The Missing Link of Air Pollution: A Closer Look at the Association Between Place and Life Expectancy in 146 Mid-Sized Cities

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ABSTRACT

Clean air has long been a priority for environmental planning policy in the U.S. From 2016 to 2020, the Trump administration removed 94 environmental regulations that protected the water, air and soils from pollution. Research has been mixed on the relationships between air pollution and life expectancies; some recent work suggests that these relationships cannot be empirically supported. Our research explores how people living in places with high levels of pollution have lower life expectancies. We test this relationship using four different U.S. Environmental Protection Agency (EPA) measures of air quality to analyze the impacts of air pollution. Data for these types of airborne pollution were used to assess the relationships of human mortality rates in 146 semi-isolated, medium-sized U.S. cities.

Accounting for control factors, these data indicate that in areas with high levels of air pollution, men and women in lower income quartiles live for 4 or 5 fewer years than in cities with relatively clean air. A more rigorous regression analysis reveals that all four of EPA's measures are statistically significant and have strong coefficients nearly equal to income and gender. The implications of these findings have very specific implications for public health and planning—air quality matters for more than just climate value, it is associated with shorter human lifespans. Our research shows the importance of how environmental planning measures that reduce air emissions impacts life expectancies. It underscores the importance of local policies that reduce emissions from stationary sources and offer incentives to increase the proliferation of clean fuel vehicles.

INTRODUCTION

Recent research has generated controversy concerning whether air pollution has an impact on life expectancy. Chetty et al. found that "…variations in life expectancy were correlated with health behaviors and local area characteristics" [1]. Contradicting land use and planning literature, they could not connect air pollution with to shorter life expectancies. They, said that "…physical aspects of the local environment affect health, for example, through exposure to air pollution…" were not supported by their work. While the research underscores decades of urban planning work indicating land use and public health are connected, it takes a more passive approach to the impacts of vehicle miles traveled and air quality—stopping short of connecting the compounding effects of local environmental conditions on health trajectories.

The Chetty team has encouraged further analysis of their data. In our view, one limitation of their work was that the spatial scale of the measurements taken were at the national level. The team chose not to test whether pollution impacted lifespan by city despite available air pollution test variables on 547 places in the data set of 741 urban commuting zones (CZs). Our work uses a smaller spatial scale to investigate whether air pollution is associated with variations in the median human lifespan in cities. We gathered EPA airborne emissions data on four measures: sulfur oxides (SO_x), nitrogen oxides (NO_x) and particulate matter (PM 2.5µ and PM10µ). Much of this air pollution is caused by local stationary power sources and vehicles. This research is positioned to complement land use planning, transportation planning and engineering research aimed at reducing the harmful impacts of air pollution emissions from a human health and climate perspective.

BACKGROUND

A vast amount of research on local air pollution illustrates its negative effects on human health and planning considerations with far-ranging consequences for people of all races, genders, ages, income levels and occupations.

Impacts of Air Pollution on Human Health

Numerous scholarly articles argue that pollution adversely impacts human health [2,6]. These effects can be exacerbated by the proximity to higher amounts of air pollution. While multiple variables affect the quality of life for the groups discussed, air pollution appears to be a key component. These works span the globe and cross disciplines from public health to city planning and engineering. Worldwide, air pollution was responsible for 7 million premature deaths in 2010 [7]. The Organization for Economic Co-operation and Development (OECD) states that by 2050, air pollution will be the number one cause of premature death rates rising ahead of current primary causes including sanitation and dirty water [8]. *The Lancet* estimates that 1.2 million premature deaths occur annually in Chinese cities due to polluted air, shortening life expectancies from four to thirteen years [9,13]. A study by the EPA estimated that a Trump Administration rollback of pollution restrictions on coal plants (that covered requirements for cleaning coal ash and toxic heavy metals such as mercury, arsenic and selenium) could result in up to 1,400 more premature deaths annually in the U.S. [14].

Air pollution is potentially even more damaging for infants. Studies have verified a link between fetal exposure to pollution and higher infant mortality rates [15]. Reductions in atmospheric carbon monoxide (CO) levels reduce instances of low birth weight and development issues as children grow older [16,18]. Prinz et al. have shown that prenatal exposure to a variety of types of air pollution negatively affects academic test scores and economic outcomes [19]. Lower labor force participation and lower earnings are correlated with higher exposure to pollution [20,21].

