Project Final Deliverable

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1. Introduction

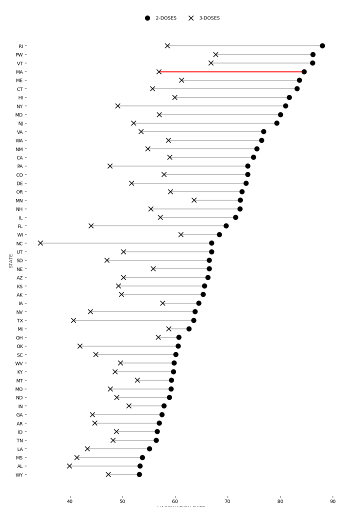
In Massachusetts, vaccination disparity emerges as a formidable public health challenge, necessitating refined strategies. analysis of 2-dose and 3-dose vaccination coverage across 335 MA cities and towns reveals striking vaccination variability. This multifaceted conundrum warrants an integrative approach that elucidates causative elements in hopes of sculpting potent interventions. Healthcare authorities in MA are concerned about vaccine uptake disparity among diverse demographic groups, especially the pediatric and geriatric cohorts.

We conducted an in-depth examination of a broader scope of variables including age, ethnicity, the Social Vulnerability Index (SVI), gender, economic status, employment, and population density, building upon the previous year's analysis that focused on age, race, and the impact of grassroots initiatives. These factors are scrutinized to understand their correlation with vaccine hesitancy in MA, particularly in urban locales like Revere, Wellesley, and New Bedford. Our methods, encompassing census and health record data interpolation, regression, and hypothesis T-tests, aim to uncover patterns in vaccine perceptions across different demographics.

By uncovering the roots of vaccine reluctance, our overarching goal is to help foster a collaborative environment, uniting MA policymakers and community leaders to promote health inclusivity. We hope our efforts will provide actionable insights into various population strata, shaping practical policies to increase vaccine acceptance and thereby elevate the overall public health.

Figure 1: Country-Level Full Vaccination Disparity (world.ipynb)

Figure 1 shows in the initial throes of the COVID-19 pandemic, the international community rapidly galvanized to deploy the COVID-19 vaccine, endeavoring to stymie viral transmission. reached laudable country-level full vaccination rates, surpassing 80% in numerous instances. A multitude of other nations reached laudable country-level full vaccination rates, surpassing 80% in several instances, while a substantial swath of the global populace achieved a less vaccination benchmark of approximately 60-70% in most cases.



In the United States, a parallel zeal was evident, with Massachusetts commendably ascending to the status of the sixth most vaccinated state (Figure 2.). However, our granular analysis at the city and town level uncovered significant divergence in vaccine uptake, unveiling numerous, previously unnoticed "pockets" of vaccine hesitancy (Figure 3.) Alarmingly, we even identified two towns where not a single resident had received two-dose vaccinations.

Figure 2. State-Level Full Vaccination Disparity (State.ipynb)

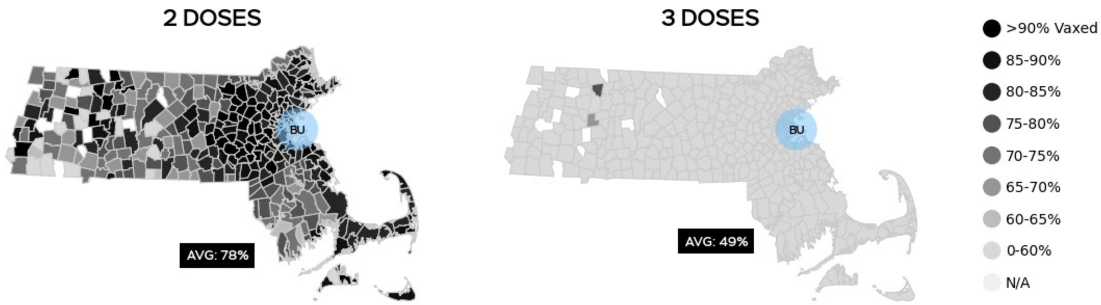


Figure 3. City-Level Full Vaccination Disparity (City.ipynb)

COVID-19 vaccination can be a medically complex decision for certain people, with the attitudes towards vaccines varying wildly. However, given that COVID-19 hospitalizations consume substantial community resources, mitigating disparities in vaccination rates and overcoming vaccine hesitancy stand as paramount public health challenges. They necessitate nuanced strategies aimed at maximizing individual health, while optimizing for overall community health outcomes. Therefore, this multifaceted conundrum warrants an integrated approach that elucidates the potential underlying causative etiology of immunization shyness among diverse demographic groups and paves the way for sculpting efficacious interventions.

2. Data Collection & Project Scope

The Massachusetts Department of Public Health (MDPH) stewards a comprehensive COVID-19 Vaccination Database, indispensable for surveilling statewide immunization trajectories. This repository elucidates a granular spectrum of vaccination indices, segmented by demographic attributes such as age, gender, and race, and vaccination phases, including initial, full, and booster doses. When analyzed in conjunction with socio-economic metrics such as the Social Vulnerability Index (SVI)—which encapsulates variables of at-risk cohorts including poverty, low educational attainment, and unemployment, obtained from MDPH and US Census Bureau APIs—this nexus of data streams creates a detailed panorama of public health landscapes.

In this analysis, we examine vaccination rate data across five Massachusetts cities with disparate economic profiles (Figure 2, Left). These cities—New Bedford, Chelsea, Newton, Revere, and Wellesley—are represented in Figure 2, Right, with each city distinguished by a unique color. Our goal is to uncover the nuanced factors that influence vaccination uptake in these locations, thereby advancing our understanding of the generalizable determinants that drive immunization inequities worldwide and unraveling the intricate web of public health dynamics.

The MA COVID-19 Vaccination Data is collected and maintained by the MA Department of Public Health (MDPH). This dataset is crucial for understanding the progress of the COVID-19 vaccination campaign, identifying areas with lower vaccination rates, and planning public health interventions. The data encompasses detailed information regarding COVID-19 vaccination rates across different age groups, gender and race in various cities of MA, including Wellesley, Newton, Revere, Chelsea, and New Bedford. The dataset includes key metrics such as the number of people vaccinated in each age group, the total population of each age group, and the breakdown of those partially vaccinated, fully vaccinated, and boosted as well as gender and race. This comprehensive data collection enables the MDPH to monitor vaccination trends, assess community health needs, and guide policy decisions. We access this data through the MDPH's public health database API, which ensures timely and accurate information. This dataset is instrumental in calculating SVI, such as identifying vulnerable populations based on age and vaccination status, and understanding the distribution of healthcare resources.

The US Census data is collected by the US Census Bureau and serves various purposes, including determining congressional representation, allocating federal funding, and understanding population trends.The US Census data covers a wide range of information, including race, ethnicity, population and housing statistics, redistricting data, and more. We use the US Census API to obtain the SVI (poverty level, education, unemployment, elderly population) as well as income and unemployment rate.

In this paper, we focus on 5 cities and would like to investigate the differences of vaccination rate among five cities: Chelsea, New Bedford, Newton, Revere, and Wellesley. We start with looking at the vaccination rates among five cities.

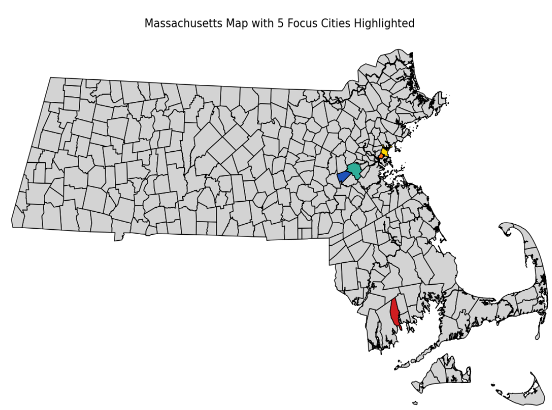


Figure 4. Locations of the 5 Cities (5Cities.ipynb)

3. Preliminary analysis

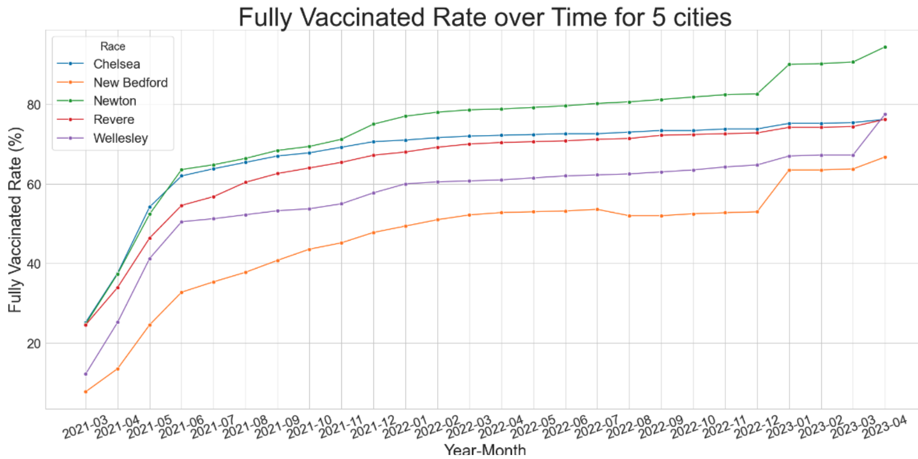


Figure 5. Fully Vaccination Rate over time by Five Cities. (data_explore_vac.ipynb)

The provided graph delineates the progression of full vaccination rates over time in five distinct cities spanning from March 2021 to April 2023. The vaccination rates have increased across all cities, yet the gradient of increase and the final vaccination percentages point to a significant heterogeneity in public health outcomes. Newton leads with the highest vaccination rates, potentially reflective of its elderly population. Revere and Chelsea exhibit comparable rates, suggesting similar healthcare outreach or demographic patterns, while Wellesley and New Bedford follow, with New Bedford showing the lowest rates. This may indicate disparities in vaccine distribution or varying levels of vaccine hesitancy. Moreover, despite initially lower vaccination rates in Wellesley compared to Revere and Chelsea, Wellesley's rates ultimately surpassed those of the latter two cities by April 2023.

Personal beliefs and attitudes can significantly influence vaccination decisions. In the elderly, these decisions are often shaped by lifelong beliefs and the potential for side effects, which may cause hesitancy towards vaccines. For children, parents' or guardians' beliefs and the social milieu shape vaccination choices, balancing perceived risks and benefits. Furthermore, Healthcare policies and public health campaigns play a pivotal role in vaccination uptake. Targeted campaigns and policies that remove financial barriers, like Medicare, can increase vaccination rates among the elderly by emphasizing the risks of non-vaccination. For children, mandatory school vaccinations and public education on community health responsibilities ensure higher vaccination rates.

Finally, socioeconomic status is a key predictor due to its links with education and healthcare access. Among the elderly, factors like retirement income and social support impact vaccination decisions, with those in lower income brackets possibly prioritizing other needs due to cost concerns and facing challenges like limited transportation. For children, family socioeconomic status plays a significant role; higher status often correlates with better access to healthcare and higher vaccination rates, while lower status may lead to barriers such as costs and limited healthcare access. However, the 1-dose pediatric vaccination data revealed a curious trend that may indicate that high socioeconomic status may not necessarily predict a high vaccination rates.

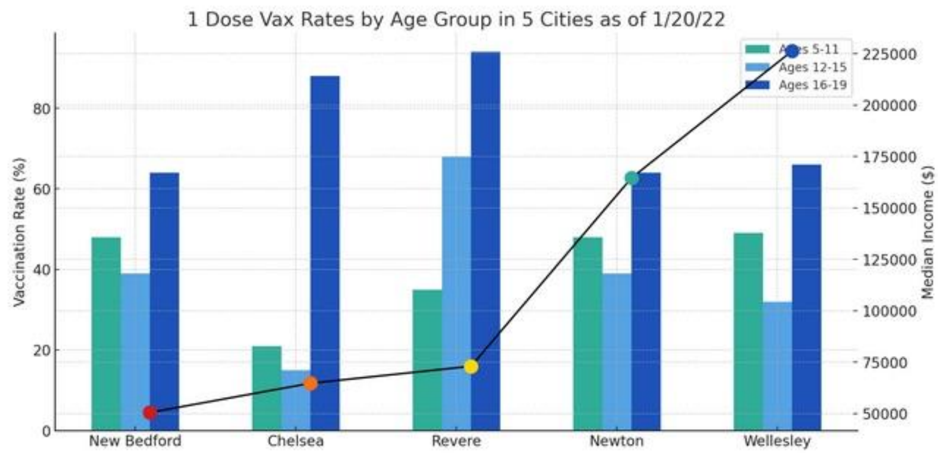


Figure 6. 1-Dose Vaccination Rates by Age Group in 5 Cities

Figure 6 depicts the first-dose vaccination rates across five cities, categorized into three pediatric age groups as of January 20, 2022. Notably, the 16-19 age group in a less affluent city such as Revere exhibits the highest vaccination rate. Meanwhile, the vaccination trends in more affluent areas like Newton and Wellesley suggest a surprising tendency for the wealthier populations to be more hesitant about COVID-19 vaccinations for their children.

Given the different vaccination rates among five cities, we are looking for the factors that may impact on the vaccination rates. As vaccination rates are highly influenced by the geographic demographic and economic indicators. In the process of exploratory data analysis, we are investigating how the income level, poverty level, employment rate, education, age, race and gender departs among five cities. Further, how these factors affect the difference of vaccination rate among five cities.

Social Vulnerability Index (SVI)

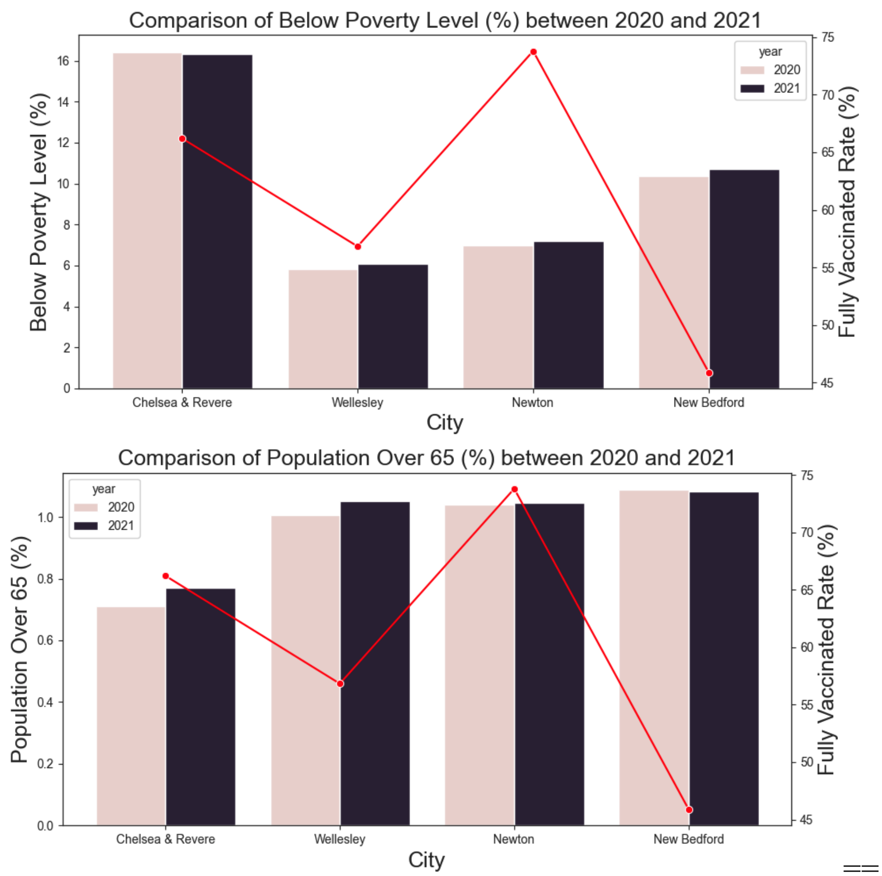
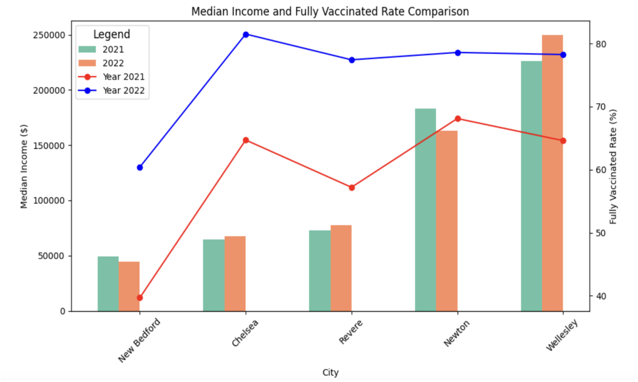


Figure 7 & Figure 8 SVI among Five Cities (data_explore_vac.ipynb)

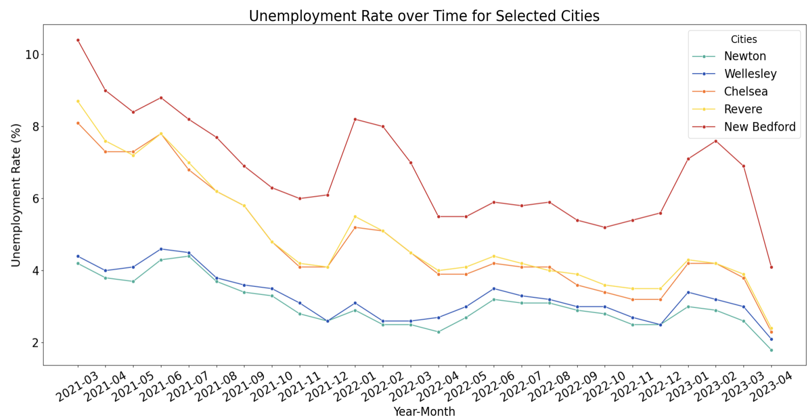
The Social Vulnerability Index (SVI) comparison employs bar graphs to depict two distinct socio-economic parameters: poverty level and the population aged over 65. This comparison spans 2020 and 2021 across Suffolk (Chelsea & Revere), Norfolk (Wellesley), Middlesex (Newton), and Bristol (New Bedford) counties. New Bedford exhibits a heightened economic vulnerability index concerning poverty levels and its elderly populace. Given these variables, it is hypothesized that New Bedford would manifest a diminished vaccination rate, correlating with its economic fragility and less educational attainment. Conversely, the other three cities are anticipated to demonstrate elevated vaccination rates, attributable to their larger senior populations.

Furthermore, our analysis extended to socio-economic factors, specifically income levels and unemployment rates.

Economic Factors



(income_unemployment.ipynb, p. 24)

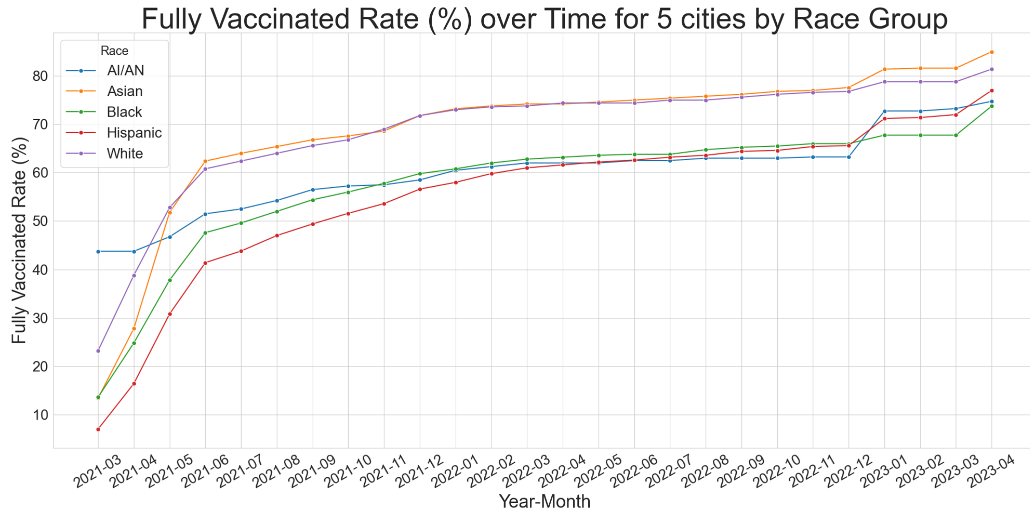


(income_unemployment.ipynb, p. 209)

Figure 9 & 10. Median Income and Fully Vaccinated Rate Comparison with the Unemployment Rate Over Time for Selected Cities.

Figure 9. shows that Wellesley and Newton, with the highest median incomes among the five cities studied, may experience better healthcare access and higher vaccination rates. Higher incomes typically afford residents more flexible schedules and better healthcare literacy, enabling easier access to vaccination services. Contrary to expectations, Chelsea, despite its modest median income, records a robust vaccination rate. This anomaly may be attributed to 'La Colaborativa's' proactive engagement, a local entity that collaborated with the East Boston Neighborhood Health Center to facilitate community vaccinations, thus significantly boosting Chelsea's vaccination rate amidst its economic adversities. Figure 10 illustrates the unemployment rates across five cities, highlighting Chelsea, New Bedford, and Revere as the highest. This indicator is pivotal, often mirroring broader socio-economic challenges, including poverty. The presumed lower vaccination rates in these cities are conjectured from a confluence of factors inherent to economic disadvantage, such as health prioritization, and access to information and education.

Race



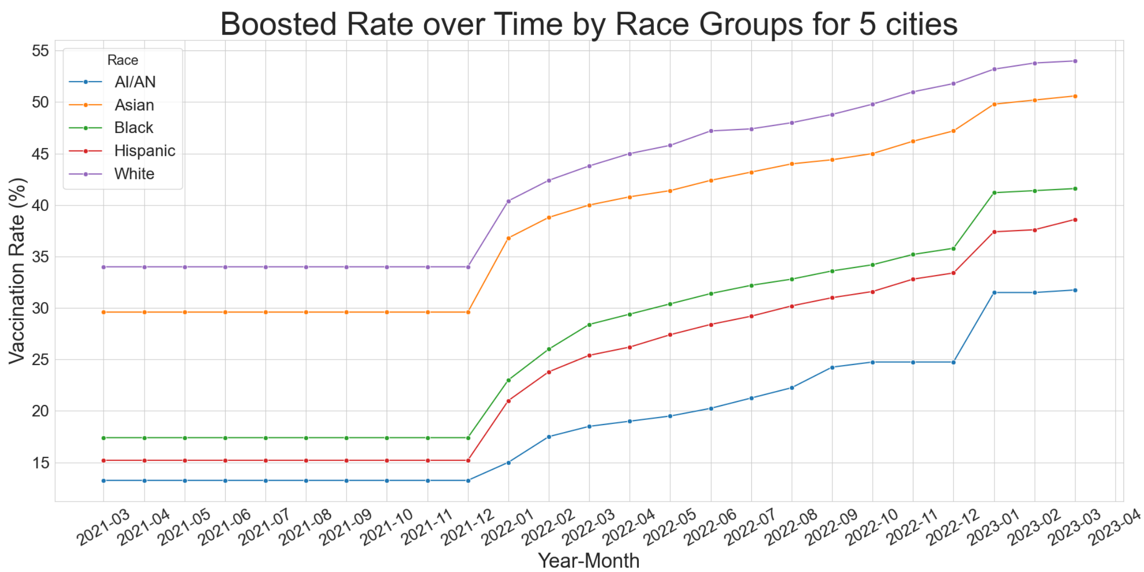


Figure 11 & 12 : 2-Dose & 3-Dose Rate over Time for 5 Cities by Race (data_explore_vac.ipynb)

From Figure 11, stratified by racial demographics, a clear upward trend is observed from March 2021 to April 2023 among five cities with initial rates near 20% escalating to a range between 70-80%. The data indicate a hierarchy in vaccination rates with the White population leading, followed by Asian, Black, Hispanic, and American Indian and Alaska Native (AI/AN) groups, respectively. This hierarchy suggests potential disparities that could be rooted in systemic factors such as healthcare accessibility, socioeconomic status, or vaccine hesitancy. Notably, the Hispanic demographic initially exhibited the lowest vaccination rate among the five racial categories. However, by the end of April 2023, the vaccination rate for Hispanic Americans exceeded that of Black and AI/AN communities.

Figure 12. reflects the booster vaccination rates across five racial groups in five cities from December 2021 to March 2023. The booster rates have risen from an average of approximately 15% to around 40% for all groups. The data indicate a hierarchy in vaccination rates with the White population leading, followed by Asian, Black, Hispanic, and AI/AN groups, respectively. It indicates that while progress has been made in administering booster shots, there is a crucial need for strategies to increase equity in vaccination efforts.

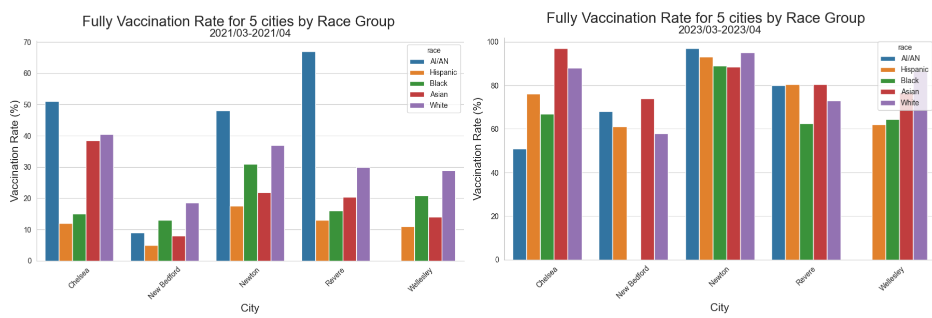
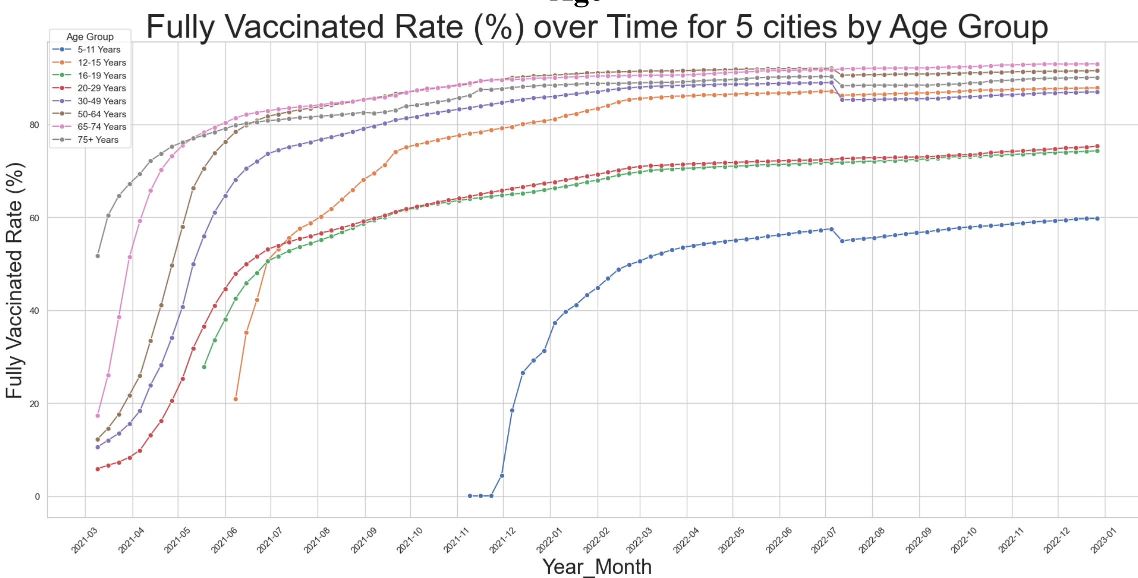


Figure 13 & 14 : Histogram of Single Time Points for 5 Cities by Race (data_explore_vac.ipynb)

These histograms reveal race-based vaccine disparities within each city. In March 2021, the Hispanic vaccination rate lagged behind the Black community across all five cities. Yet, by April 2023, the trend reversed, with the Hispanic group surpassing the Black community. Similarly, the Asian demographic, initially trailing behind the White and Black groups in March 2021, eventually overtook the Black group in all cities and even surpassed the White group in Chelsea, New Bedford, Newton, and Revere by the end of April 2023.

