Demographics and mitigation efforts associated with the county-level impact of COVID-19 in Pennsylvania

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Abstract

The COVID-19 pandemic deeply impacted the world in 2020, with the U.S having over 20 million total cases by the end of the year. An important lesson learned through the response effort in the U.S. was that minority groups and those of low socio-economic status were those most affected by the pandemic, both on an individual level and a community level. The main objective of this paper was to determine whether these demographic disparities could explain to an extent the county differences in the impact of COVID-19 in Pennsylvania, and whether the phased re-opening strategy also contributed to this variation between counties. To meet this objective, a linear mixed model was developed to examine associations between demographic variables and the daily incidence rate over time. To assess the impact of phased re-opening on COVID-19 incidence, the number of days spent in phases before complete re-opening was also examined as a factor to the linear mixed model. This analysis found that lower median income, lower median age, and higher a percentage of urban land-use was associated with increases in the daily incidence rate. However, these associations changed depending on the time period, with race being a significant effect especially during March to June. As far as the phased re-opening strategy, the model results suggested that from March to June, phase changes were in response to each county's incidence rates, but that counties that stayed in the first phases longer had lower incidence rates in the last three months of 2020. This research adds to the growing body of

evidence that racial, income, and health disparities impact community-level outcomes of COVID-19, and therefore need to be considered when implementing a public health response.

Table of Contents

List of Tables

List of Figures

1.0 INTRODUCTION

1.1 COVID-19: History, impact, and the public health response

The COVID-19 pandemic caused by the SARS-CoV-2 virus began in Wuhan, China in December 2019.[1] By the time the World Health Organization (WHO) declared it a pandemic on March 10, 2020, there were already over 100,000 cases and over 4,000 deaths in 114 countries.[2] Historically, though there were two previous epidemics caused by coronaviruses (SARS-CoV in 2002 and MERS-CoV in 2012), COVID-19 was the first ever declared pandemic caused by a coronavirus.[2]

First reports in January showed cause for concern, as by mid-January, cases had already been reported in other provinces of China, Thailand, Japan, South Korea, USA, Vietnam, and Singapore.[3, 4] Even though compared to Middle East Respiratory Syndrome (MERS) and Severe Acute Respiratory Syndrome (SARS), its case-fatality rate was calculated to be relatively low at about 3% (compared to 37% for MERS and 10% for SARS), early calculations also showed a rate of spread similar to the previous SARS outbreak.[5] With its lower case-fatality rate and less severe symptoms compared to previous coronavirus epidemics, the concern for public health officials was that cases would be more difficult to identify, and people would be more likely to spread to others while being unknowingly ill. Furthermore, its place of origin, Wuhan, is a major center for transportation – not only for travel across China, but also in international travel.[6]

By February, the virus was definitively travelling internationally and spreading from person to person in other countries. Europe began seeing its first cases, and Italy and South

Korea became the first countries outside of China to experience intense outbreaks.[7] The U.S. also experienced community transmission of COVID-19 starting in February, and occurring in all 50 states by the end of March. At this time, case rates varied widely by state and county, with some places such as New York City, NY being classified as hotspots.[8] Though, by the end of 2020, every state and county had experienced community transmission of COVID-19 and various peaks and valleys of cases and deaths.

The response from public health officials varied between countries in scope and specific strategies, but there were some commonalities. For one, a priority in all countries was monitoring cases. Contact tracing and isolating cases had been shown to work in previous epidemics, and was done to some extent in every country.[9, 10, 11] In the US, specifically, travelers from China were screened in the first few months, and eventually expanded to all travelers.[12, 13] Testing as many people as necessary became a priority, with the goal to lower the number cases per tests (i.e., the positivity rate).[14] As soon as cases were identified through testing, local health departments contacted cases and determined whether others need to be informed of a possible exposure.[9] Another commonality between countries was in encouraging or enforcing people to isolate or social distance. In the US, gatherings were prohibited, schools were closed, and all non-essential businesses were closed.[9] Most counties and states also declared states of emergency, which required people to stay at home unless for essential activities.[15] However, by the summer in the US, the majority of places were actively re-opening, with economic concern in mind.[15] Although not all states or counties were careful in their re-opening, most enforced restrictions to the re-openings, with the main measure being to enforce mask wearing in public.[15]

Another major part of the public health response across all countries was in communication to the public. In the US, early guidance consisted mainly of discouraging people from traveling to other countries.[13] When community transmission began to be reported in February to March, guidance focused on social distancing and washing hands often.[13] Though there was some hesitancy to encourage mask wearing in early March, the evidence was clear by April that they helped to stop the spread, and the CDC issued guidance on their use.[13, 16] The most consistent messaging from April to the present has been to stay at least 6 feet apart, wash hands often, and wear a mask.[17]

The effectiveness of public health strategies also varied by country. For some, like South Korea, the response was swift and forceful enough to slow the virus's spread, and deaths remained minimal throughout 2020.[18] The US, however, faced several problems in its response. Before the pandemic even began, the US had perpetually underfunded public health infrastructure in favor of health research and health technology development.[19] Public health funding tends to be in response to crises, instead of investing in preparation for crises.[19] Many states have more of a centralized health department, meaning that the decision-making and public health funding comes mainly from the state department, instead of local health departments.[20] The issue with this governance structure is that state health departments are especially underfunded by the federal government, and in all health emergencies, including COVID-19, centralized state health departments have been shown to be slower than decentralized structures to make decisions and to implement those decisions.[19, 20] The US also had a major issue with the politicization of public health mitigations. Trust in science and health advice was already highly dependent on political affiliation, with Democrats having more trust than Republicans.[21, 22] This difference between views on public health messaging only worsened during the pandemic, as conflicting information and misinformation were mainly perpetuated by conservative news media and the president.[23, 24] States with Republican governors were slower in implementing mitigation efforts, and despite having lower incidence rates in the first couple months, did worse in both case rates and mortality rates from July to the rest of 2020.[25, 26] However, the main mitigation strategies were shown to help slow the virus's spread. In general, stay-at-home orders, social distancing recommendations, and face mask recommendations or mandates were shown to reduce the incidence rate, mortality rate, and the hospitalization rate.[27, 28, 29, 30]

