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RESEARCH ARTICLE

Food Security and Lifestyle Vulnerabilities as Systemic Influencers of COVID-19 Survivability

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ABSTRACT
Research on the COVID-19 pandemic has revealed some previously concealed links between underlying health conditions like obesity, diabetes, and heart disease and COVID-19 fatalities. This raises questions about the importance of healthy diets and lifestyles for the survivability of COVID-19 infections and possibly other infectious diseases. We statistically examine the connections between social determinants of health, reported health outcomes, and COVID-19 survivability using available data from over 3000 counties across the United States. Our study shows that preexisting conditions such as diabetes and cardiovascular disease reduce the observed survivability of COVID-19 prior to the broad availability of vaccines. Furthermore, we test several of the social determinants of health identified in the literature and find them to be statistically correlated with negative health outcomes with the expected sign. For example, improved food security and better access to exercise correlate with lower observed diabetes rates and improved cardiovascular health. Our findings also indicate the positive impact of food assistance programs like the so-called food stamps program of the United States Department of Agriculture, however, some of our findings differ between rural and urban counties across the United States. Based on our findings, we estimate that twenty-two-thousand (22,000) lives could have been saved in 2020 if residents in all U.S. counties were as healthy as those in the healthiest counties found in our sample. We further estimate that reducing food insecurity, and improving access to exercise could have prevented ten-thousand-eight-hundred (10,800) fatalities attributed to COVID-19 in 2020.

Keywords: Food access, food security, preexisting illness, diabetes, cardiovascular health, social determinants of health, food assistance, COVID-19 survivability.

1. Introduction

The COVID-19 pandemic caused by the novel corona virus has raised renewed concerns about the risks associated with food insecurity, lack of exercise and other lifestyle related vulnerabilities.[1-3] Sadly, access to healthy, unprocessed food and safe outdoor exercise is highly uneven in communities across the United States.[4-6] Additional food security and exercise barriers during the COVID-19 pandemic resulted from social distancing measures, and supply chain disruptions due to high infection rates in U.S. warehouses, distribution centers and food processing plants. Government imposed travel restrictions also created regional shortages in seasonal labor supplies to harvest crops. Combined, these factors generated renewed concerns about the health risks associated with food insecurity and lifestyle related conditions.

While some of the ramifications of the pandemic may be considered temporary, the longer-term impact of food and nutrition security and exercise on the survivability of COVID-19 deserve closer examination since they may be instructive for future public health emergencies and associated lifestyle vulnerabilities. Several recent studies examined the impact of food-related health conditions, such as diabetes, hypertension, and cardiovascular disease, and their social determinants on increased COVID-19 risks.[7-9] Our research seeks to extend the work of these studies by statistically assessing the connection between risk factors associated with pre-existing health conditions, their social determinants, and the impact of these risks on the survivability of COVID-19 infections. We call the first set of indicators 'physical' and the second set of indicators 'social'.

The U.S. county-level data we use for our analysis stems from various publicly available sources, including the Center for Disease Control, the Robert Wood Johnson Foundation, the University of Wisconsin Population Health Institute, and USA-Facts. These sources compile numerous available variables that can be considered physical health indicators, socioeconomic indicators, and daily COVID-19 infection and death counts for the more than 3000 counties across the United States.

We examine the statistical relationship between various health conditions previously identified in the literature as potential risk factors, such as obesity, diabetes, and heart disease, and their impact on COVID-19-related deaths. We also test for an indicator referred to in the U.S. Census as 'Non-Hispanic Black' populations, since race is widely reported to be indicative of other underlying health disparities in the United States. During the COVID pandemic, this resulted in significantly lower survival rates among African Americans and other non-white populations in the United States.[10, 11]

Having identified a set of indicators reflective of the health conditions that appear to impact the survivability of COVID-19, we then proceed in a second step of our analysis to identify some of the social factors influencing these health conditions. Our social determinants of health build on the existing literature and include food security, income, physical exercise, and the so-called food stamps program of the United States Department of Agriculture which provides food assistance to low-income households. [12-15] We argue that these social determinants indicate the need to address broader systemic circumstances which render health conditions such as diabetes and cardiovascular health as primarily lifestyle-related and therefore preventable.

To assess the potential benefits associated with improvements in our selected social determinants of health, our identified health conditions, and COVID-19 survivability rates, we estimate in a third step the implications of a 'what if' scenario whereby we calculate the hypothetical impact of improvements in the social determinants of health, and our identified health conditions, on the COVID-19 death toll in 2020.

We conclude with a discussion of our results and lessons learned for an improved survivability rate of COVID-19 in 2020. The connection between actionable social determinants, life-style related health conditions, and COVID survivability rates may also offer valuable insights regarding public policy measures which can reduce vulnerabilities to future public health risks and improve public health outcomes overall.

2. Methodology

As previous findings suggest, the survivability of COVID-19 infections seems to parallel the risks associated with other known health conditions like obesity, diabetes, and cardiovascular disease. Theses health conditions are in turn related to various lifestyle factors including food security,

exercise, and socio-economic factors like income and education. A number of the studies documenting the impact of lifestyle related risks on the survivability of COVID infections rely, however, on relatively small data samples, and while there are consistencies in the impact of lifestyle related factors, cultural differences may also be present.[16-20]

We therefore turn to county level data for over three-thousand (3,000) counties across the United States to examine the chain of relationships between the social determinants of health associated with individual conditions (i.e. income and education levels), those associated with community conditions (i.e. food security and opportunities to exercise), the prevalence of socially determined health conditions (i.e. diabetes and cardiovascular health), and observed COVID-19 fatality rates.

a. Health indicators and COVID-19 fatalities

To assess the impact of pre-existing health conditions on the observed number of COVID-19 fatalities across the United States, we form the hypothesis that the number of observed COVID-19 deaths per county population d for each day i in each county j is a function of the number of infections per county population c (i.e., the number of known COVID-19 cases divided by the county's population) and several fixed health indicators: the diabetes rate h_d measured as the percentage population with reported diabetes cases; the obesity rate h_o as a percentage of the population; cardiovascular health measured as cardiovascular death per 100 of the population h_c; cancer deaths per population h_n; the share of non-Hispanic black populations per county h_b; the share of population over 65 years of age h_o. These indicators describe the health conditions of the population in a county as follows:

$$d_{i,j} = \beta_0 + \beta_1 c_{i,j} + \beta_2 c_{i,j} h_{j,d} + \beta_3 c_{i,j} h_{j,o} + \beta_4 c_{i,j} h_{j,c} + \beta_5 c_{i,j} h_{j,n} + \beta_6 c_{i,j} h_{j,b} + \beta_7 c_{i,j} h_{j,o} + \varepsilon_{i,j} \quad \text{Equation (1)}$$

where $\varepsilon_{i,j}$ represents the error term for day i and county j

Instead of using the reported daily values for new COVID-19 deaths and cases, which show weekly patterns and a likely delay between observed cases and resulting deaths, we apply kernel smoothing to the observations with a band width of 20 days to help us align the average number of cases and deaths around each given day.

b. Pre-existing health conditions and COVID-19 fatalities

In a second step of our analysis, we test the impact of selected social determinants of health building on the existing literature. Our variables include food security, physical exercise, food assistance, as well as median household income, and education levels. We consider these indicators at the county level based on data available through the University of Wisconsin and the United States Center for Disease Control and Prevention.[21, 22] We then test the proposition that these lifestyle related factors also indicate increased vulnerabilities to COVID-19.

Our selected indicators expressing the social determinants of health do not have a common unit of measure. Given the non-commensurability of values, it can be challenging to assess the importance of each indicator. Median household income is measured in monetary units of U.S. dollars; several other indicators represent a share of population and range from 0 to 1; to capture the education level in a county, we use an indicator which measures the percentage of people aged 25 to 44 with some post-secondary education;[21] our food security measure captures the percentage of the population in a county without consistent access to a reliable source of food; the share of the people receiving food assistance (food stamps) is taken from the U.S. CDC report;[21] finally, we use the measure of reported exercise opportunities which describes the share of the population with adequate access to physical activity.[22] To account for differences in urbanization and related differences in access to services, we also include an index measuring the proportion of the population in a county living in sparsely populated rural areas.

c. Calculating prevention effects through 'what if' scenarios

In a final step, we use the estimated relationship between the health indicators identifies as statistically significant and COVID-19 fatalities to calculate the number of lives that could have

been saved if all U.S. counties had exhibited our selected health indicators at the most favorable levels. In this counter-factual 'what if' exercise, we consider not only those health conditions which could be augmented through preventive measures and treatments specific to the underlying health conditions themselves such as diabetes rates and cardiovascular disease, but we also include those indicators which are exogenous, such as the U.S. Census designation of 'Non-Hispanic Black' populations and age over 65 years. We then estimate the best outcomes by creating 'what if' scenarios which assume that all counties perform as well as the best performing county in our sample and calculate the impact on COVID-19 fatalities.

Similarly, we calculate the contribution of our selected social determinants of health to two health outcomes, namely diabetes rates and cardiovascular fatalities in counties across the United States. We base our calculations on the differences between the highest and lowest observed values for the selected social determinants of health.

3. Modeling Results

Table 1 summarizes the mean and standard deviation for our selected health indicators for all counties of the United States where data was available. We find that the contribution of several of the reported health conditions, including diabetes, cardiovascular health, and cancer prevalence, on COVID-19 fatality rates is statistically significant.

Table 1: Overview of health condition indicators across US counties

	N	Mean	SD	Min	Q1	Median	Q3	Max
Share of diagnosed diabetes	3041	0.105	0.038	0.015	00.079	0.099	0.125	0.330
Share of obese population	3041	0.329	0.056	0.123	0.292	0.331	0.367	0.579
Cardiovascular death per 100	3041	0.243	0.058	0.059	0.202	0.237	0.276	0.548
Cancer deaths per 100	3041	0.232	0.060	0.048	0.195	0.234	0.270	0.543
Share of population over 65 yrs.	3041	0.192	0.046	0.048	0.162	0.188	0.216	0.576
Share of black population	3041	0.092	0.144	0.001	0.008	0.024	0.106	0.854

a. Pre-existing health conditions and COVID-19 survivability

Table 2 shows the estimated coefficients for equation (1). The estimated intercept close to zero suggests that the specification of our model is appropriate as it does not predict COVID-19 deaths without COVID-19 cases. The coefficient associated with the change in cases per population is negative and statistically significant. The magnitude of the coefficients is relatively small as would be expected, given that the fatality rate of COVID-19 for healthy populations is relatively small. The negative sign could reflect the positive effects associated with the use of masks and improved hygiene like frequent hand washing, which may have contributed to a reduction in flue related deaths even as COVID cases increased. However, judging from the very small size of the impact, the effects are likely to be small overall.

Table 2: Estimated coefficients linking health indicators to the rate of COVID-19 deaths

	Estimate	Std. Error	t value	Pr(>|t|)
Intercept	0	0	99.746	0
$C_{i,j}$	-0.002	0	-16.364	0
I($C_{i,j}$ * diabetes share)	0.014	0.001	26.067	0
I($C_{i,j}$ * over 65)	0.067	0.001	97.532	0
I($C_{i,j}$ * obesity share)	-0.002	0	-5.698	0
I($C_{i,j}$ * cardio deaths)	0.01	0	24.99	0
I($C_{i,j}$ * cancer deaths)	-0.001	0.001	-2.487	0.013
I($C_{i,j}$ * black)	0.007	0	43.238	0
Adjusted R^2	0.305			
Number of observations	1,046,104			

The estimated coefficient for the diabetes share in our sample is 1.4 percent, suggesting that the presence of diabetes caused 1.4 percent of COVID-19 cases to result in deaths. For the obesity share indicator, we observe a small negative coefficient which suggests that obesity does not increase the probability of deaths from COVID-19. These results are not surprising since obesity has been linked to diabetes, heart disease and other health conditions and may not in itself impact the

vulnerability to COVID-19.[21, 22] Cardio-vascular health, as measured by cardiovascular deaths per 100 in our sample, is associated with an increase of COVID-19 fatality rate. The small negative coefficient associated with cancer death rates is not statistically significant at the one (1) percent level and may reflect the reduced access to care during the height of the COVID pandemic. At 6.7 percent, the coefficient for age over 65 suggests that 6.7 percent of COVID-19 cases among populations over 65 years of age resulted in deaths. Finally, we observe that our race variable is associated with a small but statistically significant increase 0.7 percent of additional COVID cases resulting in deaths. This appears to corroborate the documented social disparities of health that resulted in increased COVID fatalities among non-white populations in the United States.[10, 11]

The adjusted R^2 for our model is thirty (30) which indicates that our model can explains thirty (30) percent of the variation in COVID fatality rates across the more than 3,000 U.S. counties in our sample. Our findings are consistent with previous studies. For example, Holman et al. find higher fatality rates for people with diabetes and diabetes-related complications such as cardiovascular and renal disease;[9] Srivastava finds higher levels of mortality among patients with cardiovascular disease and COVID-19 infections;[8] and Popkin et al. provide a comprehensive review of the relationship between obesity, its health effects, and increased COVID-19 cases.[7]

Our results indicate considerable variations in the survivability of COVID-19 related to the health conditions we examine. Our findings suggest a maximum predicted survivability rate associated with a 0.5 percent COVID fatality rate in Chattahoochee County, Georgia, and a minimum survivability rate associated with a 3.8 percent COVID fatality rate in Sumter County, Florida. Figure 1 shows our results for all counties with available data.

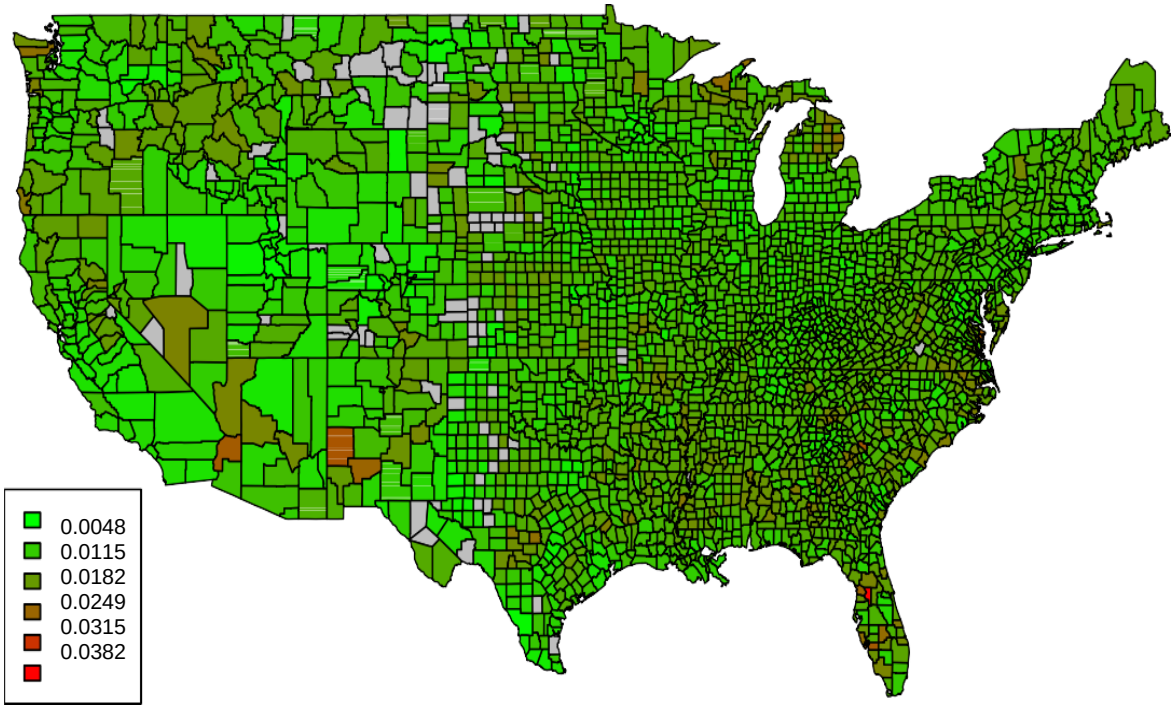

Figure 1: Estimated share of COVID-19 cases across US counties that result in fatalities based on selected indicators (diabetes, obesity, cardiovascular, cancer, black and over 65)

b. Social Determinants of Health and COVID Vulnerabilities

When examining our results regarding the impact of our selected social determinants of health, our model shows the social determinants 'food security' and 'exercise' as statistically significant. Both have been recognized in previous studies as lifestyle related factors which impact health outcomes.[25-28] The United States Department of Agriculture (USDA) conducts an annual food security survey through the U.S. Bureau of the Census, and defines food security as all

people at all times having access to enough food to support an active and healthy life.[4] In its 2020 Household Food Security report the USDA identified 10.5 percent of U.S. households as food insecure, with 4 percent of households reporting 'very low' food security. The 'very low' designation indicates that one or more household members experienced hunger or disrupted eating patterns at least sometime during the year. Our findings, also reveal income and education as statistically significant determinants of health outcomes.

As Table 3 shows, there is considerable variability in our social determinants across counties in the United States. For example, the observed median income varies between $25,000 in Wilcox County, Alabama, and $140,000 in Loudoun County, Virginia. Access to physical exercise varies from a low of zero (0) percent in Atkinson County, Georgia to 100 percent in Aleutians East County, Alaska. The share of adults aged 25 to 44 with some college education varies between fifteen (15) percent in Hudspeth County, Texas, and 100 percent in Loving County, Texas. Utilization of food assistance ranges from a low of zero (0) percent of food assistance recipients in Teton County, Wyoming to a high of fifty-five (55) percent of food assistance recipients in Todd County, South Dakota. Finally, the lowest share of food insecurity is reported at three (3) percent of the population for Steele County, North Dakota while the highest share of food insecurity at 36 percent is reported in Jefferson County, Mississippi.

Table 3: Description of social determinants of health at the county level

	N	Mean	SD	Min	Q1	Median	Q3	Max
Median income ($ 1000)	3134	52.80	13.88	25.39	43.68	50.57	58.85	140.38
Food insecurity index	3134	0.13	0.04	0.03	0.11	0.13	0.15	0.36
Share of pop. on food stamps	3134	0.14	0.07	0.00	0.09	0.13	0.18	0.54
Share of pop. with some college educ.	3134	0.58	0.12	0.15	0.50	0.58	0.66	1.00
Access to exercise	3134	0.63	0.23	0.00	0.49	0.66	0.80	1.00
Share of rural population	3134	0.59	0.31	0.00	0.33	0.59	0.88	1.00

Table 4 shows the coefficient estimates for the relationship between our selected social determinants of health and the share of the population diagnosed with diabetes for each county. All of the stand-alone coefficients in the top sectionof the table are significantly different from zero, except median household income, and the share of food assistance recipients. This suggests that a higher share of food assistance recipients, populations with higher education levels, and increased opportunities to exercise are associated with a lower share of the population being diagnosed with diabetes. Higher food insecurity, on the other hand, is correlated to a higher share of the population being diagnosed with diabetes. Our findings linking higher food security and access to exercise opportunities to lower incidents of diabetes are broadly consistent with previous research, which found, for example, that positive lifestyle interventions such as improved nutrition and more physical activity, were associated with preventing or postponing type 2 diabetes.[27, 28]

The bottom part of the table shows the same coefficients as the top portion yet associated with the share of rural populations. The findings suggest that social determinants of health relative to the diabetes share of the population differ for rural areas as compared to the more urban and peri-urban counties in our sample. For example, the positive correlation between food security and diabetes is largely erased in counties with a larger share of rural populations. On the other hand, food stamps appear to be associated with higher incidents of diabetes in rural areas. Our estimated coefficients further show that higher education levels in more rural areas are correlated with additional reductions in the prevalence of diabetes compared to more urban and peri-urban areas. Finally, the benefits associated with access to exercise appear to be largely erased in more rural areas as the value of the coefficient is almost completely offset by the more positive impact of exercise opportunities on diabetes.