Age



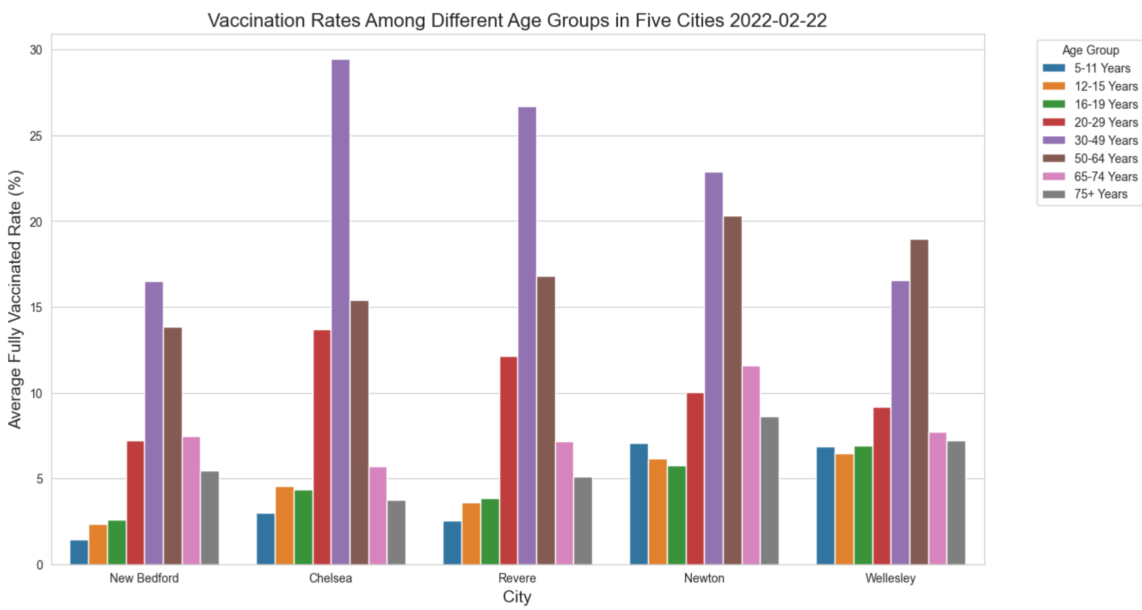


Figure 15 & 16 Vaccination Rates and Vaccinated People Among Different Age Groups in Five Cities

The bar chart showcases the vaccination rates across different age groups in five cities as of Feb 02, 2022. This time is picked due to the fact it was the time slot that age group 5-11 Years came into play. This visualization reveals distinct patterns in vaccination uptake among various age demographics. Chelsea ranks third in average vaccination rates among the considered age groups and has the highest vaccination rate in the 30-49 age group , suggesting effective local vaccination campaigns possibly bolstered by grassroots organizations. In addition, the bars of richer cities are more constant than the poor ones.

The vaccination trends among the 20-29 and 30-49 age groups decline in correlation with the wealth levels of the five cities, indicating a potential lack of vaccination interest among more young affluent populations. Moreover, the vaccination patterns in wealthier cities appear more uniform than their less affluent counterparts. This observation leads to a hypothesis: Cities with higher socioeconomic status may exhibit less drastic differences in vaccination rates across various age groups. This difference could be attributed to the fact that the working-age group of individuals (aged 30-49) was often subjected to vaccine mandates, particularly in occupations involving physical labor rather than cerebral work.

Population Size

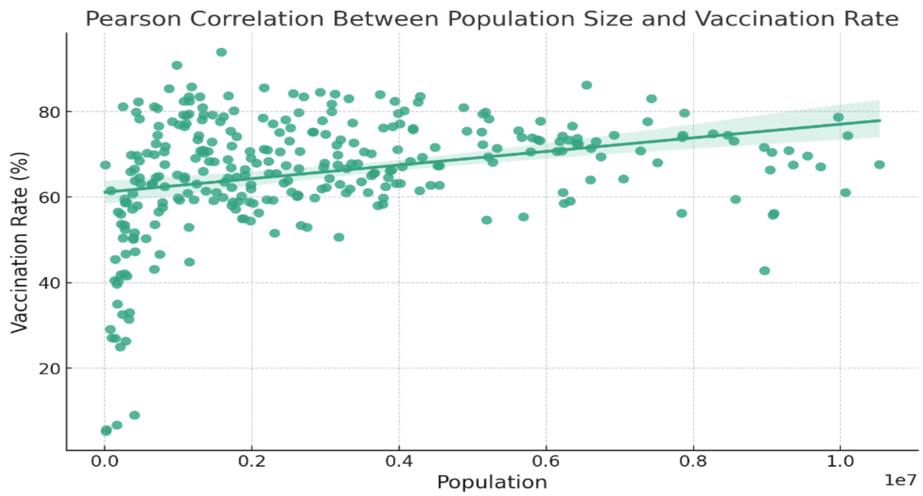


Figure 17: Pearson Correlation Between Population Size and Vaccination Rate

Figure 17visualizes the correlation between population size and vaccination rates as of 2023-02-15 across various cities (green dots). The distribution of these points suggests that population size is not a strong linear predictor of vaccination rates, highlighting the multifaceted nature of vaccination campaigns influenced by public health policies, community outreach, and socio-economic conditions. This complexity calls for a nuanced approach to public health strategies.

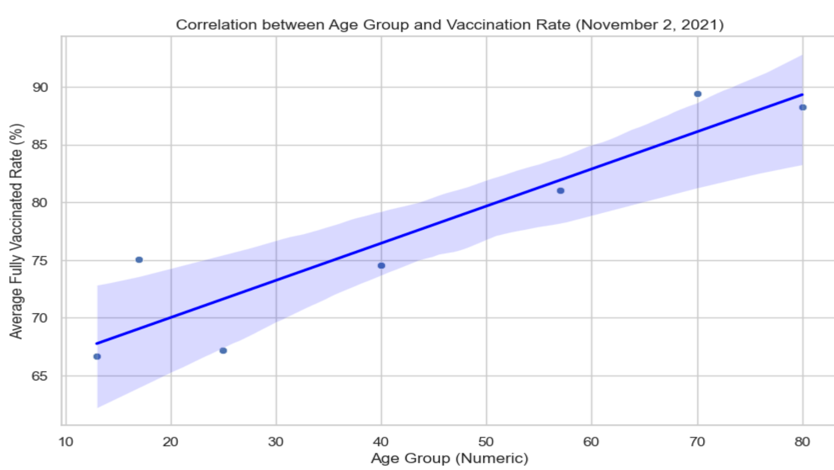


Figure 18: Pearson Correlation Between Age Group and Vaccination Rate

Figure 18 presents a scatter plot with a regression line, dated November 2, 2021, illustrating the correlation between diverse age groups (12-15, 16-19, 20-29, 30-49, 50-64, 65-74, 75+) and vaccination rates. This timeframe allows for an exploration of the fully developed correlation between age and vaccination.

