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COVID-19 and the city: Did urbanized countries suffer more fatalities?

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ABSTRACT

In this paper we derive a theoretical model of the spread of a viral infection which we use as basis for an estimation strategy to test four interrelated hypotheses on the relationship between country-level COVID-19 mortality rates and the extent of urban development. Using data covering 81 countries we find evidence that countries with a higher population density, a higher share of the urban population living in the largest city, and countries with a higher urbanization rate had on average the same or fewer COVID-19 fatalities compared to less urbanized countries in 2020. Even though COVID-19 spreads faster in cities, fatalities may be lower, conditional on economic development, trust in government, and a well-functioning health care system. Generally, urbanization and city development are associated with economic development: with the resources urbanized countries have, it is easier for them to manage and maintain stricter lockdowns, and to roll out effective pharmaceutical interventions.

1. Introduction

Cities do not have a good image in times of pandemics. They have been referred to as “urban graveyards” (Curtis, 2016, p. 139; Van der Woude, 1982) in historical accounts of the bubonic plague, reminding us that “density and connection to the outside world – the defining characteristics of great cities – can also turn deadly” (Glaeser, 2020, p. 2). Wade (2020) recounts how the fear of the deadly disease motivated rural people to prevent London inhabitants from fleeing the city during the bubonic plague in 1625. Fast-forward to the COVID-19 pandemic, and the fear that cities may become “urban graveyards” remain. Just as people fled London in 1625, many fled their cities in 2020 — also facing resistance from rural inhabitants in some cases. An estimated 15–20 % of Manhattan’s population, for example, left the city in the wake of COVID-19 (Coven, Gupta, & Yao, 2020). Inhabitants of Norway’s rural north (Fitjar, 2020). Similarly, in the UK, it was reported that “Londoners are not welcome in Cornwall” and in France that “Parisians are not welcome in rural areas” (Rockl & Sjödin, 2020). In July 2020, the United Nations declared cities to be the epicenter of the COVID-19 pandemic (UN, 2020).

There are indeed good reasons to expect, a priori, that cities may be danger zones during a pandemic. Cities have larger and denser populations than towns and rural areas, making the risk of transmission, and thus death, higher (Rockl & Sjödin, 2020). Cities also tend to be better connected to the rest of the world which allows easy entry for viruses originating elsewhere (Azad & Devi, 2020; Tsiotas & Tselios, 2022). Cities, however, may be ultimately safer in terms of saving lives, because they provide better access to information, medical services, and technologies — all of which can reduce the risk of death in case of an infection. The benefits of technology, information and infrastructure may outweigh the negative effects of population density and connectivity, at least in terms of fatalities. Which effect will dominate is an empirical question, and one that has been somewhat neglected. As Hamidi et al. (2020, p. 496), for example, point out “[t]he impact of density on emerging […] infectious diseases has rarely been studied”. This comparative neglect is also reflected in an OECD (2020) study on COVID-19 and cities, wherein the bulk of the analysis is devoted to the...
economic impact of the pandemic.

In this paper we ask how accurate this perception that cities and urbanized countries suffer more fatalities is, focusing on population density and urbanization variables. Our research methodology is as follows. We start by scrutinizing the existing literature on COVID-19 and population density, as well as references to previous pandemics. We then derive a theoretical model of the spread of a viral infection which we use as basis for our own estimation strategy. This model is based on the standard SIR (Susceptible, Infected, