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The link between the two epidemics provides an opportunity to remedy obesity while dealing with Covid-19

Emiliano Lopez Barrera\textsuperscript{a}, Dragan Miljkovic\textsuperscript{b,\ast}

\textsuperscript{a} Department of Agricultural Economics, Texas A&M University, College Station, TX, USA
\textsuperscript{b} Department of Applied Economics, North Dakota State University, 500 Richard Barry Hall, NDSU Dept. 7610, Fargo, ND 58103-6050, USA

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Abstract

The World Health Organization proclaimed the global epidemic of obesity more than twenty years ago. However, there has never been a coordinated action to address the problem on the global level. Covid-19 virus pandemic is world’s largest public health problem currently. Many comorbidities associated with Covid-19 and obesity mortality are common. We determine that obesity is single largest and most common cause of mortality in Covid-19 patients globally based on a sample of 171 countries, while economic variables have no impact. This creates an opportunity to finally address the obesity global epidemic through an effort coordinated on the global level.

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\ast Corresponding author.
E-mail address: Dragan.Miljkovic@ndsu.edu (D. Miljkovic).

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1. Introduction

Obesity is a complex disease involving an excessive amount of body fat (Mayo Clinic, 2022). The World Health Organization (WHO) described obesity as a global epidemic more than twenty years ago (World Health Organization, 2000a). The problem remains as continuous global increase of obesity did not subside. In 2016, more than 1.9 billion or 39% of adults aged 18 years and over (39% of men and 40% of women) were overweight (World Health Organization, 2020b). Of these, over 650 million adults were obese. That translates into about 13% of the world’s adult population (11% of men and 15% of women) were obese in 2016. In addition, over 340 million children and adolescents aged 5–19 and an estimated 38.2 million children under the age of 5 years were overweight or obese in 2016 (World Health Organization, 2020b). Global epidemic implies that the problem exists on all continents and in almost all countries, with a few exceptions in Sub-Saharan Africa and Asia (World Health Organization, 2020b). It has been long hypothesized and confirmed that globalization is a major contributor to spreading of obesity and diet-related chronic diseases globally (e.g., Miljkovic, Shaik, Miranda, Barabanov, & Liogier, 2015; Miljkovic, de Miranda, Kassouf, & Oliveira, 2018; Oberlander, Disdier, & Etilé, 2017). If we understand globalization as a process by which national/regional economies, societies and cultures have become integrated through a global network of economic, technological, socio-cultural, political and biological factors (Croucher, 2018), rather than the trade liberalization only, the possibility of its resulting externalities, including increasing rate of obesity, rises significantly (Miljkovic et al., 2015).

Overweight and obesity are major causes of many comorbidities which can lead to further morbidity and mortality. For example, increased overweight and obesity have been associated with increased death rates for all cancers combined and for cancers at multiple specific sites (Calle, Rodriguez, Walker-Thurmond, & Thun, 2003). Furthermore, increasing body mass index (BMI), as a standard measure of obesity in adults, is associated with glucose intolerance, dyslipidemia, hypertension, type 2 diabetes, kidney failure, and osteoarthritis (Martin-Rodriguez, Guillen-Grima, Martí, & Antonio, 2015). Moreover, all degrees of obesity are associated with asthma, heart failure, and severe mental disorders. Type II and morbid obesity are associated with chronic obstructive pulmonary disease and depression (Martin-Rodriguez et al., 2015).

The WHO has declared the novel coronavirus SARS-COVID-19–2 (COVID-19) outbreak a global pandemic on March 11, 2020 (Cucinotta & Vanelli, 2020). The virus has wreaked havoc worldwide, bringing the life we know to almost a halt. Studies to date show that advanced age and the presence of one or more underlying health conditions are risk factors for increased severity of the disease (Hussain, Mahawar, Xia, Yang, & Shamsi, 2020). Many of the underlying conditions considered as the risk factors for increased mortality due to COVID-19 are ones and the same as the comorbidities associated with increased obesity and overweight (Hussain et al., 2020; Martin-Rodriguez et al., 2015).

We empirically test and demonstrate in this paper that higher obesity rates indeed cause an increase in mortality rates in those infected by COVID-19 globally. Moreover, we also demonstrate that, on global level, high obesity rates are the primary cause of higher mortality rates due to COVID-19. This also holds true across all COVID-19 mortality rate quantiles and after controlling for several other comorbidities or exogenous factors. As obesity is a non-contagious disease, it has always been difficult to establish international standards on how to address the problem. Considering findings on causal linkage between obesity and COVID-19 mortality, we...
propose more wholistic policies to combat global obesity with the goal to decrease co-morbidities and mortality rates associated with both obesity and COVID-19.

2. Data and methodology

2.1. Data and variables description

There are 171 countries in the sample, and they are listed in the Appendix. The definition of and sources for each variable are provided in Table 1.

2.2. Causality between the obesity rates and mortality rates due to COVID-19

We use the methods of Directed Acyclic Graphs (DAGs) (Imbens, 2020; Pearl, 1995, 2000; Pearl and Mackenzie, 2018) to test for causality between the COVID-19 attributed deaths (per-million) and variables representing major comorbidities including the adult obesity and the share of the at-risk population based on the advanced age (Hussain et al., 2020). Control variables used are each country’s human development index (HDI), COVID-19 vaccination rate, and population density in the country.

