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**Modeling Geographic Factors and Assessing their Accuracy in Identifying Health Disparities in
Fayette County**

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Honors Capstone
University of Kentucky
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Abstract

The purpose of this capstone is to conduct a review of existing literature to determine the effects of a variety of geographic variables on health and wellness. The student will use their findings to create a visual aid to displaying these geographic factors and their distributions within Fayette County. Furthermore, the student will analyze the intersection of these variables to predict potential pockets of discrepancy within Fayette County. Based on this analysis, the student will propose possible interventions with a basis in current literature. This project will provide the student with the opportunity to conduct a study of existing literature, research geographic factors influencing health in Lexington, predict possible health discrepancies, and recommend a solution moving forward. Each of these skills is vital for a successful career in research and care within the health field and requires the use of critical thinking skills vital to academic success.

Key Terms:

Built Environment- Modeling Geographic Factors and Assessing their Accuracy in Identifying Health Disparities in Fayette County

The field of public health in the United States can trace its roots as far back as the late 1700's with the passing of the Act for the Relief of Sick and Disabled Seamen and the establishment of the US Marine Hospital Service. In its earliest form, Public Health in the United States was primarily concerned with preserving the critical naval capabilities of a young and rapidly growing nation. However, it was not long before state legislators, like Massachusetts senator Lemuel Shattuck, realized a need to record the birth and death of their citizenry, and eventually government officials expanded their focus to include the prevention and treatment of acute infectious disease within the civilian population, such as typhoid, cholera, yellow fever, and Spanish Influenza. With the advent of modern medicine, including antibiotics and widespread vaccination, the threat of serious infectious disease outbreaks have been mostly eliminated. However, the widespread availability of high calorie foods and an increasingly sedentary population have given rise to a new type of threat, one which our health system was designed to address; chronic disease.

Many such diseases (specifically Diabetes, Heart Disease, Obesity, and several types of cancers) are highly influenced by lifestyle behaviors. Sedentary individuals and those with unhealthy diets are significantly more likely to develop these chronic health conditions, and only through consistent, long term intervention can they be effectively treated. While a wide number of variables influence the ability to prevent and manage chronic disease, of particular interest are those which can be defined geographically. From the outset, the primary question guiding this research was "How does where you live affect your health?" This question prompted several others, including "What factors in the world around you can influence your health?" and "Can health disparities be identified based on geography, without input from the respective health data?". The focus is on looking for relationships between everyday, easily locatable things that can be quickly compiled to give a snapshot view of the built environment in an area, and whether those objects reflect or perhaps otherwise influence the health of the population.

Access to quality food and healthcare are vital to health. Additionally, increasing levels of education have been strongly linked with overall health. Access to these resources can be geographically defined, at least to an extent, by simply mapping out the locations and distributions of grocery stores, primary care offices, and schools in an area. Unfortunately, a model of this kind requires a compromise; It would be nearly impossible for an undergraduate student with limited resources to properly display the locations and distribution of all schools, grocery stores, and primary care offices in the state, in addition to the health data for each county. What's more, the University of Wisconsin Public Health Institute has already done something similar, although without modeling the locations of these resources. This author has decided instead to focus on the specific geography of Fayette County. To this author's knowledge, an investigation of this kind has not been done before, and may help identify more concrete ways to improve the built environment of the County than a state-wide study could offer.

Unfortunately, this novel focus comes at a cost; health data is not readily available at the ZIP Code or neighborhood level. While it is much simpler to model and analyze the distribution of various geographic resources within a single county, actually gathering health data from residents within Fayette County would be a massive logistical undertaking, one that could not conceivably be accomplished within the time constraints of a semester long 3-credit Capstone class. The best way to solve such a problem would be to avoid it entirely.

Conversely, finding median incomes for various ZIP Codes is easily achievable to anybody with an internet connection. Why is this significant? Because for the purposes of this project, median income can be used to estimate health. The relationship between these two variables can not be understated. An enormous volume of research has been dedicated to the subject, and while the exact nature of the relationship between health and wealth may not be entirely clear, it is both empirically apparent and intuitive evident that money is necessary for the prevention and treatment of the chronic diseases that have come to plague the nation.

The relationship between health and wealth is so universally pervasive that not only does it apply throughout each of the fifty United States, it holds true across the globe. For example, the health-wealth gradient of sixteen different countries “reveals that in all countries rich persons tend to be healthier than poor persons”, and that this relationship is consistent in countries as diverse as Israel, Poland, and Spain (Hansen, 2011). Income has been consistently to be “one of the strongest and most consistent predictors of health and disease in public health research” (Minnesota Department of Health, 2014). What’s more, the Minnesota Department for Health (2014) concludes based on existing literature that “the relationship between income and health consistently...appears as a gradient, with the poor experiencing the worst health, but also where the health of those with modest incomes is worse than the health of those with the highest incomes”. Therefore, while there is little precedent in the way of using income in place of health data, there is a large amount of literature indicating that it is a feasible option.

Interestingly, there is even some precedent for the use of income disparity to represent health disparity via the Gini coefficient. The Gini coefficient is one of the predominant measures of income inequality in the current literature, but there are several instances of its use as a measure of health inequality in the literature (Musgrove, 1986; Kerani et al., 2005; Turrell and Mathers, 2001). It is therefore not too great of a stretch to use income in place of actual health data to distinguish health outcomes within Fayette County.

Finally, it is important to note that there is a demonstrable relationship between income and health at a state-wide level in the Commonwealth of Kentucky. The University of Wisconsin Population Health Institute published a report in 2017 called “2017 County Health Rankings: Kentucky”. This report contains, amongst many other things, information on the health outcomes, education levels, food indices, primary care provider ratios, and median incomes of every county in the state. This can be used to create scatterplots relating each of these datasets (college education, primary care provider ratio, food index, and income) to the Health Outcome ranking of each county and using linear regression to quantify the strength of each relationship.

In this study, Health Outcomes were calculated by measuring both length of life and quality of life. Length of life is a measure of years of potential life lost before age 75, whereas quality of life incorporates four different factors; population in poor or fair health, poor physical health days, poor mental health days, and low birthweight. Length of Life and Quality of life combine to create a comprehensive single score that can be used to compare different counties and easily plot relationships with other variables. While strong relationships were observed with education, income, food index, it is interesting to note that of all of these relationships, Median Income was the variable most strongly associated with health. (See Figure 1 on the following page).

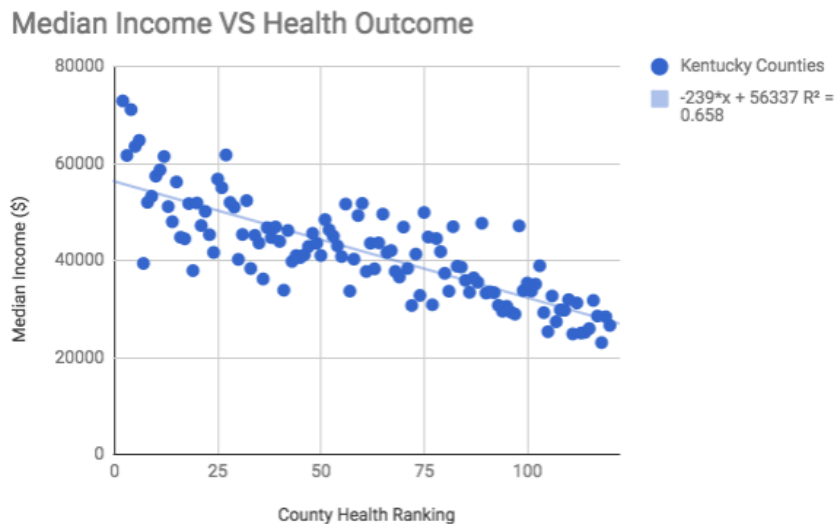


Fig 1.
The relationship between county health rank and median income. Line of best fit and R^2 values are provided. Data courtesy County Health Rankings.