After one year of the world being overwhelmed and devastated by the COVID-19 pandemic, there were over 100 million cases and about 2.5 million deaths in 219 countries.[31] In the U.S. alone, there were almost 30 million cases and over 500,000 deaths by March 2021.[31] Despite the public health crisis this virus has caused, there exists a more positive outlook one year later. As of April 25, 2021, three different vaccines have been authorized by the FDA for emergency use, and about 28.8% of the US population has been fully vaccinated, with millions of doses administered every day.[31] Public health campaigns continue to encourage people to social-distance and wear a mask, but they also include reasons to get vaccinated and ways to provide access to the vaccine for all communities.[32]

1.2 COVID-19 in Pennsylvania

The course of the epidemic in Pennsylvania (PA) was fairly similar to the rest of the US. The first cases occurred on March 6, and within two weeks, many counties were experiencing community transmission.[33] Throughout 2020, the state had three peaks of COVID-19 cases on April 8, July 23, and December 10, which corresponds to when the US as a whole experienced surges.[34] Pennsylvania's case fatality rate is about 2%, which is also consistent with the entire country.[34]

Months before the first case, the PA Department of Health began meeting daily to prepare their response effort and track the virus in the state.[35] On March 16, all schools were closed, and visitation was stopped at nursing homes and correctional facilities.[35, 36] The governor then issued a statewide shutdown on March 19, which closed nonessential government offices and businesses.[37, 38] These nonessential business closures were enforced only through fines.[37, 38] Some counties were issued stay-at-home orders on March 23, but a statewide order occurred on April 1.[35] Though the governor began recommending mask wearing in public on April 3, a mask mandate for businesses did not occur until April 15, and a mandate for all public places did not occur until July 1.[35, 39]

Less than two weeks after the first peak, the state announced its plan to reopen Pennsylvania, which consisted of a phased reopening strategy.[35] The phases were "red", "yellow", and "green", with each county moving to the next phase when they had met several requirements. These were not necessarily strict requirements and were subject to the Department of Health's and the governor's interpretation. The requirements did include monitoring case rates in the county and the surrounding region, and whether counties had the necessary protective equipment for healthcare facilities and widely available testing for its population.[35] By the announcement of this plan, all counties were already in the red phase, which consisted of closing nonessential businesses, closing schools, and a stay-at-home order in place. The yellow phase allowed certain businesses and all schools to open with safety measures in place (e.g., proper sanitation and lowered maximum occupancy), with restaurants only being allowed outdoor dining.[35] This phase also removed the stay-at-home order, but only allowed social gatherings to be less than 25 people.[35] The green phase was fairly similar to the yellow phase, but allowed more businesses, such as movie theaters and gyms, to open with those same safety measures in place.[35] In all phases, mask wearing was required in public.[35]

1.3 Socioeconomic and demographic disparities are linked to increases in the rate and severity of COVID-19 in the United States

Many studies throughout 2020 have shown that there are groups of people who were disproportionately affected by COVID-19 in the US. For instance, older age groups are much more likely to experience severe symptoms, be hospitalized, and die due to COVID-19.[40, 41, 42, 43, 44] Several studies show that the median age of those hospitalized range from 60-65 years old, and that those who are over 65 years old account for about 78% of deaths in the US.[41, 42, 43, 44] However, the median age of those who test positive is much younger at around 36-44 years old.[45, 46, 47] McLaughlin, J. M., et. al (2020) studied the effect of age on the rate of COVID-19 per county in the US and found that counties with a median age of less than 50 years old had higher incidence rates than those with median ages greater than 50 years old.[48]

Race and ethnicity can also be major predictors of the rate and severity of COVID-19 in US communities. Among those who are Hispanic or Latino or who are black (non-Hispanic), the rate of infection, of hospitalization, and of deaths is higher than other race and ethnicity groups.[40, 41, 42, 43, 44, 45, 46, 49, 50, 51, 52, 53, 54, 55, 56, 57] The percent of hospitalizations due to COVID-19 attributed to people who are black ranged from 24-33%, and for those who are Hispanic was around 26%.[40, 41] As far as the mortality rate, those who are black accounted for 18-22% of all deaths in the US due to COVID-19, and those who are Hispanic accounted for 15-24%.[43, 44] For perspective, the proportion of the US population that identifies as black is about 13% and that identifies as Hispanic is about 18%.[58] Moore, J. T. (2020) also found that counties with either higher rates of people who are black or higher rates of people who are Hispanic had increased incidence rates.[51] Parcha, V., et. al (2020) found that the case rate was three times higher in black people than in white people, and the mortality rate was two times higher.[52] Other race and ethnicity groups have been shown to be at higher risk for infection and more severe outcomes. Sze, S., et. al (2020) found that the risk for infection was 1.5 times higher among those who are Asian than among those who are white.[53] Arrazola, J., et. al (2020) found that the mortality rate among those who are American Indian or Alaska Native was almost two times higher than among white people.[59]