DAGs represent, “…principled, nonparametric framework for causal inference, in which diagrams are queried to determine if the assumptions available are sufficient for identifying causal effects from non-experimental data. If so, the diagrams can be queried to produce mathematical expressions for causal effects in terms of observed distributions; otherwise, the diagrams can be queried to suggest additional observations or auxiliary experiments from which the desired outcomes can be obtained” (Pearl, 1995, p. 669). These causal relations are determined by computer algorithms which produce graphs with nodes (vertices, variables) and edges between nodes. Visually, a DAG is a graph, which is an ordered triple \( \langle V, M, E \rangle \). Here, \( V \) is the vertex set, which is a non-empty set that contains nodes, \( M \) is a non-empty set of marks which shows the directedness of an edge, and \( E \) is the edge set, containing ordered pairs representing edges between nodes (Ramsey, Glymour, Sanchez-Romero, & Glymour, 2017). These edges indicate a causal relationship between nodes and can be either directed or undirected edges (indicated by the marks). For two arbitrary nodes A and B, with a directed edge (indicated by a line with an arrow) from node A to node B, we can say that node A is a cause of node B. For an undirected edge (indicated by a line between nodes) between node A and node

| Variable | Description | Source |
|----------|-------------|--------|
| death    | COVID-19 attributed deaths (per-million) cumulated until 08/01/2021 | European CDC |
| obesity  | Percentage of adult obesity in the country (in 2016) (most recent observation) | WHO, Global Health Observatory |
| hdi      | Country’s Human Development index (most recent observation for each country within the last five years) | World Bank |
| over65   | Population ages 65 and above (% of total population) (in 2019) | World Bank |
| vaccination | Percentage of population with at least 1 dose (until 08/02/2021) | NCD Risk Factor Collaboration |
| pop_density | Population density (people per sq. km of land area) (in 2019) | World Bank |
B, we can say one of the following: a) node A is a cause of node B, b) node B is a cause of node A, c) there is some unmeasured confounder of A and B, d) both a and b, or e) both b and c.

For the DAG method, the search for the edges depends on the algorithm and one might find different outcomes based on the algorithm used. In this study we use LiNGAM (Shimizu, Hoyer, Hyvärinen, & Kerminen, 2006) which is one of the first of the algorithms that assumed linearity among the variables and non-Gaussianity of error term and is one of the most used for smaller models as is the case of the present study. The underlying idea for this searching method is to use the Independent Components Analysis (ICA) algorithm to check all permutations of the variables to find one that is a causal order, that is, one in which earlier variables can cause later variables but not vice-versa. For the implementation of ICA we use is FastIca (Hyvärinen, Karhunen, & Oja, 2004). Since we assume the model is a DAG, there must be some permutation of the variables for which the main diagonal of the inverse of the weight matrix contains no zeros. In addition, a lower triangular weight matrix provides evidence of a causal order. Once a causal order is being established, the next step is to eliminate the extra edges. For this, we use the causal order to define knowledge of tiers and run Fast Greedy Equivalence Search (FGES). The implementation of LiNGAM has one parameter, penalty discount, used for the FGES adjacency search. The method as implemented does not scale much beyond 10 variables, making it very suitable for models with a small number of variables as is the case of the present study. We check the robustness of DAGs’ using the FASK algorithm (Sanchez-Romero et al., 2018) finding similar results. These results are generally consistent with the LiNGAM algorithm outcomes and available from the authors upon the request. We also test the results in different contexts, meaning with and without imposing prior knowledge regarding the causal relationship between percentage of people vaccinated and COVID-19 attributable mortality.

We used TETRAD software version 6.9.0 in our DAGs analysis. Five optimizers can be used to search the configurations of parameters: Powell, EM, RICF, accurate regression, and random search. We used “accurate regression” estimates which presuppose that the input parametric model is a DAG, and its associated statistics are based on a linear, non-Gaussian model. The results did not change when using other optimizer algorithms.

2.3. Quantile regression

DAGs analysis results, in addition to their significance on their own, are used as the identification strategy to test the hypothesis of obesity on mortality from the COVID-19 in resulting regression analysis. Quantile regression (Koenker & Bassett, 1978; Koenker & Hallock, 2001) is used to determine if the positive impact of adult obesity persists across the quantiles of the COVID-19 attributed mortality rates. The quantile regression is a method that provides parameter coefficients estimation for any quantile in the range of zero and one (0,1) conditional on the exogenous variables. Where a simple ordinary least square regression is based on the mean of the distribution of the regression’s variable, the quantile regression assumes that the possible difference in terms of the impact of the exogenous variables along the conditional distribution is important.

3. Results

Two different models are analyzed for the period starting at the beginning of the pandemic through February 01, 2022: first assumes that vaccinated people are those who received at most two shots of the vaccine, while the second includes those who received booster dose as well.
First, we focus on results of the model where vaccination implies at most two doses of a vaccine received. The DAGs indicate that there is unidirectional causality going from both adult obesity and larger older population share towards the COVID-19 attributed mortality rate. Associated statistics indicate that both of these variables are most and equally important causes of the COVID-19 mortality rate worldwide. The level of socio-economic development as measured by the HDI has no direct causal link with the COVID-19 attributed mortality rate. The DAG produced that result while imposing prior knowledge. HDI, however, does cause an increase in obesity rates in adults but also the longer life, as measured by an increase in the share of population over the age of 65. Hence, one might say how there is an indirect causality of relative affluence on increase in COVID-19 attributed mortality rate. This finding has important implications on targets of global policies directed at alleviating global both obesity and COVID-19 epidemics. Finally, there is no causality from vaccination rates to COVID-19 attributed mortality rates, while the relative level of affluence as measured by the HDI leads to higher vaccination rates. Population density has no causal relationship with any of the considered variables including COVID-19 attributed mortality rates.

Although we considered other variables in the preliminaries of this study (e.g., number of hospital beds, macro-economic variables), their inclusion in the final analysis would be to the detriment of the number of countries that could be examined in the study. In other words, due to the lack of data, there is a trade-off between a more comprehensive approach to the causality of the COVID-19 attributable diseases and a broader examination that could bring most countries into the analysis (which is the scope of the present study). In addition to that, variables such as GDP or number of hospital beds are also indicators of the level of economic development and are highly correlated with but less comprehensive than the HDI. Hence, most comprehensive economic development indicator/variable (HDI) is selected in the model.

Figure 1 contains the DAG while the associated statistical results are provided in Table 2.

We now turn to the second model which includes those who received not only two vaccine shots but a booster dose as well. These results remain similar but with one fundamental difference: larger share of the population older than 65 does not cause increase mortality from COVID-19. This has important implications as older population seems to be better protected due to booster shot from COVID-19 and thus less vulnerable. Obesity, however, remains the
key direct causal contributor to mortality from COVID-19. The level of economic development
as presented by HDI has two important indirect causal impacts on mortality from COVID-19,
moving in opposite directions. Just like before, relative affluence leads to increased obesity
levels and, in turn, increased mortality from COVID-19. However, higher HDI also implies
larger share of older population and causes more booster vaccines being inoculated. In this case,
it seems that the larger affluence level does serve as a protector of older population via high
rates of booster shots injected. Fig. 2 contains the DAG while the statistical results are provided
in Table 3 associated with this model.

Results from the DAGs analysis are used in this step to facilitate proper econometric model
specification and serve as an indirect test for endogeneity (Miljkovic, Dalbec, & Zhang, 2016).
Quantiles have been designated in 10 percentile increments. The results are reported in Table 4.
The results indicate that strong positive relationship between the adult obesity rates and the
COVID-19 attributed deaths persists at 10% significance level or lower for all but the lowest
thirty percentile. Coincidently, countries with lowest mortality rates are also the countries
with lowest prevalence of obesity. An important policy implication of this result is its global
nature thus enabling universal policy that could address both obesity and COVID-19 epidemics
globally.

The results indicate that strong positive relationship between the adult obesity rates and the
COVID-19 attributed deaths persists at 10% significance level or lower for all but the lowest

![Fig. 2. Causality (including booster) using Directed Acyclic Graphs through february 01, 2022.](image-url)
thirty percentile. An important policy implication of this result is its global nature thus enabling universal policy that could address both obesity and COVID-19 epidemics globally.

The relationship between the share of 65 and older population and the COVID-19 attributed mortality rates is equally transparent. It is positive and statistically significant at 5% or lower significance level at all but the lowest 20 percentiles only. This result is consistent with the DAGs established in the first model, positive causation between the share of 65 and older population and the COVID-19 mortality rates. Finally, no significant correlations at any percentile but the 90th are observed between the HDI and mortality rates, and none at all between the vaccination rate or population density and the COVID-19 attributed mortality rates.

3.1. Robustness check

The robustness of the results is checked by running the analysis for the period from the beginning of the pandemic through August 01, 2021, i.e., the early vaccination stage. We consider people who received at least one dose of a COVID-19 vaccine. The results are qualitatively identical to those of the double vaccinated population on February 01, 2022.

The DAGs and associated statistics are presented in Figure 3 and Table 5, respectively. Results from the DAGs analysis are again used in this step to facilitate proper econometric model specification and serve as an indirect test for endogeneity (Miljkovic et al., 2016). The results from the quantile regression are reported in Table 6.

The results indicate that strong positive relationship between the adult obesity rates and the COVID-19 attributed deaths persists at 5% significance level (or better) for all but the lowest twenty percentile. Countries with lowest mortality rates are also the countries with lowest prevalence of obesity.

The relationship between the share of 65 and older population and the COVID-19 attributed mortality rates is also strong. It is positive and statistically significant at 10 percent significance level (or better) at all but the lowest and highest 10%iles only. This result is consistent with the DAGs established positive causal relationship between the share of 65 and older population and the COVID-19 mortality rates. Finally, no significant correlations at any percentile are observed between the vaccination rate and population density, and the COVID-19 attributed mortality rates. The HDI is negatively correlated, at 10% significance level, only at the 60th percentile with the COVID-19 attributed mortality rates. Hence, direct impact of economic affluence on the mortality due to COVID-19 is all but negligible globally.

3.2. Further robustness check

To further check for the robustness of the above results, same analysis is conducted but on the mortality data through November 30, 2020. Therefore, we consider the period prior to the
Table 4  
Results of the quantile regression accounting for fully vaccinated (including booster) – period through 02/01/2022.

| q10  | Deaths | Coef.  | Std. Err. | T     | P > t | [95% Conf. Interval] |
|------|--------|--------|-----------|-------|-------|----------------------|
| obesity | 37.69894 | 25.71025 | 1.47 | 0.148 | -13.71188 | 89.10975 |
| hdi    | -4095.171 | 4890.102 | -0.84 | 0.406 | -13873.53 | 5683.192 |
| older_65 | 58.3222 | 62.37209 | 0.94 | 0.353 | -66.3985 | 183.0429 |
| density | 0.0821239 | 0.2114574 | 0.39 | 0.699 | -0.3407112 | 0.5049591 |
| boosters | 4.034748 | 12.32981 | 0.33 | 0.745 | -20.62023 | 28.68973 |
| _cons  | 2130.156 | 2728.813 | 0.78 | 0.438 | -3326.444 | 7586.756 |