Urban Planning Considerations

Related public health issues connect to the urban planning discipline. For example, many studies have considered the connection between increased walking and cycling, decreased emissions and increased public health outcomes, encouraging planning for community walkability as a mitigation strategy [22,24]. One of the most cited is Frank et al.’s which found that for every

5% increase in walkability there were over 5% fewer grams of NOx and volatile organic compounds emitted [25]. Economic planners have shown health benefits in terms of jobs and productivity. For example, Hanna and Oliva found that a 19.7% decrease in SO_X emissions result in an increase of 3.5% in working hours for immediate neighbors within 3.1 miles (5 km) of a heavy polluter; this includes a 6% increase in the probability of those residents working over 40 hours weekly and a 2.5% increase in the probability of them working over 10 hours weekly [26].

Planning and environmental literature shows that many of the areas with the most sources of air pollution are located in racial and ethnic minority neighborhoods [27-34]. While there has been debate as to populations that were forced to self-select into these locations, recent work suggests that many air polluting sources were located in minority neighborhoods after their racial composition had been established [4,35,36]. The evidence consistently supports the premise that that minority populations are disproportionately impacted by pollution [11,37-39,40].

Recent work by Chetty et al. explores how *place* shapes life chances, yet provides inconclusive results with regard to the impacts of air quality. While the data from Chetty provides an accurate measurement of lifespan by city and affirms that places with higher incomes have longer life expectancies using granular life expectancy data, it fails to assess highly localized impacts of air pollution [1,41-44]. Numerous studies emphasize that from a land use and transportation perspective, local conditions matter in relation to air pollution exposure [17,45-47]. They also relate to global climate related initiatives to reduce greenhouse gas (GHG) emissions, helping to reduce some of the burden of these issues.

Reductions in fossil fuel combustion processes correspond with reductions in CO_2 emissions, lowering levels of criteria pollutants and particulates [48]. The benefits of reducing GHGs correspond to roughly a half million fewer premature deaths due to other types of air pollution and to a slowing in the effects of global warming by 2030 [49]. A study by Burtraw et al. estimated that the total short-term health benefits gained through ancillary NO_X and SO_X reductions, and taxing all GHGs could justify the initial cost of the tax [50].

In the realms of planning and land use, the connections between air pollution and health have focused on urban heat island effects and climate mitigation. For example, Brian Stone's work advocated for air quality management from a pollution and climate adaptation prospective; he sees much of the public health benefits sourced from urban heat reduction measures [51,52]. While Schweitzer and Zhou provided an analysis of how more compact cities can result in fewer air emissions, they do not address how the benefits of reducing pollution emissions connect back to public health in compact cities [53].

Boswell, Seale and Greve argue for climate mitigation strategies in land use and transportation planning, yet cite secondary sources in making their case for the health benefits of climate-related pollution emissions reduction strategies [54].

In this context we position our work to extend the planning literature, underscoring the health benefits of compact cities, and re-evaluating Chetty et al.'s work at a smaller spatial scale [1]. This is positioned in the spirit of action, akin to the response to Stone by Winkleman that we need to "…re-imagine how our communities and regions look and function" while addressing the adverse impacts of air quality [55].

METHODOLOGIES

In contrast to the work of Chetty et al., we consider an air quality analysis that focuses on a local spatial scale. Instead of the larger state and CZs, we use the much smaller and generally more consistent unit of *county* as our level of analysis. While smaller geographical units may be used, given the research question (*viz*. "Is pollution in cities associated with variations in lifespan?"), and data restraints (EPA data used here is available for roughly 547 counties in the U.S.), we chose to minimize the reductionist fallacy rather than the ecological fallacy.[1]

When using U.S. counties as the unit of analysis, two concerns make replicating recent research difficult: spatial lag and case selection. While we recognize many local policies happen at the level of cities, we use the county geographic framework as a policy lens to consider city policies, since most of our case cities contain one or multiple counties. In this sense a limitation of this study is our reference to city policy, and cities are reflective of county geography. Most of the cases used in extant research either border or are situated near other cases of similar or larger populations. They often share labor, transportation, housing markets and public policies. Adjacent counties and cities are subject to policy spillovers, whereby the impacts of one city's policies can be measured in geographically adjacent jurisdictions. Airborne emissions disregard areal units and political boundaries.