Table 4: Estimated coefficients linking social determinants to diabetes shares by county

	Est. coefficient	Std. Error	t value	Pr (>|t|)
Intercept	0.125	0.007	17.511	0
Median income ($ 1000)	0	0	0.168	0.867
Food insecurity index	0.259	0.043	5.972	0
Share of pop. on food stamps	0.04	0.026	1.53	0.126
Share of pop. with some college educ.	-0.031	0.014	-2.184	0.029
Access to exercise	-0.057	0.008	-6.723	0
Median income ($ 1000) of rural population share	0	0	-1.104	0.27
Food insecurity index of rural population share	-0.182	0.061	-2.983	0.003
Share of rural population on food stamps	0.112	0.036	3.071	0.002
Share of rural population with some college educ.	-0.038	0.019	-2.047	0.041
Access to exercise of rural population	0.045	0.01	4.52	0
Adjusted R^2	0.292			
Number of observations	3134			

Table 5 shows the general coefficient estimates for the relationship between the selected social determinants of health and cardiovascular health (top section of the table). All of the coefficients are significantly different from zero except median income. This suggests that a higher share of adults aged 24 to 44 with some college education and better opportunities to exercise are associated with a lower rate of fatalities associated with cardiovascular disease. On the other hand, higher food insecurity levels are correlated with higher incidents of cardiovascular problems. Previous studies show similar results and indicate that nutrition and physical activity positively impact cardiovascular health.[25, 26]

The bottom part of the table shows the estimates for the same variables associated with the share of rural populations. The coefficients suggest that while median income is generally not associated with poor cardiovascular health it does appear to indicate negative implications in rural areas. Similar to our findings for diabetes, we also find that the negative impact of food insecurity on cardiovascular health is reduced in rural areas. We also find that the correlation between food assistance programs and cardiovascular disease is higher in rural areas,while opportunities to exercise plays a smaller role in rural than in urban areas. This suggests that in the case of cardio-vascular health, food access alone may not mitigate health outcomes and affirms the USDA definition of food security, which highlights the importance of both qualitative and quantitative aspects of food access for improved health outcomes. In other words, more food alone may not improve health outcomes, without also considering the nutritional quality of the food.

Table 5: Estimated coefficients linking social determinants to cardiovascular health by count

	Est. coefficient	Std. Error	t value	Pr (>|t|)
Intercept	0.277	0.01	27.225	0
Median income ($ 1000)	0	0	-0.415	0.678
Food insecurity index	0.547	0.06	9.111	0
Share of pop. on food stamps	0.085	0.037	2.3	0.022
Share of pop. with some college educ.	-0.103	0.02	-5.138	0
Access to exercise	-0.074	0.012	-6.253	0
Median income ($ 1000) of rural population share	-0.001	0	-3.509	0
Food insecurity index of rural population share	-0.279	0.087	-3.197	0.001
Share of rural population on food stamps	0.086	0.052	1.672	0.095
Share of rural population with some college educ.	0.041	0.027	1.506	0.132
Access to exercise of rural population	0.052	0.014	3.595	0
Adjusted R^2	0.428			
Number of observations	3048			

c. Considering 'what if' scenarios of positive health conditions

In our fictitious 'what if' scenarios we calculate the implications of assumed health performance of all U.S. counties at the level of the best performing county. With respect to diabetes, for example, we bring the diabetes rates in all counties to 1.5 percent, which is the lowest value in our sample observed in Pitkin County, Colorado. Similarly, we assume the rate of cardiovascular deaths to be 0.1 which is also observed in Pitkin County, Colorado. The results of our hypothetical 'what if' simulations suggest that twenty-two-thousand (22,000) lives could have been saved in the United States in 2020 if the level of diabetes and cardiovascular rates in all counties were reduced to the lowest observed level. In relative terms, the simulated improvements reflected in our 'what if' scenario represent a six (6) percent increase in the survivability of COVID-19 in 2020.