| q20  | Deaths | Coef.  | Std. Err. | T     | P > t | [95% Conf. Interval] |
|------|--------|--------|-----------|-------|-------|----------------------|
| obesity | 44.26472 | 28.5701 | 1.55 | 0.126 | -12.86473 | 101.3942 |
| hdi    | -4241.41 | 4152.61 | -1.02 | 0.311 | -12545.07 | 4062.247 |
| older_65 | 48.74619 | 46.4024 | 1.05 | 0.298 | -44.04115 | 141.5335 |
| density | 0.0577842 | 0.2755103 | 0.21 | 0.835 | -0.4931327 | 0.6087012 |
| boosters | 4.766522 | 13.01408 | 0.37 | 0.715 | -21.25674 | 30.78978 |
| _cons  | 2501.206 | 2502.67 | 1.0 | 0.322 | -2503.193 | 7505.604 |

| q30  | Deaths | Coef.  | Std. Err. | T     | P > t | [95% Conf. Interval] |
|------|--------|--------|-----------|-------|-------|----------------------|
| obesity | 48.85427 | 31.63664 | 1.54 | 0.128 | -14.4071 | 112.1156 |
| hdi    | -5363.919 | 4591.916 | -1.17 | 0.247 | -14546.02 | 3818.185 |
| older_65 | 103.4288 | 36.30801 | 2.85 | 0.006 | 30.82645 | 176.0312 |
| density | 0.0180793 | 0.3221949 | 0.06 | 0.955 | -0.6261891 | 0.6623477 |
| boosters | 8.845031 | 17.28128 | 0.51 | 0.611 | -25.71102 | 43.40109 |
| _cons  | 2897.05 | 2885.193 | 1.0 | 0.319 | -2872.249 | 8666.35 |

| q40  | Deaths | Coef.  | Std. Err. | T     | P > t | [95% Conf. Interval] |
|------|--------|--------|-----------|-------|-------|----------------------|
| obesity | 58.0678 | 32.32598 | 1.8 | 0.077 | -6.571984 | 122.7076 |
| hdi    | -3106.805 | 4579.69 | -0.68 | 0.5 | -12264.46 | 6050.851 |
| older_65 | 106.5823 | 33.48615 | 3.18 | 0.002 | 39.62258 | 173.542 |
| density | 0.0202932 | 0.3088481 | 0.07 | 0.948 | -0.5972868 | 0.6378732 |
| boosters | -6.589368 | 17.57216 | -0.37 | 0.709 | -41.72707 | 28.54833 |
| _cons  | 1561.368 | 3102.309 | 0.5 | 0.617 | -4642.082 | 7764.818 |

| q50  | Deaths | Coef.  | Std. Err. | T     | P > t | [95% Conf. Interval] |
|------|--------|--------|-----------|-------|-------|----------------------|
| obesity | 59.84839 | 24.53064 | 2.44 | 0.018 | 10.79636 | 108.9004 |
| hdi    | -2696.429 | 3972.403 | -0.68 | 0.5 | -10639.74 | 5246.882 |
| older_65 | 107.7603 | 29.99376 | 3.59 | 0.001 | 47.78404 | 167.7365 |
| density | 0.0245441 | 0.3984906 | 0.06 | 0.951 | -0.7722872 | 0.8213754 |
| boosters | -15.09388 | 14.43882 | -1.05 | 0.3 | -43.96608 | 13.77832 |
| _cons  | 1610.39 | 2595.167 | 0.62 | 0.537 | -3578.969 | 6979.748 |

| q60  | Deaths | Coef.  | Std. Err. | T     | P > t | [95% Conf. Interval] |
|------|--------|--------|-----------|-------|-------|----------------------|
| obesity | 66.26767 | 20.03735 | 3.31 | 0.002 | 26.20052 | 106.3348 |
| hdi    | -2580.356 | 2861.683 | -0.9 | 0.371 | -8302.645 | 3141.932 |
| older_65 | 102.0046 | 31.58909 | 3.23 | 0.002 | 38.83829 | 165.1709 |
| density | 0.0216915 | 0.4109722 | 0.05 | 0.958 | -0.8009824 | 0.8434811 |
| boosters | -14.31505 | 14.89014 | -0.96 | 0.34 | -44.08973 | 15.45964 |
| _cons  | 1514.1 | 1928.888 | 0.78 | 0.436 | -2342.95 | 5371.15 |

| q70  | Deaths | Coef.  | Std. Err. | T     | P > t | [95% Conf. Interval] |
|------|--------|--------|-----------|-------|-------|----------------------|
| obesity | 68.68129 | 24.94501 | 2.75 | 0.008 | 18.80066 | 118.5619 |
| hdi    | -2348.03 | 3455.81 | -0.68 | 0.499 | -9258.351 | 4562.29 |
| older_65 | 117.7891 | 49.29748 | 2.39 | 0.02 | 19.21273 | 216.3655 |
| density | 0.0027999 | 0.4861505 | 0.0 | 0.996 | -0.9698381 | 0.9743979 |
| boosters | -17.36967 | 15.29658 | -1.14 | 0.261 | -47.95707 | 13.21772 |