Other groups of people disproportionately affected by COVID-19 include those with underlying conditions, those who have essential jobs and cannot telework, those with low income, those with disabilities, those with poor housing conditions, those living in urban areas, and those who are in a jail or prison.[40, 42, 45, 46, 49, 50, 56, 60, 61, 62, 63, 64, 65, 66] Underlying conditions as related to COVID-19 are mainly diabetes, obesity, hypertension, heart disease, and lung disease.[40, 41, 42, 46, 50] The term ‘poor housing conditions’ refers to crowded housing, dense housing structures, or no residence (i.e., homeless).[48, 56, 61, 64, 65, 67]

In Pennsylvania specifically, Anaele, B. I., Doran, C., & McIntire, R. (2021) found that for every one percent increase in a county’s African American population, its mortality rate due to COVID-19 increased by 3.56%.[68]

1.4 Multiple reasons for the association between demographics and impact of COVID-19

There are several mechanisms that explain the correlation between certain demographics and the impact of COVID-19. For one, people of color and of low socioeconomic status are more likely to live in dense housing structures or crowded housing.[55, 69, 70, 71] People of color or of low socioeconomic status are also more likely to be essential workers and unable to work from home than white people.[55, 70, 71, 72, 73, 74] Hawkins, D. (2020) found that black, Asian, and Hispanic people are about twice as likely to work in the essential industries of health and social services, hospital, and animal slaughtering and processing.[72] People of color are also less likely to work in high-paying occupations and more likely to have lower annual incomes, and low income is associated with higher rates of infection and deaths due to COVID-19.[50, 52, 65, 75] The U.S. Bureau of Labor Statistics (2018) shows that Hispanic or Latino people are the most likely (out of all race and ethnicity groups) to not have a high school diploma, while black Americans are the least likely to have a college degree.[75] Lower levels of education are not only related to lower income levels, but also in the ability to form important social networks.[74, 75, 76] In relation to COVID-19, being connected to healthcare professionals can help with understanding public health messaging and in healthcare literacy in general.[74, 76] In turn, communities where these inequalities exist in education, income, and occupations are shown to have less ability to handle crises on a population level.[77]

Another reason for the association between the risk of COVID-19 and certain demographics is that people of color, people with low socioeconomic status, and people with disabilities have less access to proper healthcare.[52, 70, 77, 78, 79, 80, 81, 82, 83, 84] For instance, Wadhera, R. K., et. al (2020) showed that areas in New York City where either the proportion of black people was higher or the median income was lower had fewer hospital beds per capita.[78] Lack of insurance can also equate to poor access to healthcare, and black Americans and Hispanic or Latino Americans are more likely to be uninsured than white Americans.[74, 79, 80, 82] As far as people with disabilities, Sabatello, M., et. al (2020) found that accessible facilities and equipment are not always available, and that providers often do not have proper training to care for people with disabilities.[81] Access to healthcare can also encompass a lack of trust in healthcare professionals and in health messaging due to previous negative interactions and low health literacy.[74, 81, 82, 85] People with disabilities often have issues in health messaging, either because of improper training by providers or because the messaging is inaccessible (e.g., health communication that requires sight is inaccessible to blind people).[81] Similarly, Baquero, B., et. al (2020) found that people who are Hispanic do not always have access to interpreters or multilingual healthcare professionals.[82] Indeed, this distrust in health advice is shown with COVID-19 in that Block, R., et. al (2020) found that compliance with public health messaging, such as mask wearing and social distancing, in black Americans is less than 80%, which is the threshold associated with worse health outcomes on a community level.[85]

Furthermore, these same groups of people are also more likely to have comorbidities that put them at risk for severe outcomes of COVID-19.[52, 69, 70, 73, 74, 79, 81, 84, 86] For people of color, this increased likelihood of having comorbidities can be partially explained by the stress of experiencing racism in the US.[70, 79, 86, 87, 88] Simons, R. L., et. al (2018) and Ferdinand, K., Batieste, T., & Fleurestil, M. (2020) found that stress and persistent racial discrimination are both associated with the likelihood of hypertension, cardiovascular disease, and general inflammation.[79, 86] Paradies, Y. (2006) found that experiencing racism is significantly associated with worse mental and physical outcomes.[88]

1.5 Gaps in the literature

Though the link between demographics and impact of COVID-19 has been shown through many studies since the start of the pandemic, little research has been done in Pennsylvania specifically. Studying one state can be helpful in reducing confounding factors because there is less geographic variation, and each state had different mitigation and reopening strategies. As far as mitigation strategies, though specific measures have been thoroughly researched, such as mask wearing and stay-at-home orders, there have been few studies that take a broader look at phased re-opening strategies. Research in this capacity could determine whether reactionary measures are sufficient or a more precautionary approach is needed.

1.6 Public health significance

COVID-19 was the third leading cause of death in the US in 2020, only behind heart disease and cancer.[89] By October, the CDC reported that there were almost 300,000 excess deaths reported compared to previous years.[90] This pandemic has been a public health disaster; however, this is not entirely due to public health authorities, but problems already in place, such as political polarization and poor funding. Moreover, health inequities already experienced by millions of Americans were only highlighted during the pandemic. Specific groups of people were disproportionately affected by this disease due to systemic barriers. Public health interventions must address these barriers, or they are not truly helping the entire public.

Though researching health disparities is only the first step to solving the problem, it is an important one. As this study and others show, the effect of demographics changes over time, and so consistent research helps public health officials better understand which groups are being affected the most and when changes occur. In general, further understanding into which characteristics affected a county's experience of COVID-19 can help public health officials know where to allocate resources for ongoing or future crises and where their health messaging is not being heard or understood.