The high R^2 value of .658 is important because not only does it offer additional evidence of the relationship between income and health, it offers evidence supporting the use of income as a proxy for health specifically within the state of Kentucky.

That is the measure this model will use. However, is there actually evidence that access to grocery stores, primary care office, and school locations has a positive effect on health? Do the geographic distributions of these resources give an accurate representation of accessibility, especially within a single county where every single resource is within driving distance?

Primary Care

Access to primary care in particular is just as likely to be predicated by insurance and personal income as it is to geography. There is, however, evidence that primary care location plays a large role in access, and obviously primary care has been irrefutably linked with improved health outcomes on numerous occasions (Starfield et al., 2016; Comino et al., 2012; Engstrom et al., 2010). Clearly physical access to primary care is a prerequisite for obtaining care, but how common a barrier is it? In a large representative study with over twenty thousand respondents, geographic barriers (primarily a lack of transportation) proved to be one of the top five barriers to timely primary care access (Rust et al 2008). While other variables were deemed more significant (specifically difficulty scheduling appointments, long wait times, and poor office hours), those respondents citing a lack of transportation as a barrier to care were two and a half times as likely to report using the Emergency Department than those who did not, and fifty percent more likely to use the ED than any other respondent group, (Rust et al., 2008). These data imply that those who face geographic barriers to primary care end up relying on extremely expensive acute care medicine to treat ailments that respond far better to preventative and long-term interventions. Their quality of care is reduced while the relative cost of their care rises. This is of particular concern for this demographic; it is reasonable to infer that those without transportation are more likely than others to be economically vulnerable, and the last thing they need is care that is both less effective and more expensive.

Unfortunately, there is not a general consensus regarding this relationship between health and primary care proximity. In fact, the data from the 2017 County Health Rankings indicates that there is not a relationship at all. (See Figure 2 on the following page)

Primary Care Provider Ratio vs Health Rank

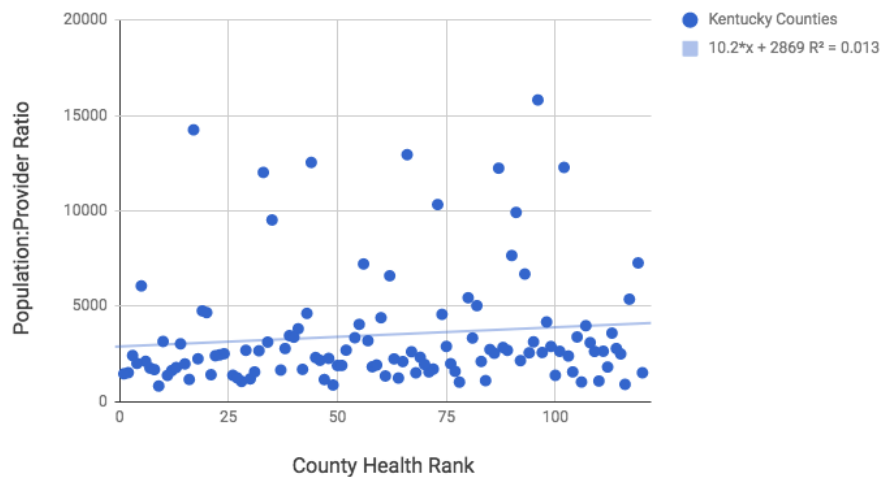


Fig 2.
Relationship between the ratio of primary care providers relative to the health outcomes of a county in the state. Data courtesy County Health Rankings.

Note the small positive trend actually correlates primary care provider ratio with a higher numerical Health Outcome rank, meaning a poorer health outcome score relative to other counties. This is the opposite of what would be expected. However, the negligible R^2 value of 0.013 means that this “trend” is more likely to be due to chance than a true relationship; it’s obvious from even a casual look at this chart that any relationship is exceptionally weak. In contrast, a national study of primary care provider ratios in the United States did indeed find a statistically significant relationship between primary care providers and health as measured by 24 different health outcomes (Hart, 2007). Kentucky presents as one of the states that does not seem to show an overall trend one way or another; however, it is also entirely possible that a trend will resolve when focus is shifted more specifically to a single county, as the number of primary care providers in a county may not accurately represent their relative accessibility to the general population. A doctor’s office could be 20 miles away across the county and still be considered “accessible” if primary care provider ratios are used as the measure of accessibility.

Additionally, a significant body of research performed in Canada has found a strong relationship between location and primary care use. Within the context of city specific analysis, Harrington et al. (2012) states that “controlling for predisposing, enabling and need factors, living in a well-served neighbourhood was a significant predictor of realized access”. What’s more, there is evidence that “increased distance to health care services results in reduced utilisation of the health care system” (Bissonnette et al., 2010). Unfortunately, Canada’s use of a universal healthcare system means that geographic factors are likely to be overstated compared to the United States. However, this is not necessarily a bad thing; a universal healthcare system effectively eliminates other variables such as differences in health insurance, meaning that there are indeed definite relationships between proximity to provider, care utilization, and health outcomes on a scale as small as the city level. This means that it is entirely appropriate to include primary care locations in an analysis of the built environment of Fayette County.

Of further interest to this research was the discovery that that even after adjusting for insurance and other factors, “Low-access area were twenty-eight times greater for census tracts with a high proportion of African Americans than in tracts with a low proportion of African

Americans.” (Brown et al., 2016). This demographic information is readily available as far down as the ZIP Code level in Fayette County, and helps highlight valuable insight on the built environment of Fayette County. The way that racial demographics fit into this modeling method will be discussed in greater detail later in this paper.

Schools

Of the three variables, the relationship between school distribution and health outcomes may be the most tenuous. Of course, the relationship between education and health has been well established. A comprehensive literature review from Harvard University (2006) has revealed an abundance of evidence relating higher education levels and income as well as higher education levels and health. Additionally, these data concluded that “The obvious economic explanations [for the relationship between education and health] – [such as] education is related to income or occupational choice – explain only a part of the education effect.” (Cutler and Lleras-Muney, 2006). The authors contend that education itself has some kind of effect beyond income (such as inducing behavioral change) that leads to improved health in the more educated. Furthermore, data suggests that “one more year of compulsory schooling decreased mortality after age 35 by about 3%” (Lleras-Muney, 2002).

There is, however, scarcely any information directly relating the distribution of schools to health outcomes. Considering the recent rise in the use of GIS software and research into built environment, this represents a potential knowledge gap in the scientific community. Regardless, it is not unreasonable to propose a link between school distribution/location and regional health outcomes. There are a number of mechanisms that could create this theoretical relationship, such as a general improvement in the environment, or general improvement in access to these schools, but the mechanisms with support within the literature are greater ease of active school transport, and decreased dropout rates with higher school proximity; that is, children are more likely to walk to school when it is closer to home, and they are significantly less likely to drop out due to issues getting to school.