Case Selection

For case selection, researchers often use all available cities for which there is data. Since there is great variety among counties, this approach is known to urban scholars as misleading. It is highly problematic to include giant metropolises like New York City in a sample set that is dominated by smaller U.S. cities. Instead of lumping together categorically different urban centers, we select cases by using a well-validated set of decision rules from the field of urban affairs that addresses both the spatial lag and case selection concerns. We applied the research protocols found in Appelbaum's *Size, Growth, and U.S. Cities* (1978) and other studies which used this sampling technique [28,41,56-60]. This approach has been used to study a wide range of interurban phenomena, including rent differentials, income inequality, public health and quality of life.

Case selection begins with the universe of all incorporated places as defined by the U.S. Census. The population is then further reduced to those cities with populations over 50,000 which are not located within 20 miles (32.2 km) of another city of a similar size. Figure 1 shows the location of the cities used for this study. The counties in the dataset are neither evenly-distributed nor clustered, but randomly distributed throughout the continental U.S. (Moran's I: 0.049, z = 1.62). The county as a unit of analysis allows for a more granular assessment than the larger CZs. The distance between counties decreases problems of spatial proximity.

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[1] Researchers are rightfully concerned about the ecological fallacy, but seem so with the atomistic fallacy. This occurs when the characteristics of cities and neighborhoods are assumed to result from characteristics of smaller units such as Census blocks [22].