Health emergencies can be an opportune time to research inequities because those are the times when funding is at its highest. However, those inequities persistent beyond crises. As was previously stated, these health disparities were likely only highlighted during the pandemic. Any lessons learned due to COVID-19 about differences between demographics should be used as a reminder that public health as a field should always include addressing health inequity.

2.0 OBJECTIVES

The overall objective of this paper was to determine which factors contributed to county differences in Pennsylvania in their experience of the COVID-19 epidemic. The first part of this objective is to ascertain the extent to which certain demographic characteristics explain the county variation in COVID-19 impact. The second part is to determine whether differing county mitigation efforts also contributed to the variation. We hypothesized that urban population, proportion of racial minorities, and median age are positively associated with the rate of COVID-19. We also hypothesized that median income and the number of days spent in the red and yellow phases would be negatively associated with the rate of COVID-19.

3.0 METHODS

3.1 Data Collection

Daily and cumulative incidence rates of COVID-19 were collected from Pennsylvania's open-source database, which hosts the data given from the Pennsylvania Department of Health.[91] The data used for this report was retrieved on Jan-4-2021 and contained information from Mar-1-2020 to Dec-31-2020. County demographics collected were on population, race distribution, median age, median income, counties which have commercial airports, counties which have local health departments, and percent of the population that lives in urban areas. All of these but the commercial airport data, health department data, and urban living data were obtained from the U.S. Census bureau's 2019 5-year estimates.[92, 93, 94] Urban living data was available only in the 2010 Census bureau results, and so when calculating percent of the population living in urban areas, the 2010 population was used.[95] For reference, the U.S. Census bureau defines urban areas as "densely developed territory that contains 50,000 or more people".[95] The 2019 5-year estimate of population was used for all other rate and proportion calculations. Commercial airport data for each county was acquired through the Pennsylvania Department of Transportation.[96] County-specific phase change dates were collected from press releases made by Governor Wolf.[97, 98, 99, 100, 101, 102, 103, 104, 105, 106]

3.2 Statistical Analysis

Descriptive analysis (mean, standard deviation, and frequency) was done on all demographic variables, the phased re-opening data, and the cumulative incidence rate. To identify statistically significant factors, linear mixed modeling analysis was done, with the daily incidence rate per 100,000 people being the outcome of interest. The variables used in the model were the following: median age, median income, percent urban population, percent black or African American, percent American Indian and Alaska Native, percent Native Hawaiian and other Pacific Islanders, whether a county has a health department (either county department or city department), whether a county has a commercial airport, and the number of days spent in red and yellow phases.

These variables were selected based on previous literature and what factors were hypothesized to be a significant predictor of differences in the incidence rate. Though the phased re-opening occurred only during March-July in Pennsylvania, this variable was included to assess whether earlier mitigation efforts could influence the progression of the pandemic. A correlation test was performed on all continuous variables to determine whether any pairs had a significant relationship that would cause bias in the results.

The first step of the modeling analysis was to determine the best fit covariance matrices. Three different models were tested:

1. no random effects are accounted for, and county is included as a fixed effect;

2. assumes there is variance between counties' intercepts and slopes over time, and that the variance between counties' intercepts is correlated but with no pattern (random effect covariance (G) = unstructured);

3. assumes there is variance between counties' intercepts and slopes over time, and that the variance between counties' slopes over time has a correlation structure that assumes each time point is more correlated to time points near it than ones farther away (error covariance (R) = auto-regressive).

The rationale for choosing these three different structures to compare is that for one, the first model would be a baseline where there are no random effects. The second model would include random effects for county to adjust for any auto-correlation between counties. The third model would also include random effects for county, but would assume that it is most important to account for the correlation between time points.

When comparing the three, the Akaike information criterion (AIC) and Bayesian information criterion (BIC) were used to identify the best fitting correlation structure. Furthermore, not only were the models that included data from the entire ten months compared, but the entire time span was also divided into three periods. Models were similarly done with the differing covariance structures and compared using AIC and BIC. The three time periods were the following:

Time period 1 = 3/1/20 – 5/31/20

Time period 2 = 6/1/20 – 9/30/20

Time period 3 =10/1/20 – 12/31/20

The time periods were selected subjectively based on the graph of Pennsylvania's incidence rate over time, and **Figure 1** shows where each period divided in relation to this graph. Creating models for these different time periods was used as a way to compare the demographic variables during the different waves the epidemic as experienced by Pennsylvania.