The Pearson correlation coefficient for this date is approximately 0.926, indicating a strong positive correlation.This high correlation coefficient suggests that as age increases, the fully vaccinated rate also tends to increase, particularly on this date. The older age groups show higher vaccination rates compared to the younger ones. This trend is visually supported by the upward slope of the regression line in the scatter plot.

Gender

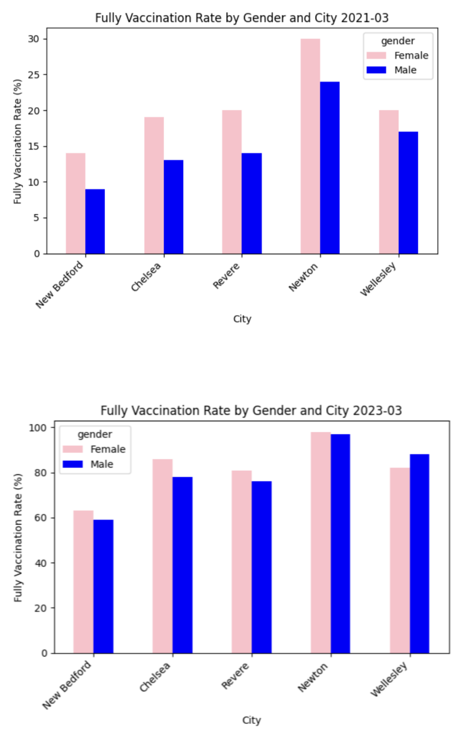


Figure 19 Fully Vaccinated Rate by Gender and City in 2021 and 2023 (gender.ipynb, p.372-374)

Initial data from March 2021 indicated a significantly higher vaccination rate among women compared to men. However, subsequent data from March 2023 reveals a diminished disparity. Intriguingly, in Wellesley, the vaccination rate for men now exceeds that of women.

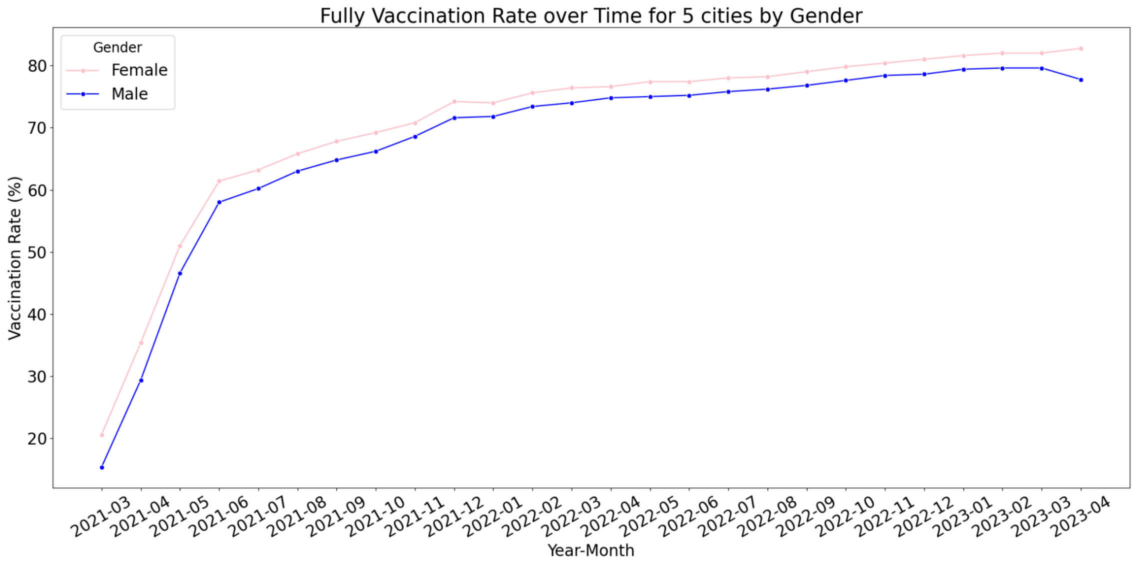


Figure 20. Vaccination Rate Over Time by Gender
(gender.ipynb, p.378)

Figure 20, highlights a consistent trend: females generally maintain a higher vaccination rate over time. This could be ascribed to a predominant female presence in the healthcare workforce, where vaccination rates are typically higher owing to both increased access and sector-specific mandates. Additionally, societal dynamics, wherein women often assume primary caregiver roles, might contribute to this trend, as they are more likely to seek vaccinations to safeguard family and communal health.

Mortality

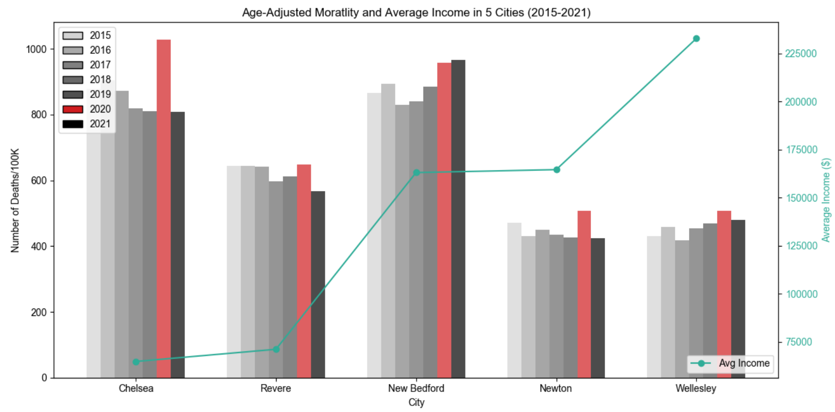


Figure 21. Age-Adjusted Mortality and Income by City

Figure 21 illustrates the mortality rates in five cities from 2015 to 2021, with data for 2020 highlighted in red. Newton and Wellesley, cities with higher average incomes, show consistently lower mortality rates, suggesting an inverse relationship between income and mortality. However, New Bedford stands as an exception to this trend.

4. Regression Analysis

In our quest to decipher the critically associated factors of the fully vaccinated rate, we amalgamated diverse factors: race, gender, age, employment rate, booster status, first dose rate, and city. Our objective was to identify the most influential features. Our initial step involved constructing a correlation heatmap, where red hues signify positive correlations, and blue hues denote negative correlations. By amalgamating these key features into a singular dataset, we endeavored to ascertain the most impactful factor. The analysis revealed a negative correlation between the unemployment rate and all vaccinated groups, suggesting an inverse relationship between unemployment and vaccination rates. Furthermore, the gender category exhibited a strong correlation with all age brackets, while the white race group showed a pronounced positive correlation with all age categories.

