on-site location to listening to both the interviewer and respondent at a remote location. Verification call-backs were also used by some states in lieu of direct monitoring. Contractors typically conducted systematic monitoring by monitoring each interviewer a certain amount of time each month. All states had the capability to tabulate disposition code frequencies by interviewer. These data were the primary means for quantifying interviewer performance. All states were required to do verification callbacks for a sample of completed interviews as part of their quality-control practices.

Telephone interviewing was conducted during each calendar month, and calls were made seven days per week, during both daytime and evening hours. Standard procedures were followed for rotation of calls over days of the week and time of day. BRFSS procedural rules are described in the *BRFSS User's Guide* at ftp://ftp.cdc.gov/pub/Data/Brfss/userguide.pdf

Detailed information on interview response rates and item nonresponse rates are discussed at http://www.cdc.gov/brfss/technical_infodata/quality.htm.

## 4. DATA PROCESSING

### A. Preparing for Data Collection and Data Processing

Data processing is an integral part of any survey. Because data are collected and sent to CDC during each month of the year, there are routine data processing tasks that need attention on an ongoing basis throughout the year. In addition, there are tasks that need to be conducted at different points in the annual BRFSS cycle. The preparation for the survey involves a number of steps that take place once the new questionnaire is finalized. This includes developing the edit specifications, programming portions of the Ci3 WinCATI software, programming the editing software, and producing telephone sample estimates for states that require them and ordering the sample from the contract vendor. A Ci3 WinCATI data entry module for each state that uses this software is produced. Skip patterns, together with some consistency edits, and response-code range checks are incorporated into the CATI system. These edits and skip patterns serve to reduce interviewer, data entry, and skip errors. Data conversion tables are then developed. These tables are used for reading the survey data from the entry module, calling information from the sample tracking module, and combining information into the final format specified for the data year. CDC also creates and distributes a Windows-based editing program that can perform data validations on properly formatted survey results files. This program is used to output lists of errors or warning conditions encountered in the data.

CDC begins to process data for the survey year as soon as states or their contractors begin submitting data to the data management mailbox, and continues processing data throughout the survey year. CDC receives and tracks monthly data submissions from the states. Once data are received from the state, editing programs and cumulative data quality checks are run against the data. Any problems in the file are noted, and a CDC programmer works with the state until the problems are resolved or agreement is reached that no resolution is possible. Response-rate data quality reports are produced and shared with the project officers and state coordinators, who review the reports and discuss any potential problems with the state. Once the entire year of data for a state has been received and validated, several year-end programs are run on the data. These programs perform some additional, limited data cleanup and fixes specific to the state and data year, and produce reports that identify potential analytic problems with the data set. Once these programs have been run, the data are ready for assigning weights and adding new variables.

Not all of the variables that appear on the public use data set are taken directly from the state files. CDC prepares a set of SAS programs that are used for end-of-year data processing. These programs prepare the data for analysis and add weighting and risk factor calculations as variables to the data file. The following variables are examples of results from this procedure and are created for the user's convenience: _RFSMOK3, _MRACE, _AGEG_, _TOTINDA. For more information, see the Calculated Variables and Risk Factors in Data Files document at http://www.cdc.gov/brfss/technical_infodata/surveydata/2011.htm. To create these variables, several variables from the data file are combined. The process of creating these variables varies in complexity; some are based only on combined codes, while others require sorting and combining of selected codes from multiple variables.

Almost every variable derived from the BRFSS interview has a code category labeled "refused" and generally given a value of "9," "99," or "999" value. Typically, the category consists of non interviews (a "non-interview" response results when an interview is terminated prior to this question and an interviewer codes the remaining responses as "refused") and persons for whom the question was not applicable because of a previous response or a personal characteristic (e.g., age). However, this code may capture some questions that were supposed to be answered, but for some reason were not, and appeared as a blank or other symbol. The combination of these types of responses into a single code requires vigilance on the part of data file users who wish to separate respondents who were skipped out of a question from those who were asked, but whose answer was unknown or who refused to answer a particular question.

**B. Weighting the Data**

When data are used without weights, each record counts the same as any other record. Implicit in such use are the assumptions that each record has an equal probability of being selected and that noncoverage and nonresponse are equal among all segments of the population. When deviations from these assumptions are large enough to affect the results obtained from a data set, then weighting each record appropriately can help to adjust for assumption violations. An additional, but conceptually unrelated, reason for weighting is to make the total number of cases equal to some desired number which, for state BRFSS data, is the number of people in the state who are aged 18 years and older. In the BRFSS, such raking serves as a blanket adjustment for noncoverage and nonresponse and forces the total number of cases to equal population estimates for each geographic region, which for the BRFSS is usually a state.

Following is a general description of the process that reflects factors taken into account in weighting the 2011 BRFSS data. Where a factor does not apply its value is set to one for calculation.

The Raking weighting methodology is comprised of two sections: Design weight and raking.