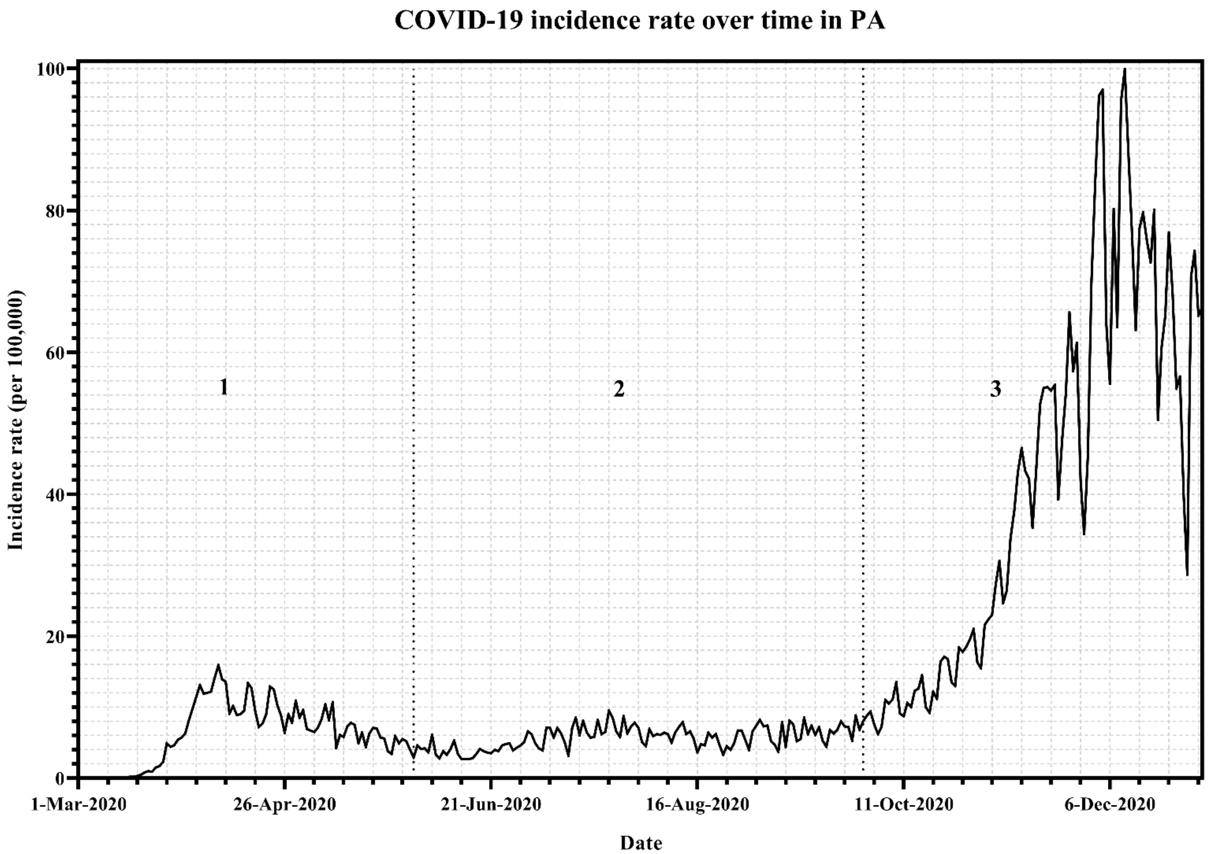

Figure 1. Daily incidence rate over time in Pennsylvania, with indicators for the three time periods

Each time period, including the entire time span, had a final model with the best fitting covariance structure and all variables included. For these final models, parameter estimates, 95% confidence intervals, and p-values are reported.

All analyses were performed using SAS 9.4 software.

4.0 RESULTS

4.1 COVID-19 and Demographic Data

For the 67 counties of Pennsylvania, the median age ranged from 31.70 to 53.10, and the median income ranged from $47,200 to $96,600 (**Table 1**). The mean percent of the population living in urban areas was 52.56% (SD=27.54). The ranges for percent of the population who are either American Indian and Alaska Native or Native Hawaiian and other Pacific Islanders were both fairly narrow, with all of the counties having less than 1% and 15 counties having 0% Native Hawaiian and other Pacific Islanders (one of which also had 0% American Indian and Alaska Native). The mean proportion black or African American was 4.74% (SD=6.72). **Table 3** shows each county's specific percent of the population that is black or African American. Of the 67 counties, 15 had a commercial airport and 10 had a health department (either a county health department or a city health department located within the county). Five counties had both a commercial airport and a health department. A map showing which counties had either variable is depicted in **Figure 2.** All correlation coefficients for each pair of variables were between -0.5 and 0.5.

As far as the phased re-opening, the first counties began closing businesses and issuing stay-at-home orders March 23, with the statewide issued order occurring on April 1. The phased re-opening strategy was announced on April 17, and the first counties started shifting to the yellow phase on May 8, with the last occurring on June 5. The average time spent in the red phase was 49.9 days (SD=12.48), and the average in the yellow phase was 22.7 days (SD=4.89). A summary of this descriptive analysis can be found in **Table 1** below.

Table 1. Descriptive analysis of fixed effects included in modeling analysis

Variable	Mean (SD)	Median	Min	Max
Median age	43.14 (3.48)	43.2	31.70	53.10
Median income (in thousands)	72.33 (11.37)	69.0	47.20	96.60
Urban percent	52.56 (27.54)	54.3	0	100
Percent black or African American	4.74 (6.72)	2.80	0.09	42.13
Percent American Indian and Alaska Native	0.16 (0.11)	0.13	0	0.59
Percent Native Hawaiian and other Pacific Islanders	0.03 (0.03)	0.02	0	0.16
Days in red and yellow phases	72.57 (12.68)	72.0	58	95
	Yes		**No**	
Commercial airport within the county	15		52	
Health department within the county	10		57	

The data collected on COVID-19 were from March 1 to December 31, and included daily and cumulative incidence rates, death rates, and hospitalization rates. The peak daily incidence rate during this time period occurred in Pennsylvania on December 10, with the rate being 99.99 cases per 100,000 people. All but two counties had their peak daily incidence rate in November or December – Pike County had theirs on April 13 and Centre County on September 8. The peak daily mortality rate in Pennsylvania was 1.87 deaths per 100,000 and occurred on December 21.