As mentioned before, decreased distance from school is associated with greater rates of active transport (Su et al., 2013). This is significant because walking to school has been associated with lower obesity and skin fold scores in schoolchildren (Rosenberg et al., 2006). These findings are consistent with the data demonstrating that both childhood and adult health show conclusive positive relationships with general activity levels (Telford et al. 2012). Additionally, research shows that “independent of potential confounders including participation in extracurricular physical activity.... Active commuting to school [is] associated with better cognitive performance,” (Martinez-Gomez et al., 2010). While all of these were relatively short term studies (less than 3 years), it is possible that long term physical health benefits of an active commute to school are magnified by its effect on cognitive performance; i.e students who are able to walk to school are both healthier in the short term and more likely to experience the health benefits of greater education.

For the intents of this paper, it is perhaps more important to note that these relationships can work in the reverse direction. If students do not live close enough to their school to walk or bike, they are not able to reap the short or long-term health or education benefits of an active commute. Additionally, distance from school has been cited as a major factor in approximately 20% of high school dropout cases (Doll et al., 2013), meaning that not only are these students not benefiting from an active transport due to school location, they are

more likely to lose access to their education, which has already been established as a critical factor in both overall health and income.

Therefore, while there is not much information specifically linking school geography with income or health, there is significant evidence supporting the possibility of such a relationship. Indeed, the scientific community could greatly benefit from further investigation in this area. The conclusively identifying the presence or absence of a relationship between school proximity and population health could help direct further public health efforts and well as provide much needed evidence to combat educational budget cuts. As far as it pertains to this investigation, however, it appears that a relationship between school proximity and population health is certainly plausible enough to include in a model of the built environment of Fayette County.

Grocery Stores

In contrast to school distribution, physical access to grocery stores has been far more conclusively related to health food consumption and overall health. Additionally, there is often significant geographic variation from neighborhood to neighborhood. One study found that “Low-income neighborhoods have fewer chain supermarkets with only 75% ($p < 0.01$) of that available in middle-income neighborhoods” while also observing that urban areas suffered from even lower availability (Powell et al., 2007). Higher food costs, especially for produce, has also been observed occurring in tandem with low physical access (Hendrickson et al., 2006). To worsen the situation, there is also some evidence that higher food costs are related to poor health outcomes, specifically in Kentucky (Hardin-Fanning and Wiggins, 2017). While some researchers believe that such findings are merely reflections of local demand (Deller et al., 2017), an analysis of the food environment in four distinct counties across the United States contends that grocery store location can actually directly influence eating patterns, arguing that “When each additional supermarket came to the neighborhood, African and white Americans’ fruit and vegetable intake increased by 32% and 11%, respectively” (Kim, 2007). This means that there is strong evidence confirming grocery stores as an important factor influencing neighborhood health.

A final justification for the inclusion of grocery stores in this model comes once again from the University of Wisconsin’s “2017 County Health Rankings: Kentucky”. Included in their research is information on county food indexing trends. Within the context of their research, food indexing is a score, from one to ten, constructed from the measurement of two separate factors; limited access to health foods, and food insecurity. These two measures are calculated from the percent of the population that is low income and the percent of the population that lives further than one mile (for urban areas) or ten miles (for rural areas) from a grocery store. The cumulative health scores for each county in Kentucky is displayed in the following chart. (See Figure 3 below)

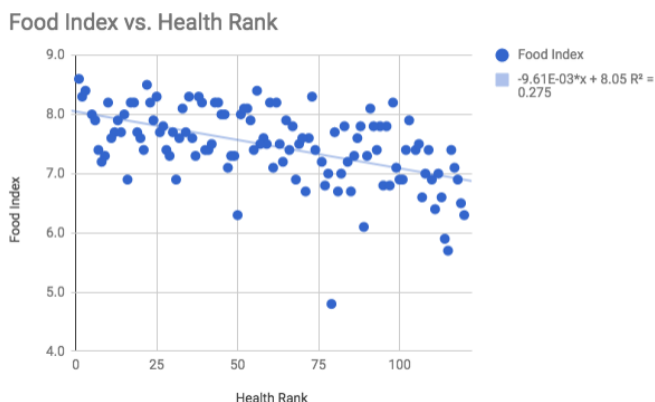


Fig 3.

The relationship between county Food Index score and health rank. Once again, lower health scores translate into numerically higher health ranks, meaning that this chart displays a positive relationship between Food Index and health. Data courtesy County Health Rankings.

While a R^2 value of 0.275 may be tempting to dismiss as insignificant, it is important to remember that an R^2 of 0.275 means Food Index can be used to explain over a fourth of the variation between county health rankings. Population health is a complex field of study and with a great number of other variables influencing outcomes, an R^2 of 0.275 demonstrates a significant relationship, one that offers great insight into possible public health interventions.

After constructing this initial graph, obvious outliers were removed to examine the effect on the data. While this specific change had little effect on overall trends due to the large sample size of 120 counties, it prompted further investigation which led to an interesting discovery: If only the middle 50% of counties are included, the relationship between Food Index and health rank becomes stronger, producing an R^2 value of .361 in the linear model. While this change in value may be spurious, it suggests the possibility that counties with extreme health outcomes, either positive and negative, are more likely to experience extremes in other variables affecting health, as well as suggesting that Food Index has a greater effect amongst counties with average health outcomes. Taken a step further, it is possible that examining trends within the middle 50% of counties partially controls for other extreme confounding variables. This would mean that Food Index, and therefore proximity to a grocery store, has an even greater influence on health than suggested by state-wide trends.

There are, however, some drawbacks to the use of Food Index as a measure of access to grocery stores. Food index takes income into account when determining access; its inclusion should therefore exaggerates the strength of the relationship between grocery store proximity and health. Also, while Food Index does factor in income, it does not factor in the effect of food stamps. The availability and use of food stamps by lower income families significantly lessens the impact of income on measured food access, particularly for the lowest earners, causing an underestimation of access with this measure. This oversight should therefore effectively minimize the effects of income on Food Index, meaning that the relationship seen above could very well be an accurate. Of course, this is all speculation. The fact remains that evidence specific to the state of Kentucky exists relating grocery store proximity to health, which is evidence enough to include grocery stores in a more detailed investigation of a single county.

Methods

The growing use of Geographic Information Systems (GIS) software is a recent trend that has the power to transforming the way that data is organized analyzed, and displayed across a variety of fields. GIS software offers a wide array of analytic capabilities and allows researchers to visually present data in ways that are easy to understand while also conveying a large volume of information (Senic, 2017). The power of such software is so great that even the most basic system can offer enormous insight into geospatial datasets. The following models were constructed using relatively new functions in Google Maps that allow the user to save or import location data and change its visual representation similar to many pay-for-service GIS software systems. This resource is available for free to anyone with internet access. In addition, all data collected is public information available online. The universally accessible nature of both the data and software used to create these models further underscore the potential for this method of environmental modeling.

Data was collected from several different sources. A preliminary search of Google Maps for “grocery stores”, “primary care offices”, and “schools” was sufficient to identify most of these locations in Fayette County. Additional searches for “market”, “grocery”, and “wholesale” were performed to find any grocery stores that were listed under different search terms.