We also find that two-hundred-and-five-thousand (205,500) lives could have been saved in 2020 if the contribution of age to COVID-19 fatalities could have been somehow erased. Similarly, if the implications of belonging to the Non-Hispanic black population suffering from health disparities in general could have been eliminated, an additional six-teen-thousand-five-hundred (16,500) lives could have been saved in 2020. While age and race clearly contributed to the survivability rate of COVID-19, we provide these figures for reference only, and do not attempt to explain the highly complex relationships between age, race, and health outcomes evident in our calculations.

To shed additional light on how the disparities in each of the selected social determinants of health in our model contributeto key health outcomes, we calculate the implications of the difference between the highest and lowest observedvalue for our social determinants of health on the share of diagnosed diabetes and cardiovascular rates. By presenting these differential impacts, we can see the importance of each social determinant forhealth outcomes across the more than 3,000 counties in the United States based on the best and worst observed social determinants. Table 6 summarizes the importance of each of the social determinants of health for two key health outcomes by showing the minimum and maximum observed value and the associated impact on diabetes and cardiovascular health.

Table 6: Implications of changes in social determinants of health for health outcomes

	Minimum Value	Maximum Value	Diabetes Impact	Cardio Impact
Median income ($ 1000)	25.385	140.382	0.002	-0.007
Food insecurity index	0.029	0.363	0.086	0.183
Share of pop. on food assistance	0.004	0.576	0.023	0.048
Share of pop. with some college educ.	0.152	1.000	-0.027	-0.087
Access to exercise	0.000	1.000	-0.057	-0.074

Our model predicts that if all counties in the United States had the best level of exercise opportunities, the resulting improvements in diabetes and cardiovascular health would have reduced the number of COVID related deaths by 1,653. Similarly, if all counties had improved their food security to the level observed in the best performing county, another 9,119 deaths could have been prevented. If education and income levels could have also been improved to those observed in the best performing county, our model predicts that an additional 6,374 and 3,479 lives respectively would have been saved in 2020.

4. Discussion of Results

Our modeling results suggest that the survivability of COVID-19 prior to the existence of an effective vaccine could have been improved by addressing pre-existing health conditions, especially diabetes and cardiovascular disease. We further observe that social determinants including food security, opportunities to exercise, access to food assistance programs, income and education can play a role in reducing pre-existing health conditions. These findings support the generally accepted notion that diabetes and cardiovascular health can in be influenced not only through improved medical treatment but also through improvements in lifestyle related factors and socio-economic conditions. These findings have implications not only for the survivability of COVID-19, but potentially for improving the survivability risks associated with future public health threats even prior to the availability of effective treatments.

In the case of diagnosed diabetes shares of

the population, we find that the greatest impact stems from changes in the share of food assistance recipients and food security in a county. Moving from the lowest to the highest observed levels of food assistance we estimated that food assistance programs contribute 6.8 percentage points to the rate of diagnosed diabetes. Moving from the lowest to the highest levels of food insecurity is expected to contribute 5.9 percentage points. Improvements in the level of education from 15.2 to 100 percent are expected to lower the diabetes share by 4.4. percent. Finally, providing greater access to exercise opportunities to the highest observed level is predicted to lower the diabetes share by 1.9 percentage points.

In the case of cardiovascular disease as measured by a county's number of cardiovascular deaths per 100 people, food insecurity has the most significant impact. Reducing the share of food insecurity from its highest to its lowest observed value is expected to reduce the number of cardiovascular deaths by 0.133 per 100 people. The observed variation in the share of people receiving food assistance is predicted to contribute 0.083 deaths per 100 people. Improving education levels from the lowest to the highest observed levels is estimated to reduce cardiovascular deaths by 0.065 per 100. Finally, improving income and access to exercise is expected to reduce cardiovascular deaths by 0.049 and 0.03 per 100 people, respectively.