(continued on next page)
Table 4 (continued)

| Deaths Coef. Std. Err. | T  | P > t | [95% Conf. Interval] |
|------------------------|----|-------|----------------------|
| _cons                  | 1408.465 2222.892 | 0.63 | 0.529 | -3036.483 5853.413 |
| q80
| obesity                | 93.80904 28.50039 | 3.29 | 0.002 | 36.81899 150.7991 |
| hdi                    | -6985.961 6448.096 | -1.08 | 0.283 | -19879.73 5907.805 |
| older_65               | 181.1685 51.22136 | 3.54 | 0.001 | 78.74509 283.592 |
| density                | 0.0394962 0.7738799 | 0.05 | 0.959 | -1.507972 1.586965 |
| boosters               | -13.22364 22.0369 | -0.6 | 0.551 | -57.28914 30.84185 |
| _cons                  | 4251.304 4388.66 | 0.97 | 0.337 | -4524.364 13,026.97 |
| q90
| obesity                | 87.44192 44.74705 | 1.95 | 0.055 | -2.035339 176.9192 |
| hdi                    | -12334.61 7165.033 | -1.72 | 0.09 | -26661.98 1992.76 |
| older_65               | 210.1969 61.08509 | 3.44 | 0.001 | 88.04972 332.3441 |
| density                | 0.0516366 0.7567624 | 0.07 | 0.946 | -1.461603 1.564877 |
| boosters               | -9.649906 21.58764 | -0.45 | 0.656 | -52.81707 33.51725 |
| _cons                  | 8628.516 4604.415 | 1.87 | 0.066 | -578.5801 17,835.61 |

Fig. 3. Causality (at least once-vaccinated) using DAGs through August 01, 2022.

Table 5
Statistical results associated with DAG in Fig. 3.

| From    | To           | Type   | Value  | SE     | T     | P     |
|---------|--------------|--------|--------|--------|-------|-------|
| older65 | adult obesity| Edge Coef. | -0.51  | 0.19  | -2.68 | 0.009 |
| older65 | deaths       | Edge Coef. | 40.34 | 14.79 | 2.98  | 0.004 |
| hdi     | older65      | Edge Coef. | 43.09 | 3.61 | 11.76 | 0.000 |
| hdi     | adult obesity| Edge Coef. | 60.09 | 10.32 | 5.88  | 0.000 |
| hdi     | vaccinated   | Edge Coef. | 137.19 | 14.87 | 9.40  | 0.000 |
| adult obesity | deaths   | Edge Coef. | 34.18 | 10.99 | 3.03  | 0.003 |

* Null hypothesis for T and P is that the parameter is zero.
Table 6
Results of the quantile regression-period through 08/01/2021.

| Quantile/variable | Coefficient | Std. Err. | t     | P-value | [95% confidence interval] |
|-------------------|-------------|-----------|-------|---------|--------------------------|
| **q10**           |             |           |       |         |                          |
| adult obesity     | 8.64        | 12.0      | 0.72  | 0.47    | -15.2 - 32.5             |
| older_65          | 9.87        | 18.3      | 0.54  | 0.59    | -26.5 - 46.2             |
| vaccination       | 1.62        | 4.9       | 0.33  | 0.74    | -8.2 - 11.5              |
| hdi               | -367.92     | 881.0     | -0.42 | 0.68    | -2120.6 - 1384.7         |
| pop_density       | 0.00        | 0.1       | -0.04 | 0.97    | -0.2 - 0.2               |
| cons              | 89.77       | 388.4     | 0.23  | 0.82    | -682.8 - 862.4           |
| **q20**           |             |           |       |         |                          |
| adult obesity     | 17.31       | 14.7      | 1.18  | 0.24    | -11.8 - 46.5             |
| older_65          | 44.83*      | 23.8      | 1.88  | 0.06    | -2.5 - 92.2              |
| vaccination       | 3.11        | 5.3       | 0.59  | 0.56    | -7.5 - 13.7              |
| hdi               | -1390.02    | 959.2     | -1.45 | 0.15    | -3298.2 - 518.2          |
| pop_density       | -0.01       | 0.1       | -0.11 | 0.91    | -0.2 - 0.2               |
| cons              | 503.43      | 514.4     | 0.93  | 0.36    | -573.6 - 1580.5          |
| **q30**           |             |           |       |         |                          |
| adult obesity     | 24.49*      | 13.3      | 1.97  | 0.05    | -2.0 - 51.0              |
| older_65          | 69.22****   | 24.2      | 2.87  | 0.01    | 21.2 - 117.3             |
| vaccination       | -0.43       | 6.1       | -0.07 | 0.94    | -12.6 - 11.8             |
| hdi               | -1214.82    | 1085.7    | -1.12 | 0.27    | -3374.6 - 944.9          |
| pop_density       | -0.02       | 0.1       | -0.26 | 0.80    | -0.2 - 0.2               |
| cons              | 327.43      | 513.9     | 0.64  | 0.53    | -695.0 - 1349.8          |
| **q40**           |             |           |       |         |                          |
| adult obesity     | 31.83***    | 11.8      | 2.70  | 0.01    | 8.4 - 55.3               |
| older_65          | 69.81****   | 24.3      | 2.87  | 0.01    | 21.4 - 118.2             |
| vaccination       | -2.13       | 5.5       | -0.39 | 0.70    | -13.1 - 8.8              |
| hdi               | -1205.47    | 1512.1    | -0.80 | 0.43    | -4213.5 - 1802.6         |
| pop_density       | -0.02       | 0.1       | -0.16 | 0.88    | -0.3 - 0.3               |
| cons              | 389.23      | 785.4     | 0.50  | 0.62    | -1173.3 - 1951.7         |
| **q50**           |             |           |       |         |                          |
| adult obesity     | 34.09****   | 12.5      | 2.73  | 0.01    | 9.2 - 59.0               |
| older_65          | 87.64****   | 26.1      | 3.36  | 0.00    | 35.8 - 139.5             |
| vaccination       | -1.12       | 5.7       | -0.20 | 0.84    | -12.4 - 10.2             |
| hdi               | -1717.06    | 1402.8    | -1.22 | 0.22    | -4507.6 - 1073.5         |
| pop_density       | -0.03       | 0.1       | -0.24 | 0.81    | -0.3 - 0.2               |
| cons              | 630.98      | 716.4     | 0.88  | 0.38    | -794.2 - 2056.2          |
| **q60**           |             |           |       |         |                          |
| adult obesity     | 49.31***    | 12.2      | 4.04  | 0.00    | 25.0 - 73.6              |
| older_65          | 104.75***   | 28.5      | 3.67  | 0.00    | 48.0 - 161.5             |
| vaccination       | -0.72       | 6.8       | -0.11 | 0.92    | -14.3 - 12.9             |
| hdi               | -2932.13*   | 1764.7    | -1.66 | 0.10    | -6442.6 - 578.3          |
| pop_density       | -0.01       | 0.2       | -0.04 | 0.97    | -0.4 - 0.4               |
| cons              | 1222.35     | 888.2     | 1.38  | 0.17    | -544.6 - 2989.3          |
| **q70**           |             |           |       |         |                          |
| adult obesity     | 46.92****   | 14.0      | 3.35  | 0.00    | 19.1 - 74.8              |
| older_65          | 71.57*      | 38.0      | 1.89  | 0.06    | -3.9 - 147.1             |
| vaccination       | -2.71       | 6.7       | -0.40 | 0.69    | -16.1 - 10.7             |
| hdi               | -654.43     | 2565.7    | -0.26 | 0.80    | -5758.5 - 4449.6         |
| pop_density       | -0.06       | 0.2       | -0.28 | 0.78    | -0.5 - 0.4               |
| cons              | 97.74       | 1386.5    | 0.07  | 0.94    | -2660.4 - 2855.9         |
| **q80**           |             |           |       |         |                          |
| adult obesity     | 65.11***    | 23.7      | 2.75  | 0.01    | 18.0 - 112.3             |