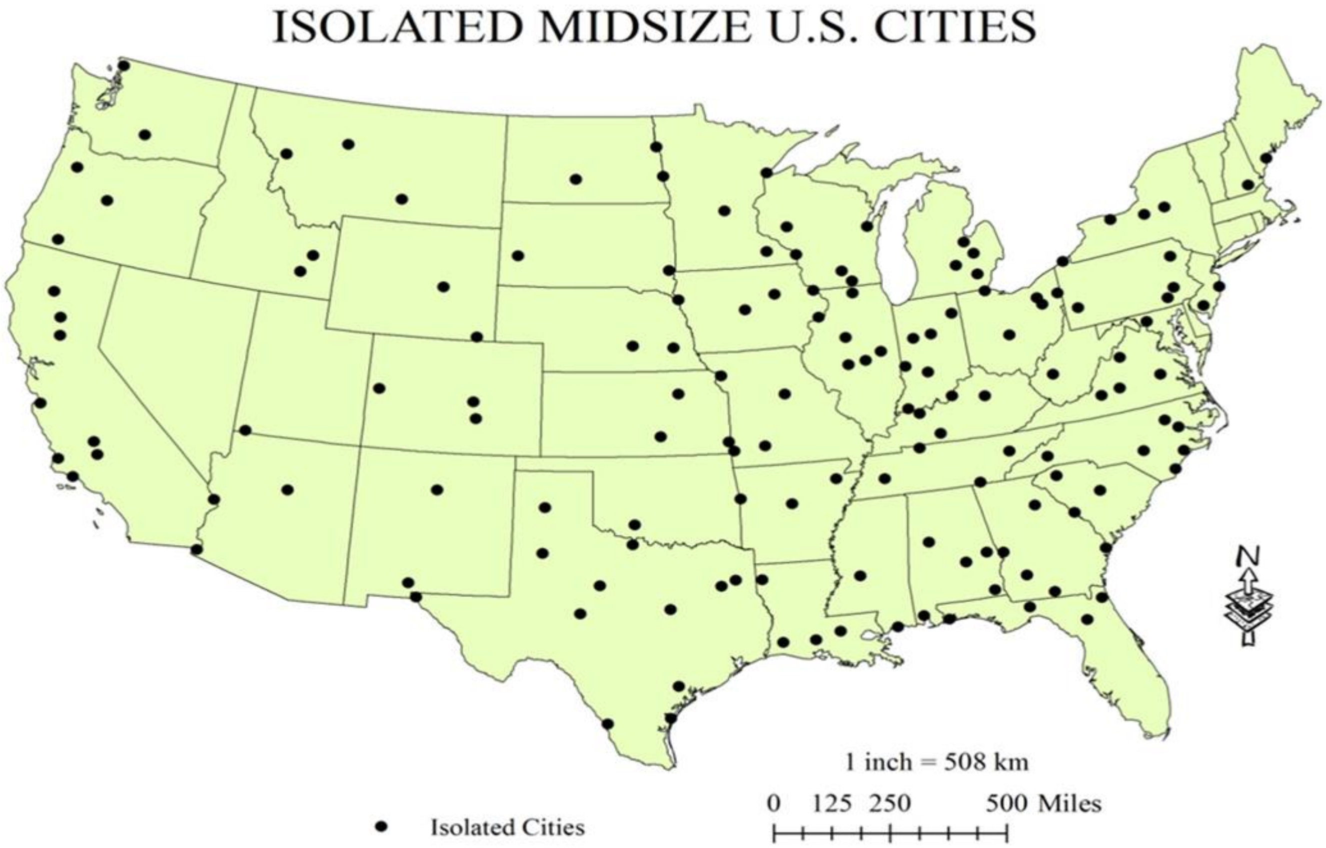


Figure 1. 148 semi-isolated, mid-sized U.S. cities.

Dependent Variable

We borrow the lifespan measure and solid life span averages for cities from Chetty who uses Social Security mortality data [1]. We focus on the dependent variable *life expectancy* of four demographic groups: poor men and women, and wealthy men and women. Poor and wealthy are defined as the lowest and highest income quartile, respectively. This measure is considered the most accurate measure of life expectancy by city. Traditionally, life span was estimated, Chetty's numbers are based on Social Security data of when a person actually died with a mean created for each county.

Control Variables

All the remaining variables used in this study are from the U.S. Census 2013 three-year estimates measured at the geographical level of the county. Researchers often use variables without regard for multicollinearity and endogeneity, namely unemployment and the Gini coefficient, a measure of statistical dispersion. We use single measures for control variables that capture broad sociological and geographical phenomena associated with life expectancy: *latitude*, *population*, *density*, *median household income*, *percent black (African American)*, *percent college educated*, and *commute mode diversity*.

Test Variables

The National Emissions Inventory, released every three years, provides a comprehensive estimate of the air emissions of criteria pollutants and hazardous air pollutants from emissions sources. State, local, and tribal air agencies provide data which supplement EPA data [61-63]. Four EPA variables, described below, are used in these studies [6,64-68].

- *Particulate matter (PM_{10} & $PM_{2.5}$):* Particulate matter refers to inhalable particles of sized 2.5 and 10 micrometers which can become deeply lodged in an individual's respiratory system or bloodstream. Studies have linked particle pollution exposure to numerous health problems (e.g., premature deaths and increased respiratory symptoms) [69,70].
- *Oxides of nitrogen (NO_x):* Oxides of nitrogen are reactive, poisonous gases, commonly emitted by automobiles, power plants, industrial boilers and turbines. Breathing high concentrations of NO_2 can irritate the airways which can aggravate respiratory diseases, like asthma, causing difficulty breathing and coughing [61,71].
- *Oxides of sulphur (SO_x):* Oxides of sulfur are colorless gases that can be detected by taste and smell. The main sources of SO_2 are from fossil fuel combustion in power plants, vehicles and other industrial facilities [61,72]. Short-term exposure to SO_2 can harm the human respiratory system, making breathing difficult [70,71].

Table 1. The impacts of air pollution on life expectancy, low vs. high emission cities.