Additional primary care locations were located by searching through the websites of each of the major healthcare organizations as well as a search of yellowpages.com, the online website for the company The Yellow Pages. Information regarding the exact location of the county line and ZIP Code borders were obtained from the Lexington, Kentucky's official website, as were a number of schools that failed to show up on Google Maps. ZIP Codes were used as the smallest division of the county due to the availability of information and incomplete coverage of the county by existing registered neighborhoods. Demographic data for each ZIP Code, including racial demographics, education levels, income, and land area data were obtained using the knowledge engine Wolfram Alpha at www.wolframalpha.com.

The maps themselves are interactive documents that allow the user, among other things, to zoom in and out, change views, hide or reveal information, assign visual symbols, and color code data. Because of this, all images attached to this paper are simply snapshots of the data they represent. General information regarding Fayette County (See Figure 4) and an overview of the data collected (See Figure 5) are included below. These are included only as a frame of reference. Maps of each specific resource type are included at the end of this paper. Trends are discussed in text and via scatterplot and regression models.

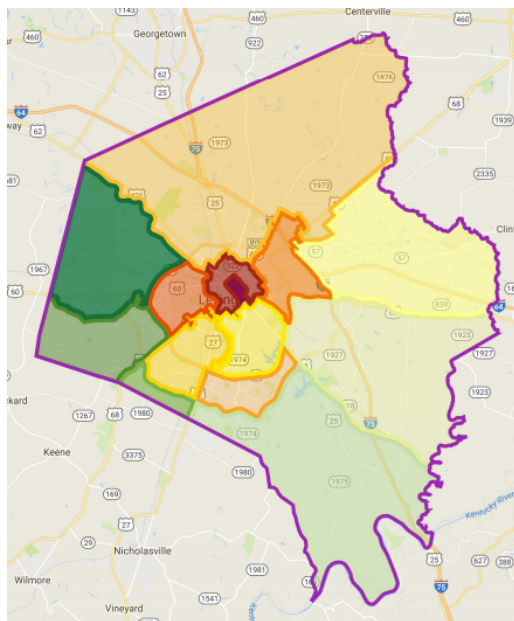


Fig 4.

Fayette County and associated ZIP Codes. The median income for each ZIP Code is presented in a color continuum with the darkest green representing ZIP Code with the highest median income and the darkest red the ZIP Code with the lowest median income. The county line is shown in purple. The median incomes of each ZIP Code were obtained from Wolfram Alpha at www.wolframalpha.com.

Note:

This map is used as the base map for each of the models shown hereafter. As previously noted, median income serves as the source of health outcome data. The terms “health” and “population health” and “health outcomes” will be used in place of income. “Grocery stores”, “primary care offices”, and “schools” will also be referred to as “resources”

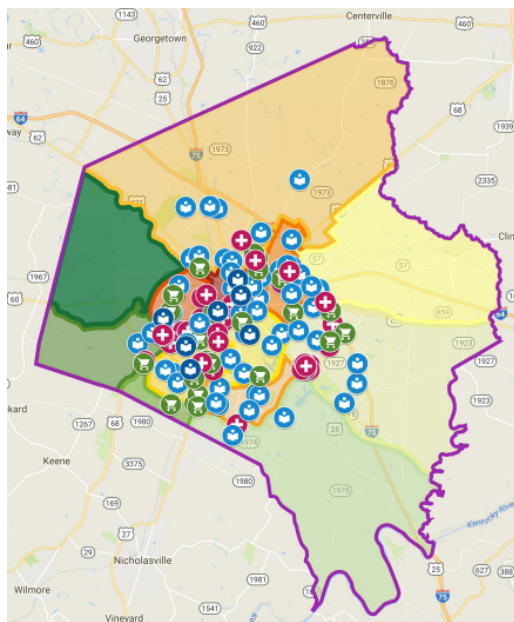


Fig 5.

An overview of grocery stores, primary care offices, and schools in Fayette County. Grocery stores are coded as green shopping carts, primary care as red crosses, public schools as a light blue book, and private schools as a darker blue book.

Results

A total of 125 resources were identified within Fayette County. These consisted of 37 unique primary care offices, 24 grocery stores, and 64 schools. Of the 64 schools, 57 were public and 7 were private. Of all resource types, private schools are most likely to be underrepresented. Unlike public schools, information about private schools is not available on the Lexington city website, and The Yellow Pages are less likely to offer a comprehensive listing of private schools due to their typically non-profit status. The large number of schools within the county minimizes the effect of one or two unidentified school locations.

While Figure 5 (see page 10) contains too much information to identify specific distribution trends, it is immediately apparent that nearly all of the resources in the county are within the boundary of New Circle Road. The resources most likely to exceed this boundary are public schools. This means that ZIP Codes closer to the middle of the city, which also tend to be lower income and have poorer health outcomes, present with a proportionally higher number of geographic resources than expected based on the literature.

In terms of raw resource count, there was no identifiable trend predicting health or income by ZIP Code alone. However, after adjusting for land area and determining relative resource density per square mile, something rather unexpected happens. (See Figure 6 below)

Resource Count vs Income

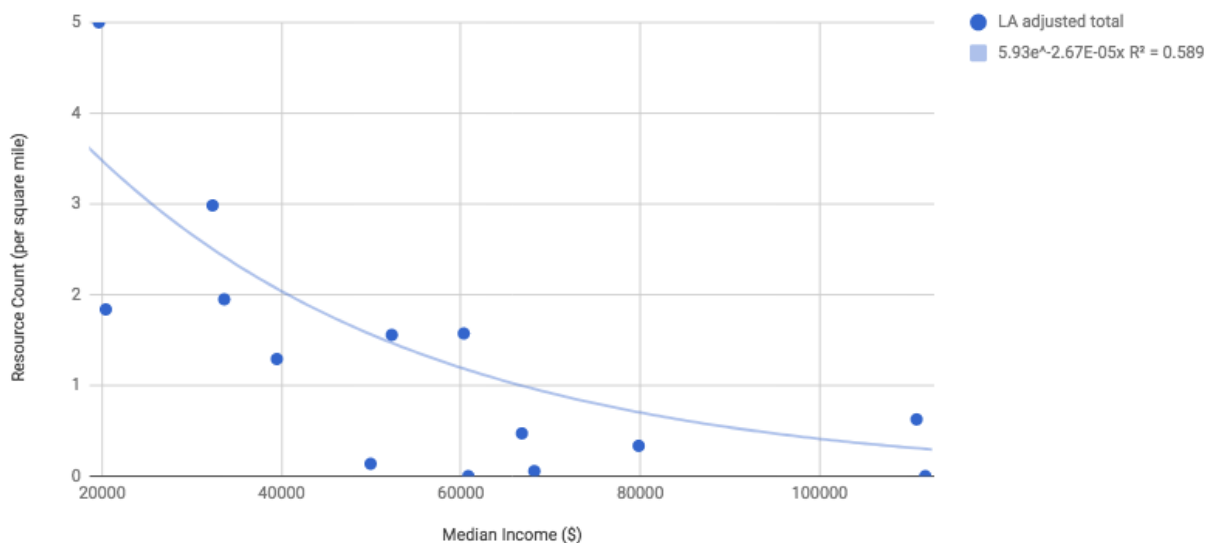


Fig 6.

Scatterplot comparing ZIP Code median income to land area adjusted resource per square mile. Individual resource distributions are attached at the end of this paper.