(continued on next page)
beginning of the COVID-19 vaccination worldwide in December of 2020. While we lose the vaccination control variable here, all other data remains the same with the exception of mortality data. In one final robustness check run, we also substitute the GDP per capita for HDI, as an alternative measure of relative affluence or development. DAGs results are presented in Fig. 4 and related Tables 7 and 8. Panel (a) presents the causal relationships from HDI to the prevalence of adult obesity and percentage of population older than 65, and from those to Covid-19 attributable deaths (per million), accounting for causality from countries’ population density. Panel (b) replicates the model but using GDP per capita instead of HDI. Arrows represent the direction of causality and values on the arrows represent their sign and strength, mean represent the mean of the variables in the model, and E represent their standard deviation. We find positive and statistically significant causalities from the prevalence of adult obesity and percentage of population older than 65 under the two model specifications (see Tables 7 and 8). HDI has an indirect impact on mortality via both obesity and older age.

The results of the quantile regression follow and they indicate similar pattern as in the original time-frame: that strong positive relationship between the adult obesity rates and the COVID-19 attributed deaths persists at 1% significance level for all but the lowest ten percentile. Countries with lowest mortality rates are also the countries with lowest prevalence of obesity.

The relationship between the share of 65 and older population and the COVID-19 attributed mortality rates positive and statistically significant at 10% significance level at the 20th, 40th, 60th, 70th and 80th percentiles only, and not significant at other percentiles. This result is again consistent with the DAGs established positive but statistically weak causal relationship between the share of 65 and older population and the COVID-19 mortality rates. The impact of older population on increased COVID-19 attributed mortality rates is established but is not as obvious as the popular narrative seems to imply. Finally, no significant correlations at any percentile are observed between the HDI or GDP per capita and population density, and the COVID-19 attributed mortality rates; hence, these results are not included in Table 9.
Fig. 4. Causality between Covid-19 mortality and related comorbidities using Directed Acyclic Graphs under two model specifications through November, 2022.
4. Policy implications and conclusions

The implications of globalization are different for different countries and regions. Rich, more developed countries are leading the charge and promote the idea of globalization, which enables them to enlarge the markets for their products and increase the socio-political influence on the rest of the world (Croucher, 2018). Many positive aspects of globalization are likely to lead to an increase in standard of living in most countries of the world. Yet, there are some unwanted side-effects of globalization such as the increase in obesity, which is now considered a global epidemic (Miljkovic et al., 2015). Likewise, the impact of globalization on spreading of infectious diseases, including COVID-19, is even more easily observed and measured (e.g., Bickley, Chan, Skali, Stadelmann & Torgler, 2021; Frenk, Gómez-Dantés, & Knaul, 2011; Saker, Lee, Cannito, Gilmore, & Campbell-Lendrum, 2004). Different nature of these global epidemics, i.e., obesity and COVID-19, seems to have triggered different approach of addressing them or a lack thereof at all. The intrinsic link between the two epidemics, as presented in our results, provides an opportunity to remedy this lack of global policy strategy when it comes to obesity.