City, State	*County*	*Poor women*	*Rich women*	*Difference*	*Poor men*	*Rich men*	*Difference*
Clean Cities							
Flagstaff, AZ	Coconino	83.87	87.74	3.87	79.11	87.02	7.91
Yuma, AZ	Yuma	83.63	86.25	2.62	79.12	82.71	3.59
Redding, CA	Shasta	82.07	87.49	5.42	77.14	84.75	7.61
Yakima, WA	Yakima	83.11	86.88	3.77	79.18	86.02	6.84
Santa Barbara, CA	Santa Barbara	84.86	88.7	3.84	80.56	86.35	5.79
	Group Average	83.508	87.412	3.904	79.022	85.37	6.348
Dirty Cities							
Roanoke, VA	Roanoke	79.2	87.58	8.38	73.23	84.22	10.99
Columbus, OH	Franklin	79.6	87.58	7.98	74.38	85.06	10.68
Richmond, VA	Richmond	79.13	87.13	8	73.62	85.14	11.52
Terre Haute, IN	Vigo	77.89	88.65	10.76	73.03	83.45	10.42
Louisville, KY	Jefferson	80.02	87.37	7.35	74.03	84.72	10.69
	Group Average	79.168	87.662	8.494	73.658	84.518	10.86
Btw Group Average		4.34	-0.25	-4.59	5.364	0.852	-4.512

Analysis

As shown in Table 1, we use cluster analysis to group the five cleanest and dirtiest cities; as reflected on those that have the least criterial pollutants and the most pollutants respectively. To test whether pollution had a significant net impact on life expectancy across cities (N=148), we constructed a series of regression models, using the backward entry removal method. The basic regression equation is as follows:

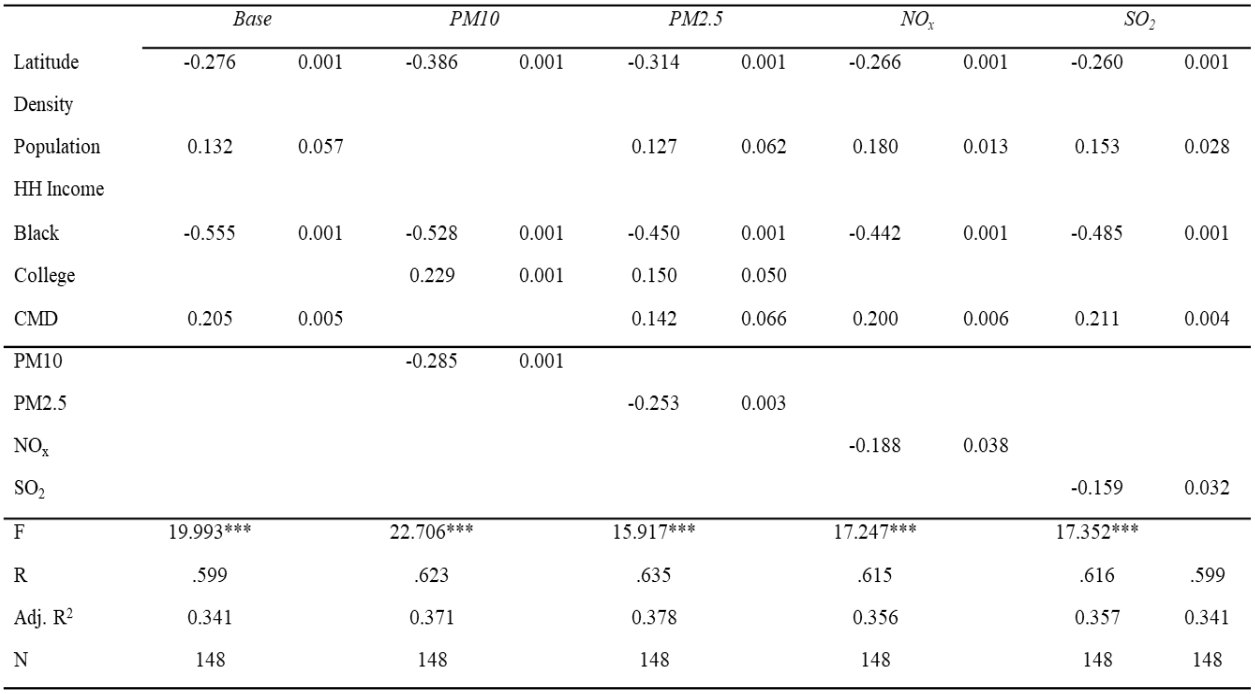
$$y = \beta_0 + \beta_1\text{*latitude} + \beta_2\text{*density} + \beta_3\text{*population} + \beta_4\text{*income} + \beta_5\text{*percent black}$$
$$+ \beta_6\text{*percent college} + \beta_7\text{*multimodality}, + \beta_8\text{*EPA measures} + \varepsilon,$$