4.2 Linear Mixed Model Analysis

The results of linear mixed model comparisons are shown in **Table 2.** Model 3 had the most consistently lower AIC and BIC, so the final models for all time periods used the Model 3 covariance structure. The general model used with both time and the intercept as random effects was the following:

$$DIR_{ij}=\beta_0+\beta_1 Time_i+\beta_2 Median\_age_i+\beta_3 Median\_income_i+\beta_4 Urban\_percent_i+\beta_5 Percent\_black_i$$
$$+\beta_6 Percent\_AIAN_i+\beta_7 Percent\_NHPI_i+\beta_8 Health\_department_i+\beta_9 Commercial\_airport_i$$
$$+\beta_{10} Days\_RY_i +b_{0i}+b_{1i} Time_i+e_{ij}$$

For subjects i=1 to 67, and for times j=1 to 306

DIR=Daily Incidence Rate

AIAN=American Indian and Alaska Native

NHPI=Native Hawaiian and other Pacific Islanders

Days_RY=days spent in the red and yellow phases

The results of the final linear mixed models are shown in **Table 4.** Analysis of the entire 10-month period showed evidence of a statistically significant association between the daily incidence rate and median age, median income, and urban percent. As the median age increased by one year, the daily incidence rate decreased by 0.2889 (p = 0.0387). As the median income increased by 1000, the daily incidence rate decreased by 0.1191 (p = 0.0216). And as the percent of the urban population increased by 1%, the daily incidence rate increased by 0.0732 (p = 0.0012).

Table 2. Results of the modeling comparison to determine the best fitting covariance structure, with a description of each type of model and the AIC and BIC for each time period.

Model	Description	Time period	AIC	BIC
1	county is a fixed effect	Entire period	190105.8	190113.8
		1	38567.3	38574.1
		2	50880.5	50887.5
		3	59552.4	59559.1
2	assumes county has variance between subjects and within subjects - and that the variance between subjects is correlated but with no pattern	Entire period	189726.8	189735.6
		1	38753.3	38762.1
		2	50053.2	50062.0
		3	59805.4	59814.2
3	assumes county has variance between subjects and within subjects - and that within-subject variance is auto-regressively correlated	Entire period	179607.5	179612.0
		1	35943.4	35950.0
		2	50136.5	50143.1
		3	59335.1	59341.8

Though the median age was shown to be a statistically significant variable for the entire 10 months, its effect seemed to be mainly in time period 2, where the daily incidence rate decreased by 0.3545 ($p<0.0001$) for every one-year increase in median age. For both the median income and urban percent factors, their impact on the daily incidence rate were seen in both time period 2 and 3. Urban percent had positive associations in both periods, so both contributed to the overall association. However, for median income, its overall negative association seemed to come only from time period 3 because there was a positive association in time period 2. During this period, as median income increased by 1000, the daily incidence rate increased by 0.0746 ($p=0.0036$).

As far as the effect of race distribution, the percent of people who are black or African American showed strong evidence of a positive association in time period 1 only, with the daily incidence rate increasing by 0.1075 ($p=0.0065$) for every one-percent increase in the proportion. Though both percent American Indian and Alaska native and percent Native Hawaiian and other Pacific Islanders had parameter estimates that suggested a positive association, the standard errors for both were too high for these associations to be statistically significant.

There was no overall statistically significant effect of days spent in the red and yellow phases, but time period 1 had strong evidence of a positive association ($\beta = 0.5984$; $p < 0.0001$), and time period 3 showed evidence of a negative association ($\beta = -0.3098$; $p = 0.0440$).

Both having a health department and having a commercial airport showed no statistically significant effect on the daily incidence rate in any time period, though there is some evidence in time period 2 for lower daily incidence rates being associated with having a health department ($p=0.0708$).

5.0 DISCUSSION

The aim of this study was to determine if certain demographic factors were associated with the county-level impact of COVID-19 in Pennsylvania, and whether variation in the timing of phased re-opening strategy was also a contributing factor. This research showed that counties' median income, median age, percent urban population, percent black or African American, and the number of days in the red and yellow phases all were associated with the daily incidence rates in at least one time period during 2020.

Initial examination of the counties' demographics showed they have comparable ranges of median age, median income, and percent urban population to the US population as a whole.[92, 93] The variation in race distribution was more limited, with the majority of counties have less than 3% of their population identifying as black or African American, but still comparable to the majority of US counties as well.[94] Pennsylvania has in general a relatively low population of those who are American Indian or Alaska Native and who are Native Hawaiian other Pacific Islanders, so their ranges were similarly limited. (**Table 1**)

Testing the three covariance structures showed that an autoregressive R matrix was the best fit in three of the four time periods, which was the Model 3 structure. Time period 2 had the only deviation and showed an unstructured G matrix fit the data best, which was the Model 2 structure. However, since Model 2 had only slightly lower AIC and BIC compared to Model 3 for this time period and the autoregressive R matrix made the most sense intuitively, this structure was used for time period 2. The autoregressive R matrix (Model 3) makes the most sense in context because this covariance structure assumes that time points closer together are more correlated to each other than time points farther apart. There seems to be no reason why this assumption would not also be correct during time period 2. (**Table 2**)

The final model for all time periods showed that the variables most consistently associated with the daily incidence rates of COVID-19 were median age, median income, and percent urban population. The results from the full 10-month time period were consistent with our hypotheses for median income and for percent urban population, but were opposite of the expected outcome for median age. Counties with lower median ages had higher incidence rates, which might be caused by older adults being able to stay at home more than younger adults or the increased incentive to do so with the increased risk of hospitalization and death.

Each time period seems to be fairly unique in which covariates were significant. Time period 1 showed that for counties with higher percent black or African American population, their daily incidence rates were higher, which was the only period where a specific race proportion was a significant factor. However, this result was heavily affected by Philadelphia County. When removing it from the model, the parameter estimate decreases to 0.087 (from 0.1075), and the p-value increases to 0.0853 (from 0.0065).