There is single largest unidirectional causality running from adult obesity to COVID-19 attributed deaths determined globally and present across all percentiles (but the lowest ten percent) of COVID-19 mortality rates. This result holds in the pre-vaccination, early vaccination, and full-vaccination (including boosters) stages of COVID-19 pandemic. This fact creates an opportunity to organize coordinated efforts to address and to remedy the problem on the global level. Such an effort is likely to have best chance of succeeding if organized by a central hub that is a well-respected global public health institution with already existing knowhow in leading similar endeavors. Most obvious candidate for this role would be the WHO. While the WHO has already taken a lead role in prescribing the guidelines for minimizing the risk of spreading and contracting the COVID-19, there is this area of combating global obesity where the WHO could contribute substantially to alleviating the mortality rate attributed to

### Table 7
Statistical results associated with DAG (panel a in Fig. 4).

| From            | To               | Type       | Value   | SE       | T  | P   |
|-----------------|-----------------|------------|---------|----------|----|-----|
| adult obesity   | deaths          | Edge Coef. | 9.2079  | 1.9154   | 4.8072 | 0.0000 |
| hdi             | older65         | Edge Coef. | 30.2060 | 2.1589   | 13.9916 | 0.0000 |
| older65         | deaths          | Edge Coef. | 4.8548  | 2.6824   | 1.8099  | 0.0722 |
| hdi             | adult obesity   | Edge Coef. | 35.7923 | 3.5584   | 10.0587 | 0.0000 |
| pop_density     | deaths          | Edge Coef. | -0.0136 | 0.0242   | -0.5618 | 0.5750 |

* Null hypothesis for T and P is that the parameter is zero.

### Table 8
Statistical results associated with DAG (panel b in Fig. 4).

| From            | To               | Type       | Value   | SE       | T  | P   |
|-----------------|-----------------|------------|---------|----------|----|-----|
| gdp_pc          | older65         | Edge Coef. | 0.0001  | 0.0000   | 6.6445 | 0.0000 |
| adult obesity   | deaths          | Edge Coef. | 9.2079  | 1.9154   | 4.8072 | 0.0000 |
| gdp_pc          | adult obesity   | Edge Coef. | 0.0002  | 0.0000   | 6.1545 | 0.0000 |
| pop_density     | deaths          | Edge Coef. | -0.0136 | 0.0242   | -0.5618 | 0.5750 |
| older65         | deaths          | Edge Coef. | 4.8548  | 2.6824   | 1.8099  | 0.0722 |

* Null hypothesis for T and P is that the parameter is zero.
COVID-19 as well as of other related comorbidities. Given that obesity is a non-contagious disease, each country chose to address it based on their own set of health standards as well as cultural values often leading to complete inaction in terms of preventative activities. Unlike obesity, COVID-19 is highly contagious and national borders are not an obstacle for its global spread. Hence global strategy in combating COVID-19 has always been desirable.

As a long-term strategy, the WHO could also assume the leadership in the global fight against obesity, indirectly one of the largest contributors to human mortality due to many co-morbidities caused by it including the COVID-19 deaths. Most economic research regarding obesity, thus far, had national focus and specific food policy and health measures. Notably, much of the literature focused on variants of habit formation and addiction theory regarding specific foods and beverages in specific countries (e.g., Miljkovic and Nganje, 2008; Miljkovic, 2008).

| Quantile/variable | Coefficient | Std. Err | t | P | [95% interval] |
|-------------------|-------------|----------|---|---|----------------|
| q10 Adult obesity | 0.488       | 0.380    | 1.290 | 0.200 | -0.262 - 1.238 |
| q10 Older 65      | 0.665       | 0.466    | 1.430 | 0.155 | -0.025 - 1.585 |
| q10 Constant      | -5.819      | 3.542    | -1.640 | 0.102 | -12.811 - 1.173 |
| q20 Adult obesity | 1.612       | 0.422    | 3.820 | 0.000 | 0.779 - 2.445 |
| q20 Older 65      | 1.182       | 0.625    | 1.890 | 0.060 | -0.052 - 2.417 |
| q20 Constant      | -14.743     | 3.823    | -3.860 | 0.000 | -22.291 - 7.196 |
| q30 Adult obesity | 2.301       | 0.473    | 4.860 | 0.000 | 1.367 - 3.235 |
| q30 Older 65      | 1.291       | 1.540    | 0.840 | 0.403 | -1.749 - 4.331 |
| q30 Constant      | -16.276     | 4.184    | -3.890 | 0.000 | -24.535 - 8.016 |
| q40 Adult obesity | 3.809       | 0.767    | 4.970 | 0.000 | 2.295 - 5.323 |
| q40 Older 65      | 3.833       | 1.901    | 2.020 | 0.045 | 0.081 - 7.585 |
| q40 Constant      | -33.590     | 5.179    | -6.490 | 0.000 | -43.814 - 23.666 |
| q50 Adult obesity | 5.054       | 1.568    | 3.220 | 0.002 | 1.959 - 8.150 |
| q50 Older 65      | 4.239       | 2.832    | 1.500 | 0.136 | -1.352 - 9.830 |
| q50 Constant      | -40.561     | 7.845    | -5.170 | 0.000 | -56.048 - 25.074 |
| q60 Adult obesity | 6.982       | 1.670    | 4.180 | 0.000 | 3.685 - 10.279 |
| q60 Older 65      | 5.352       | 3.165    | 1.690 | 0.093 | -0.895 - 11.599 |
| q60 Constant      | -50.844     | 9.084    | -5.600 | 0.000 | -68.776 - 32.913 |
| q70 Adult obesity | 9.720       | 1.589    | 6.120 | 0.000 | 6.584 - 12.856 |
| q70 Older 65      | 8.210       | 3.991    | 2.060 | 0.041 | 0.332 - 16.088 |
| q70 Constant      | -71.215     | 11.171   | -6.380 | 0.000 | -93.266 - 49.164 |
| q80 Adult obesity | 11.661      | 1.581    | 7.380 | 0.000 | 8.540 - 14.781 |
| q80 Older 65      | 16.923      | 5.959    | 3.020 | 0.003 | 5.880 - 27.967 |
| q80 Constant      | -102.863    | 16.767   | -6.130 | 0.000 | -135.962 - 69.765 |
| q90 Adult obesity | 24.578      | 5.237    | 4.690 | 0.000 | 14.240 - 34.916 |
| q90 Older 65      | 9.478       | 7.258    | 1.310 | 0.193 | -4.849 - 23.805 |
| q90 Constant      | -119.722    | 18.862   | -6.350 | 0.000 | -156.956 - 82.488 |
| Number of cases   | 173         |          |      |     |                 |
Nganje, & Chastenet, 2008; Thunström, 2010; Zhen, Wohlgenant, Karns, & Kaufman, 2011). Based on these models, the public health impacts of a fat tax (e.g., Jensen & Smed, 2013; Miljkovic et al., 2008) were typically considered for each of the countries.