Where: y is dependent variable *life expectancy* for one of our four demographic groups, β_0 is the constant, β_1 through β_8 are coefficients to be estimated, and ε is the error term. Regarding multicollinearity, tolerances are all above the critical threshold of .2. The presence of competing dependencies was explored and determined to be negative: in no case did two variables both show problematic values on the variance proportion table. Together, our methodology provides an accurate estimation and comparison of the impacts of the control and test variables on life expectancies in U.S. cities.

RESULTS

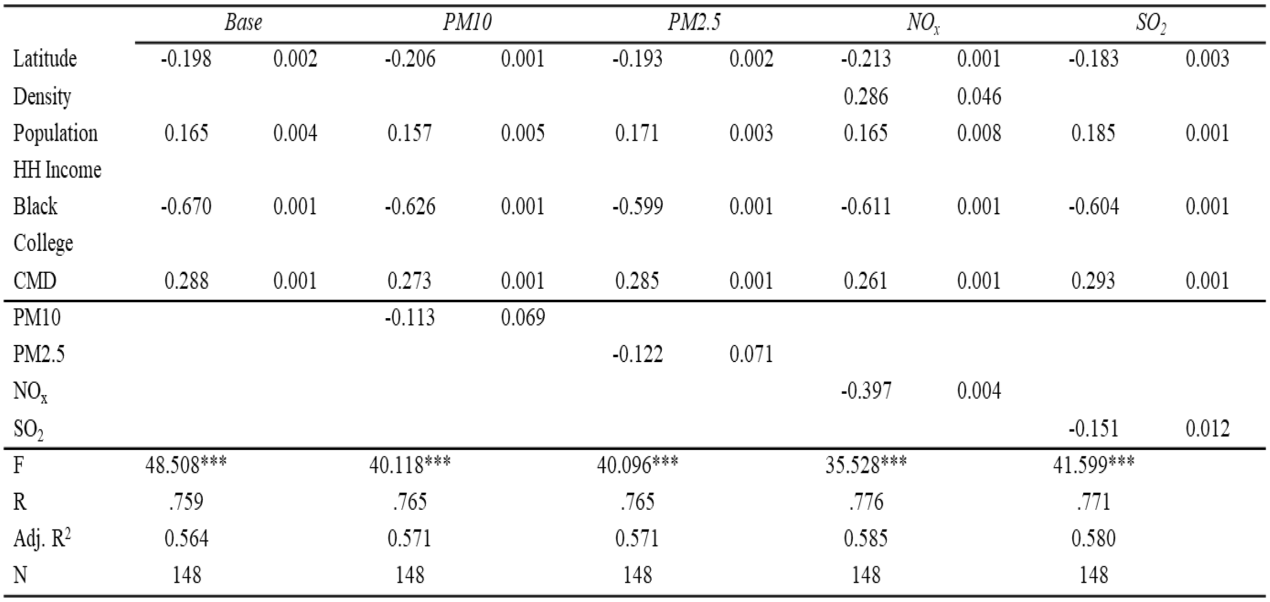
As shown Tables 2, 3, and 4 our conventional regression model predicting urban lifespan shows that the air pollution test variable using four different EPA measures is a statistically significant predictor of lifespan in some cases having a stronger impact over the standard control variables. For each group, we first provide the base model with no pollutants. Although the same factors are present for both poor men and poor women (*latitude*, *population*, *percent black*, and *multimodality*), the base model explains greater variation for poor men. Another difference is that when particulate matter pollutants are introduced, education becomes significantly positive for women's life expectance (LE).

Table 2. The impact of air pollution on poor women (LE factors).