While there does seem to be a relationship between income, i.e. health, and resource count, the relationship is in fact opposite of what the literature suggests. Not only is there a negative relationship between resource per square mile and overall ZIP Code health and income, the relationship is relatively strong, with an R^2 value of 0.589.

Certainly the presence of only 14 different ZIP Codes in the county represents a relatively small sample size that makes this relationship far more susceptible to outliers or false

trends than state-wide data from 120 different counties. Indeed, further investigation determines that the highest income ZIP Code, 40510, contains exactly zero of the resources included in this model. This can be at least partially explained by the fact that 40510 contains the Bluegrass Airport, Keeneland, and a large number of horse parks. The inhabitants of this ZIP Code are affluent, and there is almost no commercial area to speak of. However, exclusion of this area weakens the relationship only slightly, dropping the R^2 value of the exponential regression model to from 0.589 to 0.556.

There is, however, a second outlier; Lexington's downtown specific ZIP Code of 40507. Lexington's downtown ZIP Code occupies an exceptionally small area in comparison to other ZIP Codes. It is dominated by businesses and workplaces, and, like many downtowns, houses a large number of low income individuals. When 40507 is removed in addition to 40510, the relationship strength drops significantly to an R^2 value of 0.359. While significantly lower than the full dataset, the fact that the relationship still exists at all is contrary to the expected findings of this investigation.

The individual resources seem to follow generally the same pattern. When counting all ZIP Codes, an exponential regression model relating grocery stores and income yields an R^2 value of 0.581, which drops to 0.289 when omitting the same two ZIP Codes. The relationship between primary care resources and income has an R^2 value of 0.418, which also drops to 0.276 without outliers. Interestingly, the modeled relationship between school resource density changes very little, dropping from an R^2 value of 0.652 to 0.571 without 40507 and 40510.

These results indicate the existence of an exponential and negative relationship between all variables analyzed and health outcomes, including total resource density and density for each resource type. Of the relationships analyzed, increased school density is most strongly correlated with lower income and health outcome, with grocery store density showing a relationship comparable to, though slightly stronger than, that of primary care location density. For each resource type the highest resource density corresponded to the lowest income, with initial decreases leading to nearly doubled measured income (and therefore health outcomes). Each relationship weakens significantly with the exclusion of the outlying ZIP Codes 40507 and 40510, but do not disappear.

Discussion

Despite a seemingly robust background of literature predicting positive relationships between proximity to grocery stores, schools, and primary care offices, further investigation into Fayette County yielded the opposite of the expected results. There are a number of possible factors influencing this outcome.

First, and perhaps most significantly, it seems plausible that the use of median income as the measure of health outcomes was an ineffective equivalency. Substantial literature exists relating grocery store access and proximity in particular to improved health outcomes, and it is strange that that does not hold true in this context. Perhaps income is not nearly as strongly related with health on a scale of this size. Additionally, the precedent of equating income disparity and health disparity in literature relied specifically on the use of the Gini coefficient, which was not used in this investigation. It is likely that the observational nature of this exercise simplified these two values too much for the strength of their relationship to still apply.

Second, while it is well understood that access to healthcare, groceries, and school can only be beneficial (despite the negative relationships seen here), it is possible that the reliance on geographic distribution to measure access for these variables was flawed. Fayette County is

a relatively small area composed almost entirely of a single city, where most individuals with access to a car could access each of the resource types examined. Lexington's domination of Fayette County's landscape, and the sheer size of Lexington in comparison to most cities in Kentucky, also mean that the county's geographic distributions will likely more closely resemble those of a city than other counties. Resources were located primarily off of major roads and were almost exclusively found in the middle of the county. The inner city often, and in this case actually does, experience lower incomes than the outer city, meaning that resources concentrated in the middle of the county are also concentrated in low-income areas.

Finally, division of the county into ZIP Codes is not necessarily the ideal method of dividing the county. ZIP Codes, especially in Lexington, are often defined by major roads, which is where businesses are prone to congregate. This means that many resources were deemed "inaccessible" despite being just across the street from another ZIP Code. Postal codes were used due to the ready availability of both demographic information and mapping data, but perhaps analysis of the registered neighborhoods in the city, which are smaller, more numerous, and less dictated by major roads, would offer better insight into differences in the built environment relative to income and health. This would increase the sample size and decrease the effect of outliers on the results, in addition to reducing the effect of business clustering around major roads, i.e. the borders of each ZIP Code.

Recommendations

Based solely on these findings, there are few good faith recommendations to be made. If all of these resources did indeed have negative effects on health, recommendations would be made to curb the construction of schools, primary care offices, and grocery stores. Obviously such measures would do nothing to improve public health in Lexington or Fayette County.

There are still some recommendations to be made based on the literature reviewed at the beginning of this paper. Active commuting has been clearly shown to exert positive effects on health. Additionally, pedestrian friendly zoning, (including crosswalks, bike and pedestrian connectivity, street connectivity, bike lanes, and bike parking) has shown promise in not only increasing active commuter rates but also in reducing income and poverty disparities (Chriqui et al., 2017). Such zoning changes could only have a positive impact on the population health of Fayette County, and affect not just school children but every working adult as well.

It would also be advisable to educate school officials on the potential difficulties created by long commutes, particularly when considering both new school sites and student transfers to different schools. However, there may be little need for such measures, as the students in public schools are theoretically attending the school closest to them anyway.

Furthermore, the evidence supporting a direct effect of greater grocery store concentration on eating habits in low-income neighborhoods areas supports the introduction of new legislature promoting grocery business in poorer areas. The fact that low physical access to grocery stores often occurs alongside high food prices (possibly due to a lack of competition) offers further support for such interventions.

In terms of primary care accessibility, it seems that while transportation and physical access to primary care physicians are indeed factors influencing primary care use, it may be more beneficial to address the non-spatial aspects of disparities healthcare access. One of the most often cited barriers to obtaining care are poor office hours or the inability to get off work for an appointment (Rust et al 2008). It would therefore be advisable that healthcare

organizations and primary care offices in particular make attempts to offer a greater variety of available hours in an effort to improve access.

Finally, it was mentioned earlier in this paper that there has been little research into some of the relationships examined, particularly the possible relationship between proximity to school and health. Further research in these areas, and the school/health proximity relationship in particular, may yield useful information that could benefit the field of public health and identify additional interventions.

Finally, there have been few other attempts to map out more than a single geographic factor influencing health within a small area such as a city or county. While the results of this investigation yielded little usable information in this regard, it is entirely possible that more comprehensive research could reveal valuable insight not identified here. Ideally such research would be well funded and have access to or gather the raw demographic data and health outcome information of a large portion of the population examined, either via the next US Census or a (rather widely distributed) survey. This would also ideally incorporate questions concerning distance from schools, distance from grocery stores, and distance from primary care offices. Furthermore, actual neighborhood organizations should be used instead of ZIP Codes, and information specific to each gathered. The area(s) investigated would preferably include counties not exclusively composed of a single city in order control for the effects of city-specific distributions, such as those seen in Fayette County. Finally, these data must be analyzed both cumulatively (i.e. city to city) and specifically (i.e. neighborhood to neighborhood) using the appropriate statistical methods in order to identify trends which may manifest themselves differently depending on scale.