While there is a recognition among scientists about the ill-effects of obesity on human health globally, food politics and special interest lobbying successes made it unpopular and difficult to fight this problem (Nestle, 2013). The WHO’s status as the world’s leading global public health institution could ensure its credibility and neutrality to provide educational material and counseling that promote healthy nutrition and lifestyle even in nations where food industry special interests overwrite national public health and social welfare priorities. Another obstacle in the way of making reducing obesity number one public health priority globally in the long run is an emphasis of the WHO and the Food and Agriculture Organization of the United Nations on food security, malnutrition and hunger. Both prevention and reduction of post-harvest losses and advancements in biotechnology ensure enough food supply globally (Miljkovic & Winter-Nelson, 2021), thus making food security, unlike obesity, a political rather than public health issue (e.g., Kennedy, 2018; Miljkovic, 2015).

Media coverage and public perceptions have been centered on the presence of seemingly efficient and safe COVID-19 vaccines. Yet, our results suggest no direct causal relationship between COVID-19 vaccination rate and deaths attributed to COVID-19. Moreover, quantile regression results indicate that for no sample (quantile) of countries, from those with the lowest to those with the highest mortality rates attributed to COVID-19 does the vaccination rate have any impact on death from COVID-19. Only indirectly vaccination may have an impact on lesser mortality from COVID-19 as there is no direct causal link between the population of 65 and older who received booster shot, and the mortality rate from COVID-19. Obesity, however, remains largest contributor to mortality from COVID-19 in all considered cases. While our results point to obesity as the largest and most persistent contributors to mortality from COVID-19, all global and national public health efforts seem to be directed into intensifying vaccination rate while no efforts are made to address obesity and related comorbidities as at least long-term target variables.

In conclusion, comorbidities associated with obesity are same as many attributed to COVID-19 deaths. Most important finding is that obese population is identified as most-at-risk if infected by COVID-19. In turn, this finding underlines the need for centralized long-term strategy and leadership in fighting global obesity as the largest long-lasting global public health issue.
Appendix

See appendix Table A1.

Table A1
List of countries within the sample of the study. Dataset contains data on 171 countries, accounting for 98.2% of the global population in 2020.

| Afghanistan | Canada | Gabon | Laos | Nigeria | Spain |
|-------------|--------|-------|------|---------|-------|
| Albania | Cape Verde | Gambia | Latvia | North Macedonia | Sri Lanka |
| Algeria | Central African Republic | Georgia | Lebanon | Norway | Suriname |
| Angola | Chad | Germany | Lesotho | Oman | Sweden |
| Antigua and Barbuda | Chile | Ghana | Liberia | Pakistan | Switzerland |
| Argentina | China | Greece | Libya | Panama | Tajikistan |
| Armenia | Colombia | Grenada | Lithuania | Papua New Guinea | Tanzania |
| Austria | Comoros | Guatemala | Luxembourg | Paraguay | Thailand |
| Azerbaijan | Costa Rica | Guinea-Bissau | Malawi | Philippines | Togo |
| Bahamas | Cote d’Ivoire | Guyana | Malaysia | Poland | Trinidad and Tobago |
| Bahrain | Croatia | Haiti | Maldives | Portugal | Tunisia |
| Bangladesh | Cyprus | Honduras | Mali | Qatar | Turkey |
| Barbados | Czechia | Hungary | Malta | Romania | Uganda |
| Belarus | Denmark | Iceland | Mauritania | Russia | Ukraine |
| Belgium | Djibouti | India | Mauritius | Rwanda | United Arab Emirates |
| Belize | Dominican Republic | Indonesia | Mexico | Saint Lucia | United Kingdom |
| Benin | DR of Congo | Iran | Moldova | Saint Vincent | United States |
| Bhutan | Ecuador | Iraq | Mongolia | Sao Tome and Principe | Uruguay |
| Bolivia | Egypt | Ireland | Montenegro | Saudi Arabia | Uzbekistan |
| Bosnia and Herzegovina | El Salvador | Israel | Morocco | Senegal | Vanuatu |
| Botswana | Equatorial Guinea | Italy | Mozambique | Serbia | Venezuela |
| Brazil | Eritrea | Jamaica | Myanmar | Seychelles | Vietnam |
| Brunei | Estonia | Japan | Namibia | Sierra Leone | Yemen |
| Bulgaria | Eswatini | Jordan | Nepal | Singapore | Zambia |
| Burkina Faso | Ethiopia | Kazakhstan | Netherlands | Slovakia | Zimbabwe |
| Burundi | Fiji | Kenya | New Zealand | Slovenia | |
| Cambodia | Finland | Kuwait | Nicaragua | South Africa | |
| Cameroon | France | Kyrgyzstan | Niger | South Korea | |

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