Another notable part of the model results was in the effect of median income. The overall time period showed a negative association between median income and daily incidence rates, which is also shown in time period 3. However, in time period 2, counties with higher median incomes had higher daily incidence rates – though this seems to be a relatively small effect. This change was an unexpected deviation from our hypotheses, and one possible explanation is that there was some confounding factor during this time period specifically that was directly correlated with median income. Another possible explanation is that the pandemic caused unprecedented levels of unemployment and financial strain, which would have changed the median income of counties over time.[107] This variable was treated as a baseline covariate, but there might have been a large enough shift to cause this deviation.

As far as the effect of days in the red and yellow phases, the model results showed that counties that ended up staying longer in these phases had higher incidence rates in time period 1, but lower incidence rates in time period 3. This result can be interpreted as counties were reactive to incidence rates when switching to the yellow and green phases. In other words, counties with higher incidence rates stayed closed longer. However, regardless of the daily incidence rates during time periods 1 and 2, counties who stayed longer in the red and yellow phases had lower incidence rates during time period 3, even when accounting for statistically significant demographic variables. For every day increase of time spent in the red and yellow phases, a county prevented 0.3098 cases per 100,000 per day in time period 3. Over the 92 days, this would equal 28.50 cases per 100,000 prevented for each extra day spent in those phases. This suggests that there is either a long-term effect of closures or there is another confounding variable that was not accounted for in this model. (**Table 3**)

There are a few limitations to this study. For one, linear mixed modeling assumes there is a linear relationship between independent and dependent variables, and so a non-linear mixed model might have fit the data best. However, non-linear mixed modeling is out of the scope of this study. Another limitation is in the selection of demographic variables. There was data on other race groups that were excluded due to concerns of multicollinearity. Those included percent white, percent Asian, and percent of more than one race. Furthermore, the other demographic variables were selected based on what was hypothesized to be significant, and so it is possible there were other factors associated with the incidence rate but were not considered. One last limitation is that this study used daily rates of COVID-19, which relies on the reported data being an accurate reflection of daily positive cases. Testing was limited in the beginning of the pandemic in the US, and COVID-19 cases might have been underreported during this period. Reported cases also likely do not include the majority of asymptomatic cases or mild cases.

Understanding how demographic disparities affect people's health is an important first step into providing equitable healthcare to the entire population. However, the next step is implementing interventions or policy changes that address these disparities. This next step can include ensuring representation in clinical trials for treatments or vaccines, targeting public health messaging toward more affected populations, or prioritizing funding and resource allocation to high-risk communities.[108, 109, 110, 111] McClure, E. S., et. al (2020) suggests to always prioritize finding population-level solutions to address systemic public health issues.[73] For instance, a lot of the disparities that occurred during the pandemic can be linked to essential industries where people had to go to work and interact with others. Strict policy regulations might have helped with worker safety while addressing disparities at the same time. Behavioral change is still an essential part of public health interventions, but the potential impact will almost always be greater with population-level interventions and policies.

This study has shown that the effect of demographics on health can change over time, and so doing this type of research will continue to be a valuable part of reaching health equity. In general, demographic disparities were associated with Pennsylvania counties' case rates of COVID-19, and so supports the previous literature on community-level health inequity. Regardless of the type of intervention chosen to address health crises, public health officials should always address socioeconomic and race differences when planning and implementing these interventions.

APPENDIX: TABLES AND FIGURES

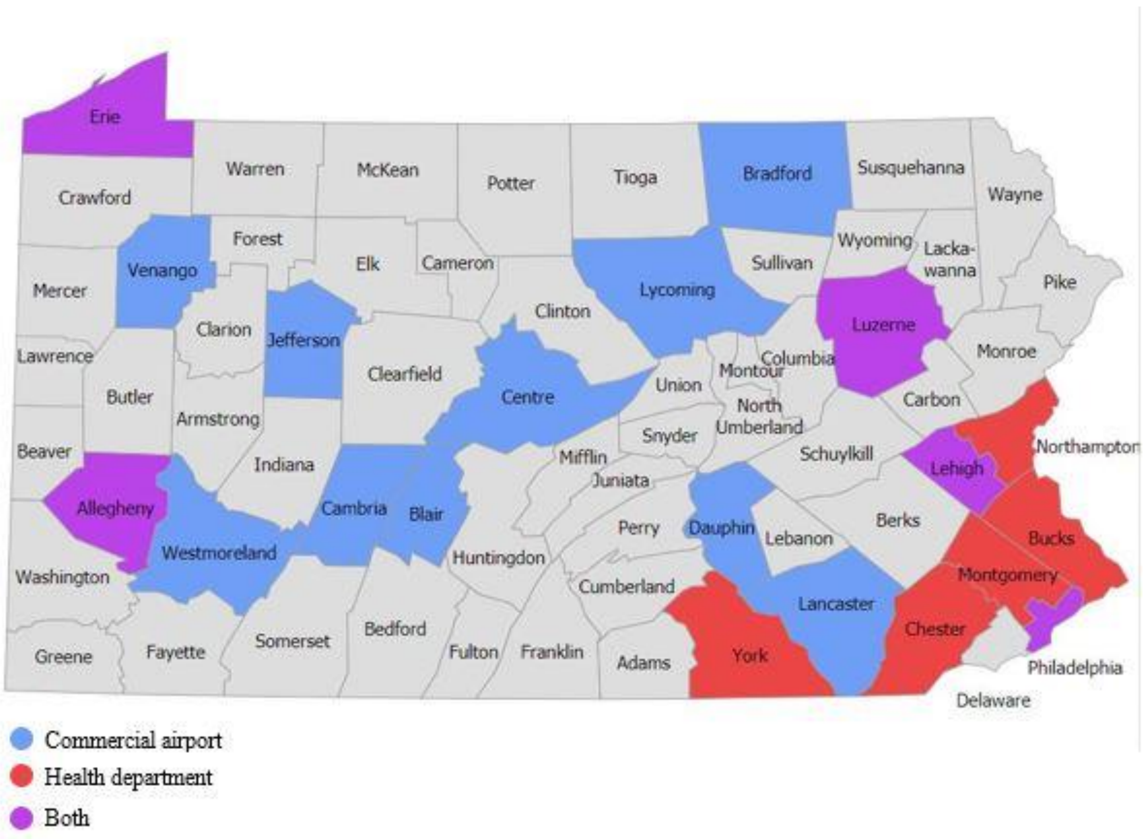

Figure 2. Map of categorical variables - commercial airport and health department