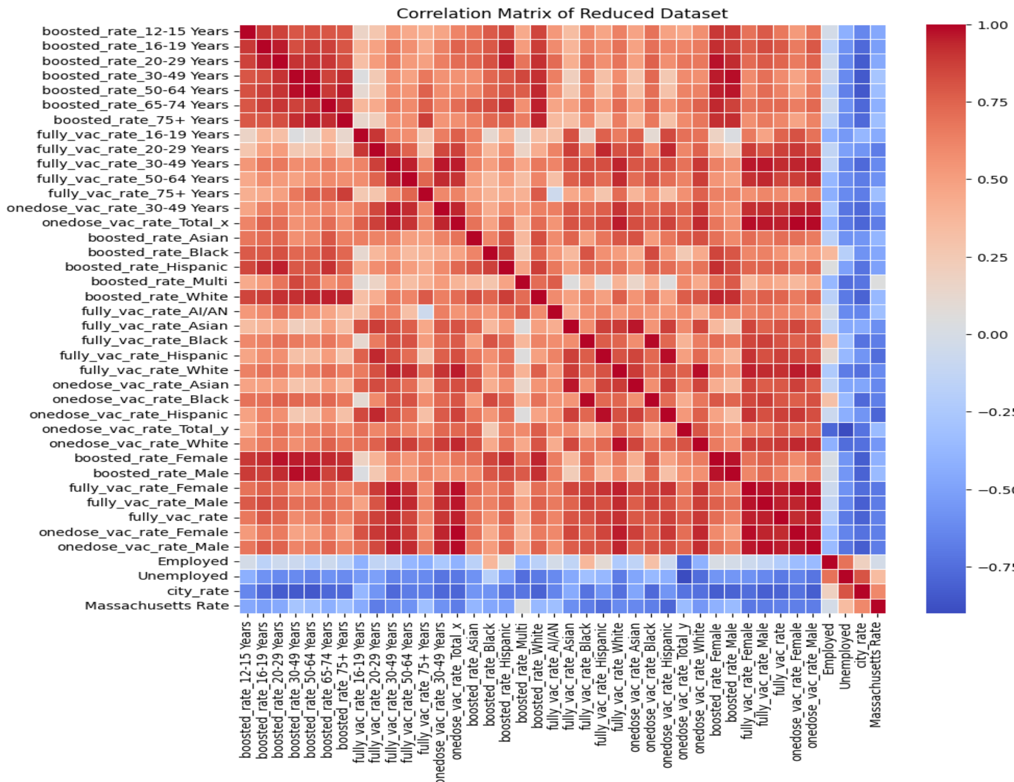


Figure 22: Correlation coefficient features.

Then, to identify the most important features we use logistic regression to get the 10 most important features as shown below.

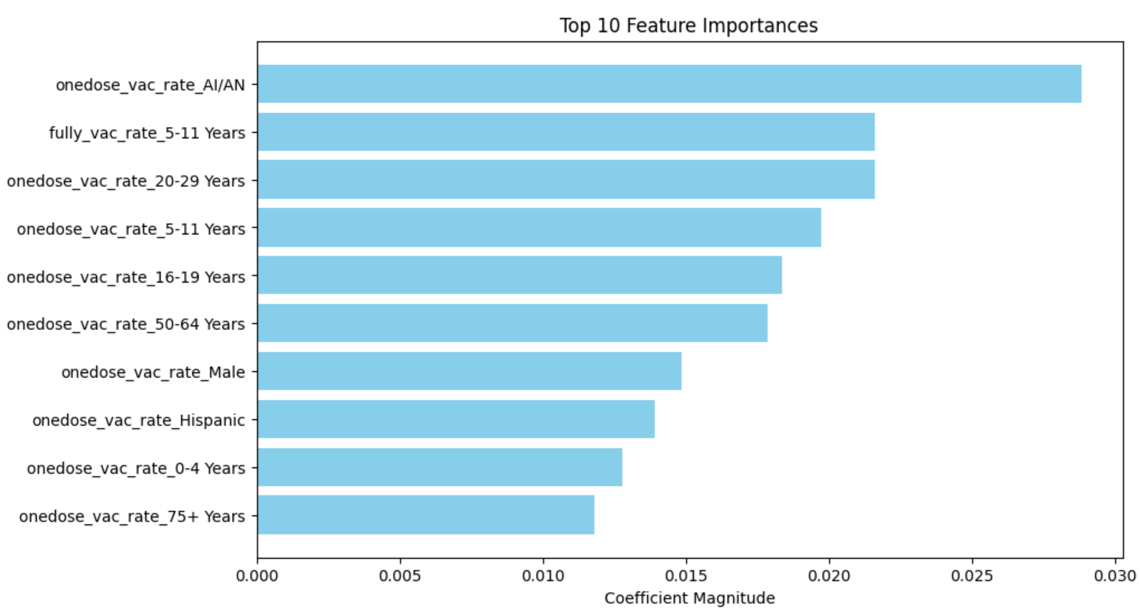


Figure 23: Top 10 Feature Importances

Based on the graph above, it is evident that the most pivotal factors of consideration are intrinsically intertwined with the variables of race, age, and gender, with the age bracket standing out as the preeminent influencer.

To engage in a more granular examination of the impact of these variables on the rate of full vaccination, while holding the city variable constant, we undertook an Ordinary Least Squares (OLS) regression analysis for each of these factors. The equation that encapsulates this analysis is as follows:

$$Fully\ Vaccinated\ Rate\ =\ Intercept\ +\ coefficient\ *\ Factors + \text{City}$$

Specifically, we did

Model 1: $Fully\ Vaccinated\ Rate\ =\ Intercept\ +\ coefficient\ *\ Gender\ + \text{City}$

Model 2: $Fully\ Vaccinated\ Rate\ =\ Intercept\ +\ coefficient\ *\ Race\ + \text{City}$

Model 3: $Fully\ Vaccinated\ Rate\ =\ Intercept\ +\ coefficient\ *\ Age\ + \text{City}$

	Coefficient	R^2
Gender-Male		
Gender-Female	2.88	0.3
Race-AI/AN		
Race-Asian	-13.41***	0.33
Race-Black	-10.16***	
Race-Hispanic	-9.51***	
Race-White	-18.64***	
Age-5-11yrs		
Age-12-15yrs	69.71***	0.55
Age-16-19yrs	56.17***	
Age-20-29yrs	51.90***	
Age-30-49yrs	67.91***	
Age-50-64yrs	73.60***	
Age-65-74yrs	76.33***	
Age-75+yrs	75.61***	

Notes: *** p-value <0.05

Table 24: Regression Results on Fully Vaccinated Rate(data_analysis_vac.ipynb)

In interpreting our findings, the coefficient attributed to the gender factor [T.Female] is 2.8760. This implies that the female gender is associated with an approximate increment of 2.88 percentage points in the vaccination rate in contrast to their male counterparts. Nonetheless, it is imperative to underscore that this association lacks statistical significance, as evidenced by a p-value of 0.140.

For all racial groups, we discern statistically significant implications on the rate of full vaccination. When compared to the baseline AN/AI group, individuals belonging to four other ethnicities exhibit conspicuously lower vaccination rates. Specifically, the coefficients for the Asian, Black, Hispanic, and White groups are -13.41, -10.16, -9.51, and -18.64, respectively. It is conceivable that this dissimilarity may be ascribed, at least in part, to the comparatively diminished population size of the AN/AI group in contrast to the other racial categories.