**Design Weight = STRWT * (1/NUMPHON2) * NUMADULT**

The stratum weight accounts for differences in the basic probability of selection among strata (subsets of area code/prefix combinations). It is the inverse of the sampling fraction of each stratum. There is rarely a complete correspondence between strata, which are defined by subsets of area code/prefix combinations, and regions, which are defined by the boundaries of government entities.

• The stratum weight (**STRWT**) is calculated using:

– Number of available records (**NRECSTR**) and the number of records selected (**NRECSEL**) within each geographic strata and density strata.
– Geographic strata (**GEOSTR)** which may be the entire state or a geographic subset such as counties, census tracts, etc.
– Density strata (**_DENSTR**) indicating the density of the phone numbers for a given block of numbers as listed or not listed.

Within each **_GEOSTR*_DENSTR** combination the stratum weight (**_STRWT**) is calculated from the average of the **NRECSTR** and the sum of all sample records used to produce the **NRECSEL**. The stratum weight is equal to **NRECSEL / NRECSTR.**

• **1/ NUMPHON2** is the inverse of the number of residential telephone numbers in the respondent's household.

• **NUMADULT** is the number of adults 18 years and older in the respondent's household.

**FINAL WEIGHT** = The design weight is raked to 8 margins (age group by gender, race/ethnicity, education, marital status, tenure, gender by race/ethnicity, age group by race/ethnicity, phone ownership). If geographic regions are included, four additional margins (region, region by age group, region by gender, region by race/ethnicity) are included.

**_LLCPWT** is the final weight assigned to each respondent.
Weight trimming is used to increase the value of extremely low weights and decrease the value of extremely high weights. The objective of weight trimming is to reduce errors in the outcome estimates caused by unusually high or low weights in some categories.

Calculation of a Child Weight
The design weight for the child weighting is calculated from the stratum weight times the inverse of the number of telephones in the household and then multiplied by the number of children
**Child Design Weight = STRWT * (1/NUMPHON2) * CHILDREN**
**CHIILDWT** = The child design weight is raked to 5 margins including age by gender, race/ethnicity, gender by race/ethnicity, age by race/ethnicity, and phone ownership.
**_CLLCPWT** is the weight assigned for each child interview.

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# ABSTRACT

## THE DISPROPORTIONATE BURDEN OF ASTHMA BY RACE, SEX, INCOME AND EDUCATION

by

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**Major:** Sociology (Medical)

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This paper seeks to understand the relationship of county level median air quality with adult asthma risk, and the disproportional adult asthma risk by sex, race, income and education, controlling for individual and county effects. The specific objectives of this work are to answer the following questions: 1) What is the difference in exposure of the median AQI by race, controlling for county and individual effects? 2) What is the difference in exposure of the median AQI by sex, controlling for county and individual effects? 3) What is the difference in exposure of the median AQI by education, controlling for county and individual effects? 4) What is the difference in exposure of the median AQI by income, controlling for county and individual effects? 5) Is the variation in asthma prevalence associated with county level median air quality? 6) Does the relationship between asthma prevalence and county level air quality vary by race, sex, education or income?

Guided by an environmental justice framework, this study includes three sources of data: the Behavioral Risk Factor Surveillance System 2011 (BRFSS), EPA's Air Quality System (AQS) database 2010, and the 2010 US Census. The associations between adult asthma risk and individual and county level variables are assessed using median AQI quartiles, t-tests, confidence

intervals and logistic regression. The results indicate that county level median air quality is associated adult asthma risk, but other county level variables are not significant, controlling for county and individual effects. The logistic regression results also indicate that the individual level factors of having a health plan, smoking, sex, age and annual household income greater than $15,000 have an association with adult asthma risk, controlling for county and individual effects. Furthermore, sex, education and income stratifications show racial differences in adult asthma risk, controlling for county and individual effects. The complex results of these findings underline the multifaceted nature of asthma risk, the importance of individuals having equal access to a healthy environment, and the need for finer-grain, longitudinal studies to determine relationships between individual and county level determinants in order to reduce asthma risk.

## AUTOBIOGRAPHICAL STATEMENT

Lisa Stack received her B.A. in sociology from Wayne State University in 2007 and her M.A. in sociology from Wayne State University in 2012. She worked as a research assistant with Dr. George Galster in the Department of Urban Studies and Planning from 2009-2014. Her research interests include health disparities, neighborhood effects on health, and land use patterns. She was a co-author of the 2014 HUD publication, *Opportunity Neighborhoods for Latino and African American Children*. Additional publications can be found in Urban Geography and the Journal of Urban Affairs. Notable presentations include: "Evolving U.S. Metropolitan Land Use Patterns, 1990-2000" 41st Urban Affairs Conference; New Orleans, LA 2011 and "Typologies of Sprawl: U.S. Metropolitan Land Use Patterns" 42nd Urban Affairs Conference; Pittsburgh, PA 2012. She co-received the Urban Affairs Association - Best 2014 conference paper award "School Performance of Low-Income Latino and African American Youth: The Role of Neighborhood Context".