Unfortunately, such methods were beyond the funding and scope of this investigation, and therefore limited this study's conclusive power; This does not, however, preclude the use of similar modeling methods in the future, nor do the unexpected trends discovered within Fayette County. There is significance evidence supporting the use of these variables in built environment analyses, and a more complete understanding of these relationships, and the interventions they suggest, can only be found through additional investigation.

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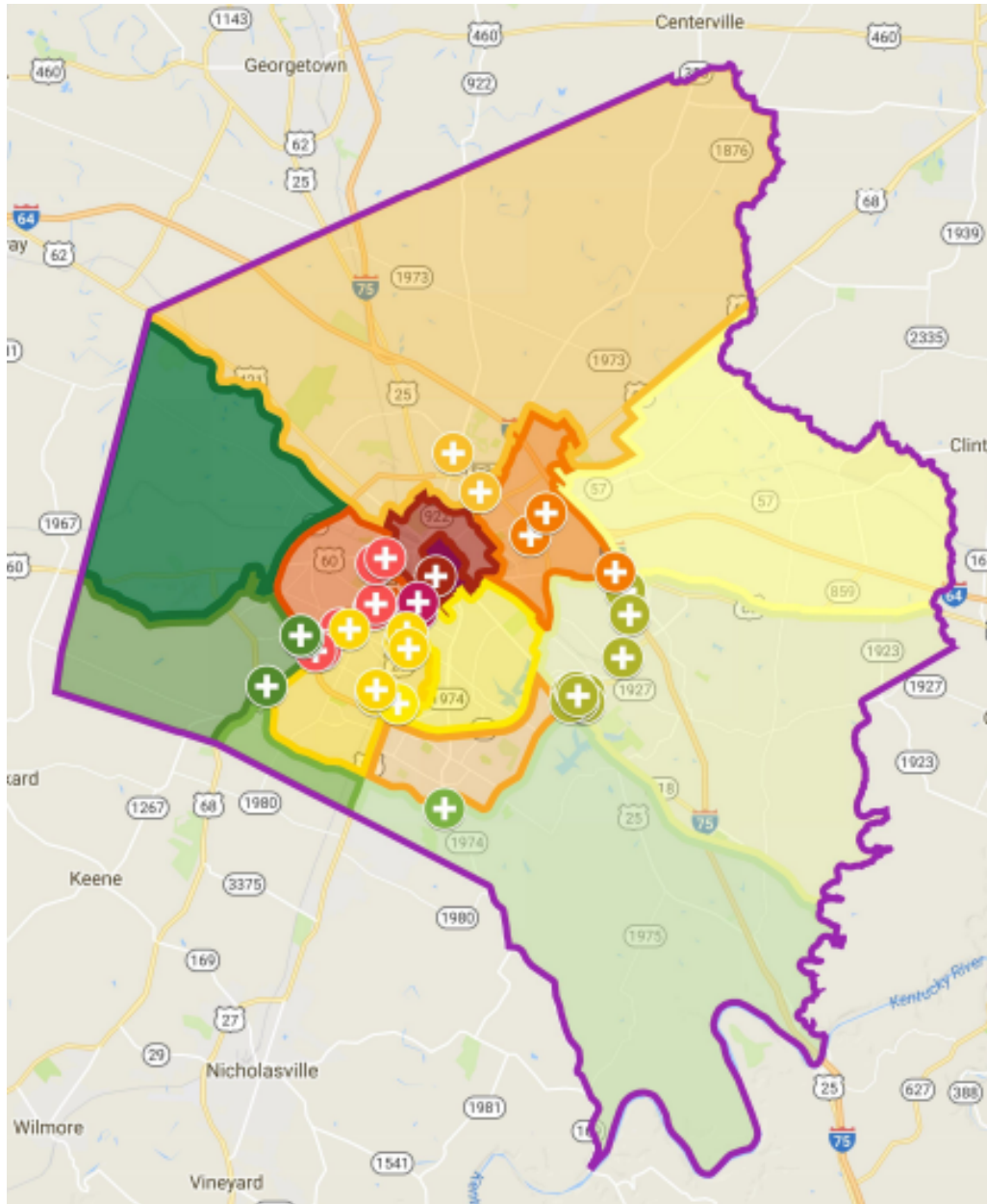


Figure 7.
The distribution of primary care offices in Fayette County.

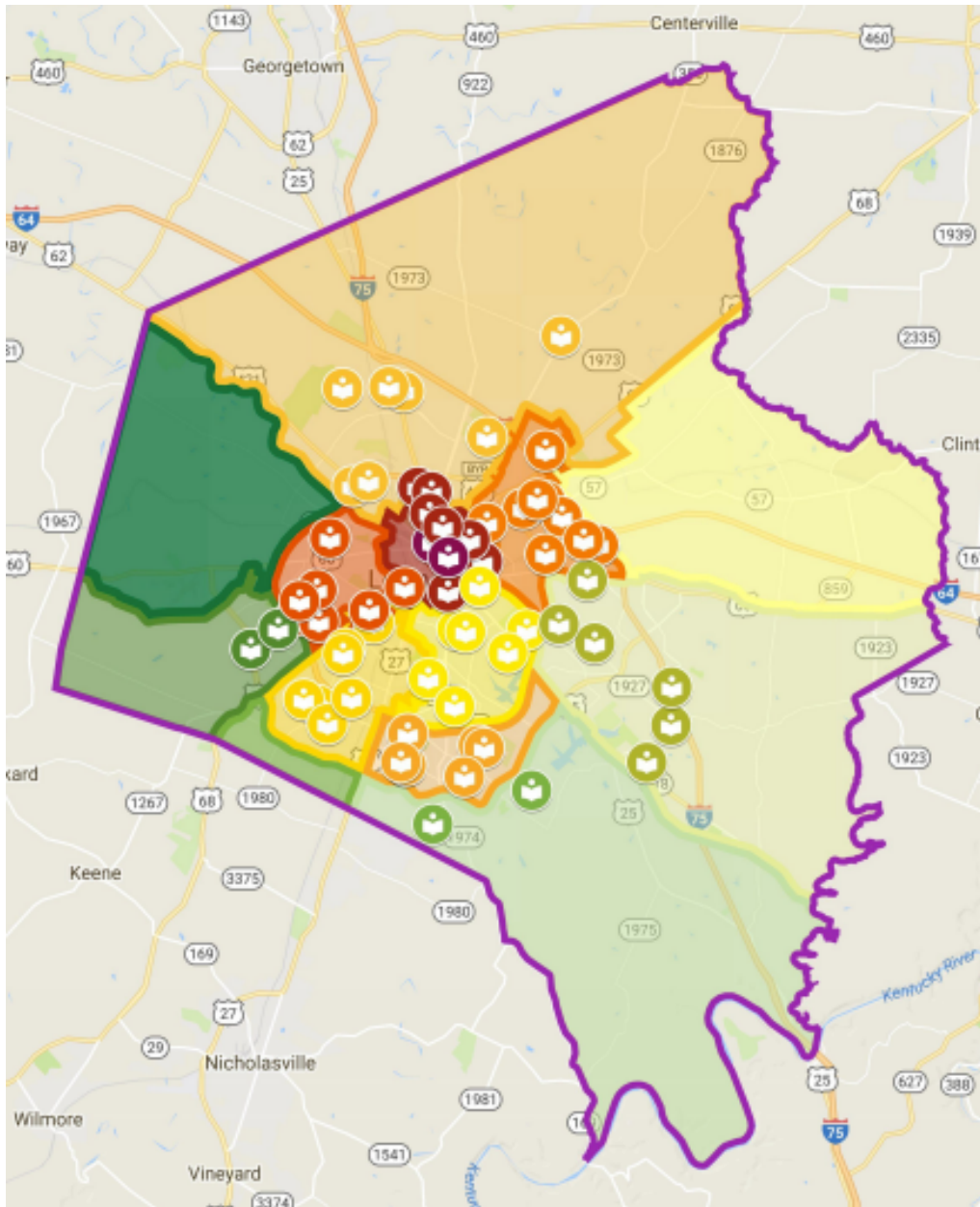
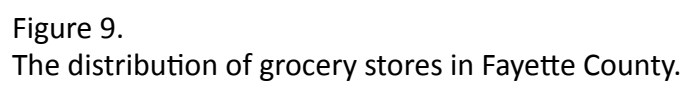


Figure 8.
The distribution of schools in Fayette County.