We recognize of course that some social determinants can be more easily improved than others. Improved access to food assistance programs, higher food security levels, and better access to exercise opportunities can be improved in the shorter to medium term through appropriate actions. The share of food insecure populations, for example, could be improved by providing more households with easy access to healthy, nutritious food; the share of households with easy access to exercise opportunities could be improved by building recreational facilities. However, it may also require better neighborhood safety so that residents can avail themselves of opportunities to exercise. A study conducted in Washington DC indicates that access to physical exercise may be confounded with community characteristics like neighborhood safety.[6, 29] In other words, the availability of exercise opportunities may not guarantee their use since safety concerns may override the known benefits of exercise.

In contrast, social determinants like income and education are more challenging and cannot be improved without significant longer-term efforts. Our results further suggest that different measures may be needed in rural and urban areas to improve health outcomes like diabetes and cardiovascular health. In light of the fact that close to eighty (80) percent of the U.S. population live in urban and metropolitan areas, policy measures addressing improved food security and exercise opportunities may prove particularly important. Increased education levels, on the other hand, may offer significant opportunities in both urban and rural areas.

Exogenous indicators in our model, like age over 65 and race, appear to significantly impact health outcomes and the resulting COVID survivability rates. It may be easy to dismiss these findings as impossible to address. Given their significance, however, we suggest that longer-term efforts to address these factors may be especially valuable. This suggests that more indirect ways in which health outcomes can be improved may require special attention. For example, better access to health care through improved mobility and better access to affordable transportation may be an indirect measure to address disparities in health outcomes associated with age and race. Improved education, food assistance, food security, and exercise, also deserve further attention especially for populations who suffer disproportionately from the negative impact of public health treats. Addressingthese factors may be challenging yet essential to reducing vulnerabilities to future health related shocks like the COVID-19 outbreak.

5. Conclusion

Our analysis identified a chain of relationships between social determinants of health,prevalent health problems like diabetes, cardiovascular health, and the survivability of COVID-19. This chain of relationships establishes an observable connection between pre-existing health conditions, widely accepted social determinants of health, and the survivability of COVID-19. We based our analysis on reported COVID-19 cases and COVID related deaths across all counties in the United States in 2020, prior to the broad availability of COVID vaccines. The health conditions we considered include diabetes, obesity, cancer, and cardiovasculardisease. We also test the impact of the share of over 65-year-olds in each

county, and the share of the population identifying as non-Hispanic black. Consistent with the findings of other studies, we find that the COVID-19 survivability rate is influenced by the rate of diagnosed diabetes cases, cardiovascular health, the share of people over 65, and to a lesser degree, race.

To understand whether the observed COVID-19 survivability rate could have been improved by more favorable pre-existing health conditions, we then considered a set of social determinants of health, namely income, education, food security, access to exercise, and the share of food assistance recipients. We test the impact of improving these social determinants of health on the two health conditions we found to be most significant in impacting COVID survivability rates, namely the diabetes rate and cardiovascular health measured in cardio-vascular fatalities per 100 of the population in a county.

Using county level data for over 3,000 counties across the United States and the predicted coefficients of our model linking social determinants and health outcomes, we then calculate the hypothetical impact of improved social conditions on the 337,300 COVID deaths reported in the United States in 2020. Our findings indicate that 10,800 lives could have been saved through improved diabetes rates and cardiovascular health associated with improvements in food security, food assistance and exercise to the level observed in the best performing county in our sample. We also estimate the impact of improvements in household income and education levels and find that an additional 9,900 lives lost to COVID in 2020 could have been saved.

Finally, we note that characteristics which influenced COVID survivability rates in 2020, such as age over 65 and a race variable identified in the U.S. census as no-Hispanic black, are linked to a potential COVID survivability rate of 205,500 persons related to age, and 16,500 related to race. This suggests that age and race related conditions dwarf medical conditions like diabetes and cardiovascular disease. Measures to address issues around geriatric care and mobility, and racially based health disparities may therefore offer significant opportunities for improving the survivability of COVID-19 and, potentially similar public health threats in the future.

By shedding light on the chain of impacts between social determinants of health, health conditions, and the survivability of the COVID-19 pandemic, we hope to encourage policy considerations that can meaningfully reduce the impact of future adverse shock events similar to those experience by the global COVID pandemic.

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