	Base		*PM10*		*PM2.5*		*NO_x*		*SO_2*	
Latitude	-0.276	0.001	-0.386	0.001	-0.314	0.001	-0.266	0.001	-0.260	0.001
Density										
Population	0.132	0.057			0.127	0.062	0.180	0.013	0.153	0.028
HH Income										
Black	-0.555	0.001	-0.528	0.001	-0.450	0.001	-0.442	0.001	-0.485	0.001
College			0.229	0.001	0.150	0.050				
CMD	0.205	0.005			0.142	0.066	0.200	0.006	0.211	0.004
PM10			-0.285	0.001						
PM2.5					-0.253	0.003				
NO_x							-0.188	0.038		
SO_2									-0.159	0.032
F	19.993***		22.706***		15.917***		17.247***		17.352***	
R	.599		.623		.635		.615		.616	.599
Adj. R^2	0.341		0.371		0.378		0.356		0.357	0.341
N	148		148		148		148		148	148

Table 3. The impact of air pollution on poor men (LE factors).



	Base		*PM10*		*PM2.5*		*NO_x*		*SO_2*	
Latitude	-0.198	0.002	-0.206	0.001	-0.193	0.002	-0.213	0.001	-0.183	0.003
Density							0.286	0.046		
Population	0.165	0.004	0.157	0.005	0.171	0.003	0.165	0.008	0.185	0.001
HH Income										
Black	-0.670	0.001	-0.626	0.001	-0.599	0.001	-0.611	0.001	-0.604	0.001
College										
CMD	0.288	0.001	0.273	0.001	0.285	0.001	0.261	0.001	0.293	0.001
PM10			-0.113	0.069						
PM2.5					-0.122	0.071				
NO_x							-0.397	0.004		
SO_2									-0.151	0.012
F	48.508***		40.118***		40.096***		35.528***		41.599***	
R	.759		.765		.765		.776		.771	
Adj. R^2	0.564		0.571		0.571		0.585		0.580	
N	148		148		148		148		148	

Table 4. The impact of air pollution on wealthy men and women (LE factors).

	Wealthy Women Base		*Wealthy Men Base*		*Wealthy Men NO_x*	
Latitude						
Density						
Population	-0.133	0.052				
HH Income						
Black	-0.318	0.001	-0.331	0.001	-0.249	0.002
College	0.514	0.001	0.511	0.001	0.534	0.001
CMD			0.170	0.014	0.161	0.019
PM10						
PM2.5						
NO_x					-0.136	0.084
SO_2						
F	28.462***		45.336***		35.241***	
R	0.610		.697		.705	
Adj. R^2	0.359		0.475		0.482	
N	148		148		148	

Aside from *percent black*, the most significant factor in both the poor men's and women's model, the pollution variables are of comparable strength to all the other significant factors: *latitude, population* and *multimodality*. Factors comprising the poor men's models are similar. However, poor women seem more vulnerable to *particulate matter*, while men are more impacted by NO_x and SO_x. Another difference is that compared to poor women, in no circumstances does education play a role for poor men. *Density* only plays a role when NO_x is introduced to the model. Finally, living in a wealthier county does not seem to have a measurable impact on the LE of lower income populations. *Population* seems to have a positive impact, while colder, more northerly *latitudes* have a negative impact.

As is often the case, for the model exploring higher income individuals, the data is less compelling. For example, there is little discernable correlation between LE and pollutants and income for women. In contrast, college education replaces *percent black* as the strongest control variable. Furthermore, unlike the case for lower income women, *population size* has a negative association with LE, yet *latitude* has no measurable effect. Unlike nearly every other model, the built environment in terms *multimodality* has no role in the LE of wealthy women. For wealthy men, the model differs only in that *multimodality* plays a role, *population* does not, and NO_x has a measurable impact on their LE.

Our analysis illustrates that air pollution has a greater tendency to occur in the nation's poorest cities. Residents die before their time—by as much as 5 years—and this is concentrated in black communities. As Tables 2, 3 and 4 illustrate, NO_x and SO_x and particulate matter all are negatively correlated with life expectancies. Most acutely, PM_{10} is strongly associated with reduced life expectancy. This extends the work done by Chetty and others, showing pathways between urban emissions and health outcomes—a true missing link in the research dialogue.