Grocery Store Density vs Income

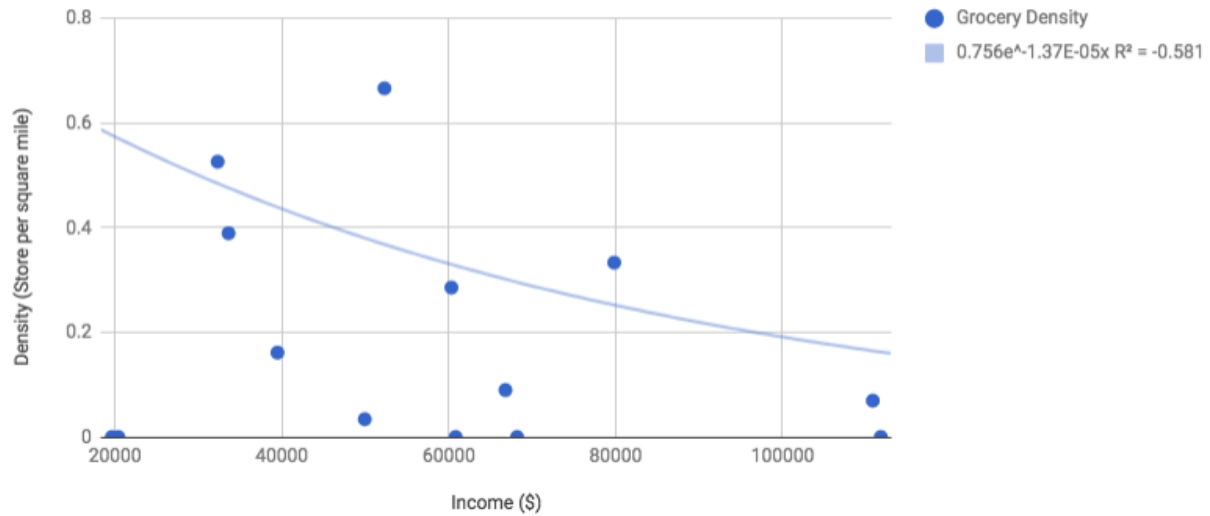


Figure 10.

This chart shows the relationship between ZIP Code grocery store density and ZIP Code median income. The overall trend is negative and exponential, with a R^2 value of 0.581.

Grocery Store Density vs Income

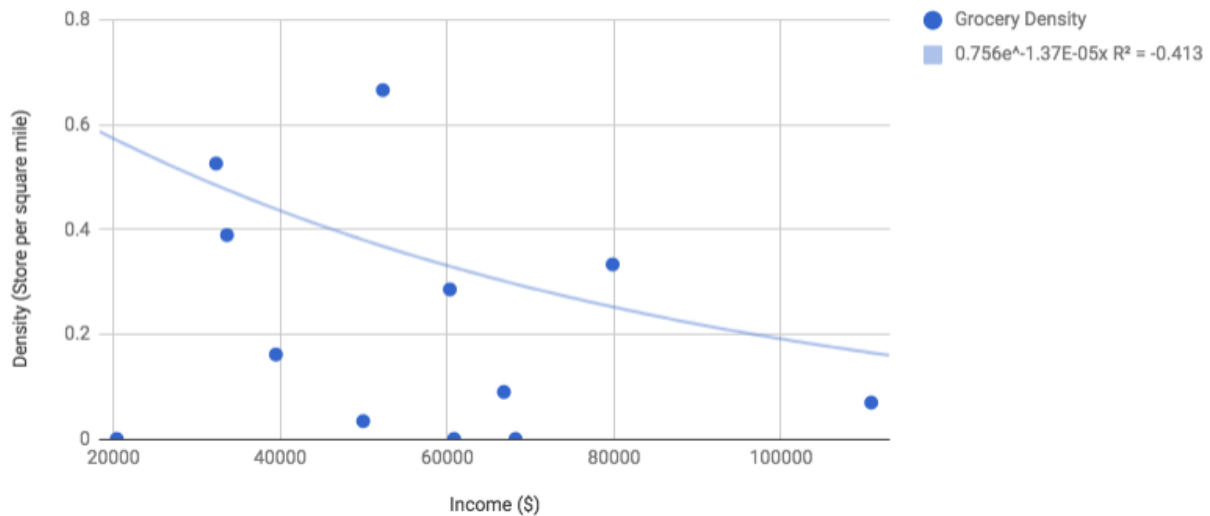


Figure 11.

This chart shows the relationship between ZIP Code grocery store density and ZIP Code median income after omitting 40510 and 40507. The overall trend is still negative and exponential, with a reduced R^2 value of 0.413.

Primary Care Office Density vs Income

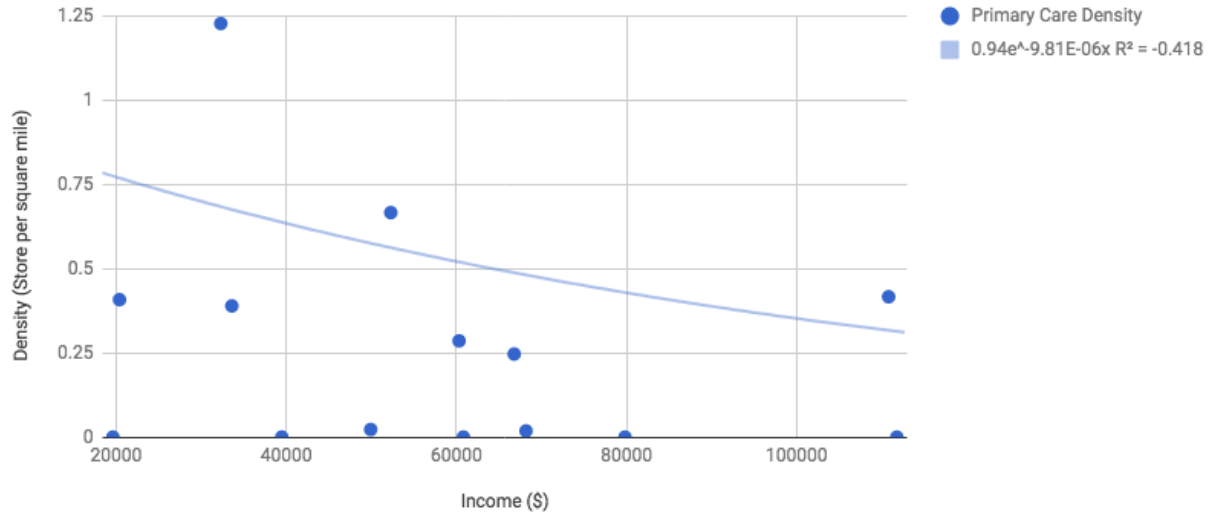


Figure 12.