The results emerging from our regression analysis for the age group demonstrate the most pronounced explanatory prowess, boasting an R-squared value of 0.55, eclipsing the influences of the other gender and age cohorts. This signifies that approximately 55% of the variance in the vaccination rate is elucidated by our model. While holding other variables constant, age cohorts wield ab influential sway over the vaccination rate, substantiated by p-values that fall below the 0.05 threshold. Notably, when compared to the baseline age group of 5-11 years old, the impact of age on the vaccination rate increases with age. Notably, the age group 65-74 years old has the largest impact on the fully vaccinated rate.

5. Conclusion & Limitations

Our comprehensive analysis has led us to a multifaceted understanding of the factors influencing vaccination rates. It is evident that demographic variables such as race, gender, and age significantly affect the likelihood of being fully vaccinated. Notably, within the race category, compared to the American Native/Alaska Native (AN/AI) group, the Asian, Black, Hispanic, and White groups have lower vaccination rates with coefficients of -13.41, -10.16, -9.51, and -18.64 percentage points respectively, all of which are statistically significant. This suggests systemic disparities that warrant further investigation and targeted public health interventions.

While gender appeared to play a role, with females showing an approximate 2.88 percentage point increase in vaccination rates over males, this finding was not statistically significant (p-value of 0.140). This indicates that while there may be a trend towards higher vaccination rates among females, the evidence is insufficient to conclusively state gender as a determinant factor without further data.
Age emerged as a crucial determinant with substantial explanatory power in our model (R-squared value of 0.55), indicating that 55% of the variation in vaccination rates could be attributed to age differences. This significant finding, particularly among those aged 65-74 years, underscores the need for age-specific vaccine outreach and education programs.

Interestingly, our findings also revealed no significant impact of the unemployment rate on vaccination rates, challenging initial assumptions about the role of economic factors in vaccine uptake. However, significant variations in vaccination rates were observed among different cities, reflecting the diverse demographic profiles across regions.

This report underscores the complexity of vaccine equity and hesitancy issues, highlighting the necessity for nuanced strategies that consider socioeconomic status, education level, and race. While our initial findings provide valuable insights, they also point towards the need for ongoing research and exploration of alternative data sources, including extended studies across various cities.

In summary, this report serves as a call to action for public health officials and policymakers to engage communities comprehensively, prioritize data collection efforts, and foster collaborations among stakeholders to address vaccine hesitancy effectively. Continuous adaptation of strategies based on emerging data is crucial in bridging the gaps in vaccine equity and ensuring comprehensive protection against preventable diseases for all individuals."

Given the datasets we have, we may have the following limitations. 1. Correlation Does Not Imply Causation: The relationships observed between vaccination rates and various socio-demographic indicators do not necessarily imply causation. While these correlations are insightful, they should be interpreted with caution, as other unmeasured variables could also influence the outcomes. 2. Complexity of Public Health Dynamics: Vaccination uptake is influenced by a myriad of factors, including public health policies, individual beliefs, and community engagement. Our dataset captures only a fraction of these elements, potentially omitting crucial variables that play a significant role in vaccination campaigns. 3. Challenges in Measuring Community Initiatives: Without specific data from grassroots organizations, it's challenging to quantify their contribution to vaccination efforts. This gap hinders our ability to fully understand and acknowledge the role of community-based initiatives in public health outcomes.

Recommendations for Further Analysis. Investigate Other Sources of Data: To compensate for the lack of grassroots data, explore alternative sources that may provide indirect insights into the activities of these organizations, such as local news reports, community surveys, or public health bulletins. Conduct Qualitative Research: Engage in qualitative studies, including interviews and focus groups with community members and local health workers, to gather anecdotal evidence of grassroots organizations' impact on vaccination rates. Compare with Similar Cities: Analyze vaccination rates in cities with similar socio-demographic profiles but without significant grassroots activities. This comparison could offer indirect insights into the potential impact of such organizations.

6. Summary

This report on vaccine equity in MA emphasizes the critical public health challenge of vaccine hesitancy and the necessity for nuanced strategies. Building upon previous analysis, this project delves into a broader scope of variables, including age, ethnicity, gender, economic status, and the Social Vulnerability Index (SVI), to understand their correlation with vaccine hesitancy.

The preliminary analysis investigates vaccination rates among different demographics and cities, revealing significant disparities influenced by factors like socioeconomic status, education, and race. However, the lack of specific data on grassroots organizations' impact and the complexity of public health dynamics.

We suggest further analysis, including exploring alternative data sources, conducting regression analysis, and expanding to other cities. In summary, the report underscores the importance of community engagement, comprehensive data collection, and collaboration among stakeholders.

7. Policy Suggestions

Based on our findings, we propose that it is important to increase vaccine access and public health education for vulnerable groups to improve the equity equity. Non-governmental organizations (NGOs) can play a crucial role by providing services in vulnerable areas and making public data from these services accessible. Additionally, fostering partnerships between NGOs and local community leaders and organizations can help customize vaccination efforts to meet the unique needs and cultural contexts of each community. Finally, implementing mobile vaccination services can further enhance access to vaccines by reaching underserved populations.

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Appendix

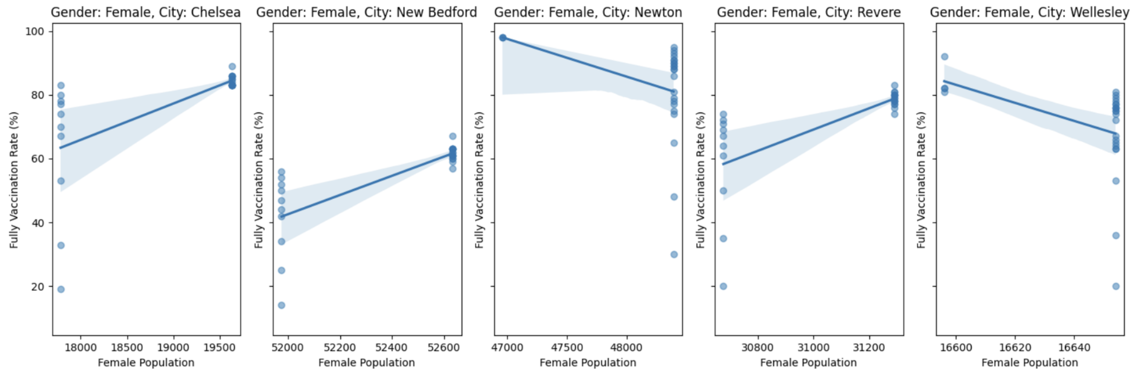

Figure A1. Comparison of Fully Vaccination Rates vs Female Population Across Cities (gender.ipynb, p.382)

This figure delineates the relationship between the proportion of the female population and full vaccination rates across various cities over the time. A direct correlation is generally observed, yet exceptions are notable in Wellesley and Newton. As previously indicated, Wellesley shows a higher vaccination rate in males than in females, while Newton presents comparable rates between genders. Furthermore, potential variances in data collection must be considered. The graph indicates that population data for each city has been updated only once in two years, signifying that data points remain constant on the x-axis (representing the female population). The US Census data lacks regular updates on real-time demographic shifts, challenging the presumption of a static female population over time.