DISCUSSION

Chetty et al. examined associations between life expectancy and income, finding that low-income populations in bigger cities with highly educated populations and more government expenditures had higher life expectancies than low-income populations in smaller cities with less educated populations and less government expenditures [1]. Our regression analysis extends that work and confirms most of the Chetty team's findings. There are social mobility benefits correlated to health outcomes for both men and women. While median household income has little role, education does matter. We find that these benefits are attainted primarily for those with higher incomes. The team chose not to test for the impacts of pollution using their data set. Other research shows that pollution results in unwalkable cities, lower housing values, greater risk of foreclosure, and reduced tax revenues to support essential services [43,73-75].

Though other behaviors matter (e.g., smoking and income levels), our research dispels several popular notions while confirming other literature from the planning field. Our research clearly shows that people are affected by the four types of pollution. It extends other research that shows that toxic air can contribute to countless other problems (e.g., higher rates of respiratory and heart diseases, more miscarriages, and certain types of cancer). The external costs of added heath care are born by the effected residents and society as a whole. In cities like Louisville, Kentucky, these impacts result in concentrated areas of health disparity [76]. In other cities such as Yuma, Arizona, people live up to five years longer than their counterparts since the air is cleaner, despite having the lowest tree canopy levels of any U.S. city. Trees provide the benefits of reducing energy consumption by shading buildings, encouraging walking, reducing flooding, improving the mental health of children, reducing traffic speed and capturing/sequestering pollutants from the local environment [39,77].

The policy implications of our findings are important for cities: reducing pollution in cities improves life expectancy. While Chetty et al. updated information to the conversation of differing life expectancies across geographic regions, their data does little to explain causality, which is necessary for policy change [1]. In fact, Chetty argues that there is little proof that pollution matters. We attempt to fill the gap between environmental degradation and lower life expectancies in mid-size cities in the U.S.

CONCLUSIONS

Our research represents the largest sample of U.S. cities (*N*=148) ever studied on the impact pollution on lifespan. We use four reliable EPA measures that are used to study mid-sized cities that are semi-independent to assess inter-city differentials of life span.

Our research determined that four measures of airborne pollution (PM_{10}, $PM_{2.5}$, NO_x, SO_x) show statistically significant relationships with shortened lives of the poor. The greater the environmental pollution in a city, the greater the reduction in median life expectancy—even when controlling for race, gender and income. Environmental degradation should be a more explicit focus of future research and public policy to better understand and address the health consequences of pollution. As the Lancet Commission [78] notes:

> *"Pollution is the largest environmental cause of disease and premature death in the world today. Diseases caused by pollution were responsible for an estimated 9 million premature deaths in 2015—16% of all death worldwide—three times more deaths than from AIDS, tuberculosis, and malaria combined and 15 times more than form all wars and other forms of violence. In the most severely affected countries, pollution-related diseases are responsible for more than one death in four."*

Using a world map, the Lancet Commission implies that the problem of air pollution in the U.S. is not as severe when compared to the consequences in some other countries (e.g., China and India). As we have documented, there are cities where pollution caused thousands of people to needlessly suffer. As we found in our research in west Louisville, 60,000 people die prematurely by an average of ten years [43,79]. Higher levels of air pollution are also linked to other major challenges such as climate change and COVID-19.

Our research not only confirms the Chetty argument that *place* matters but also identifies the significant roles of gender and income in shaping life chances. It further confirms research that shows when cities provide more multi-modal transportation options like walking, biking and transit, people get more exercise, pollution levels are lower and city resident life expectancy increases [41]. Our research shows that the decision makers in industry and government impose on a person's everyday personal problems. It shows how *place* is also a proxy for the level of environmental degradation in a city and how it impacts our lifespan [39].

Air quality varies significantly by nation, state, city and neighborhood and can cause significant health problems. Dr. Donald Schwartz, director at the Robert Wood Johnson Foundation, pointed out "Even with our investment in healthcare we (the U.S.) rank 15th out of 17 developed western countries for life expectancy." A new culture of health can only evolve from a transformation of our built environment [80]. We now know what is causing significant reductions in life expectancy in cities: poverty, gender, unhealthy behaviors and air quality. We show that pollution is a key cause of shorten lifespans by up to five years. Regulatory enforcement of clean air matters in reducing the impact of pollution on health, housing, learning and neighborhoods. It is a life and death issue.

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