This chart shows the relationship between ZIP Code primary care office density and ZIP Code median income. The overall trend is negative and exponential, with a R^2 value of 0.418.

Primary Care Office Density vs Income

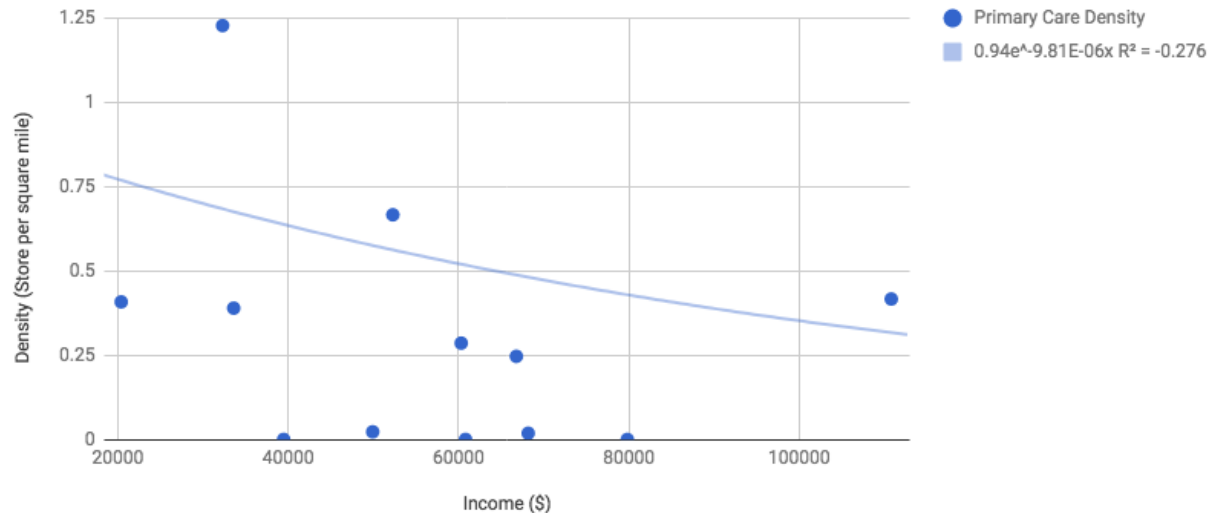


Figure 13.

This chart shows the relationship between ZIP Code primary care office density and ZIP Code median income after omitting 40510 and 40507. The overall trend is still negative and exponential, with a reduced R^2 value of 0.276.

School Density vs Income

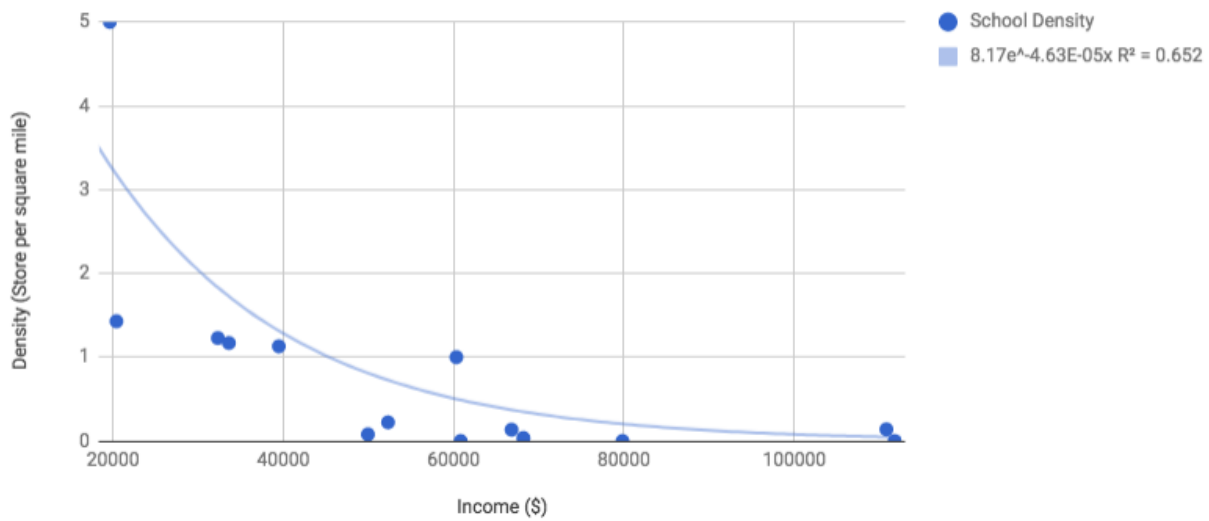


Figure 14.

This chart shows the relationship between ZIP Code school density and ZIP Code median income. The overall trend is negative and exponential, with a R^2 value of 0.652.

School Density vs Income

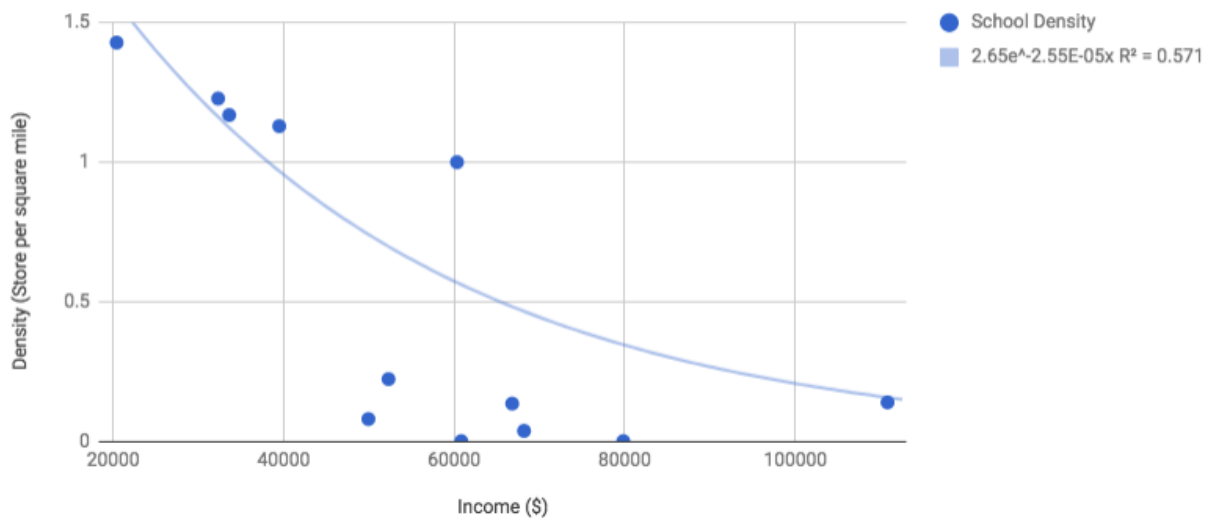


Figure 15.

This chart shows the relationship between ZIP Code school density and ZIP Code median income after omitting 40510 and 40507. The overall trend is still negative and exponential, with a reduced R^2 value of 0.571.