Table 3. Percent black or African American by county

County	Percent Black or African American
Adams	1.43
Allegheny	12.86
Armstrong	0.83
Beaver	5.82
Bedford	0.64
Berks	5.43
Blair	1.67
Bradford	0.55
Bucks	4.04
Butler	0.97
Cambria	3.47
Cameron	0.09
Carbon	2.32
Centre	3.81
Chester	5.86
Clarion	1.36
Clearfield	2.88
Clinton	1.79
Columbia	1.79
Crawford	1.62
Cumberland	3.96
Dauphin	19.53
Delaware	21.57
Elk	0.88
Erie	7.18
Fayette	4.19
Forest	25.89
Franklin	3.75
Fulton	1.52
Greene	3.12
Huntingdon	5.62
Indiana	2.30
Jefferson	0.53
Juniata	1.10
Lackawanna	2.80
Lancaster	4.17
Lawrence	3.64
Lebanon	2.47
Lehigh	7.38

Luzerne	5.10
Lycoming	4.95
McKean	2.53
Mercer	5.70
Mifflin	0.54
Monroe	14.70
Montgomery	9.19
Montour	1.80
Northampton	5.70
Northumberland	2.68
Perry	0.95
Philadelphia	42.13
Pike	6.36
Potter	0.40
Schuylkill	3.18
Snyder	1.05
Somerset	2.57
Sullivan	2.44
Susquehanna	0.67
Tioga	0.73
Union	6.42
Venango	0.79
Warren	0.48
Washington	3.14
Wayne	3.19
Westmoreland	2.36
Wyoming	1.09
York	5.92

Table 4. Results of the linear mixed modeling analysis, including parameter estimates, 95% confidence intervals, and p-values.

***p<0.10; **p<0.05; ***p<0.01**

	Entire 10 months	Time period 1	Time period 2	Time period 3
Health department (x=0 vs x=1)			*	
Parameter Estimate	1.1818	0.3588	1.2514	2.0738
95% CI	(-1.5639, 3.9274)	(-1.1784, 1.8961)	(-0.1063, 2.6090)	(-6.6903, 10.8378)
p-value	0.3989	0.6473	0.0708	0.6428
Commercial airport (x=0 vs x=1)				
Parameter Estimate	0.2324	0.8731	0.0036	-0.4505
95% CI	(-1.9281, 2.3929)	(-0.3366, 2.0827)	(-1.0647, 1.0719)	(-7.3467, 6.4456)
p-value	0.8330	0.1571	0.9947	0.8981
Median age	**		***	
Parameter Estimate	-0.2889	0.0035	-0.3545	-0.5871
95% CI	(-0.5627, -0.0150)	(-0.1499, 0.1568)	(-0.4899, -0.2191)	(-1.4613, 0.2870)
p-value	0.0387	0.9648	<0.0001	0.1880
Median income (in thousands)	**		***	***
Parameter Estimate	-0.1191	-0.0088	0.0746	-0.4696
95% CI	(-0.2207, -0.0175)	(-0.0657, 0.0481)	(0.0243, 0.1248)	(-0.7939, -0.1453)
p-value	0.0216	0.7609	0.0036	0.0045
Urban percent	***		***	**
Parameter Estimate	0.0732	0.0145	0.0289	0.1792
95% CI	(0.0289, 0.1175)	(-0.0103, 0.0393)	(0.0070, 0.0508)	(0.0378, 0.3205)
p-value	0.0012	0.2507	0.0097	0.0130
Percent black or African American		***		
Parameter Estimate	-0.0632	0.1075	-0.0484	-0.2607
95% CI	(-0.2015, 0.0750)	(0.0301, 0.1849)	(-0.1167, 0.0200)	(-0.7019, 0.1805)
p-value	0.3699	0.0065	0.1655	0.2467

Percent American Indian and Alaskan Native				
Parameter Estimate	3.4820	0.6805	0.4129	9.5562
95% CI	(-4.0844, 11.0484)	(-3.5559, 4.9168)	(-3.3284, 4.1543)	(-14.5954, 33.7077)
p-value	0.3671	0.7529	0.8287	0.4380
Percent Native Hawaiian and other Pacific Islanders				
Parameter Estimate	3.1349	7.3317	-6.6697	8.5312
95% CI	(-26.0353, 32.3052)	(-8.2041, 22.8675)	(-21.0935, 7.7541)	(-84.5786, 101.64)
p-value	0.8332	0.3549	0.3647	0.8575
Days in red and yellow phases		***		**
Parameter Estimate	-0.0458	0.5984	-0.0226	-0.3098
95% CI	(-0.1402, 0.0486)	(0.3867, 0.8102)	(-0.0693, 0.0241)	(-0.6112, -0.0084)
p-value	0.3419	<0.0001	0.3421	0.0440

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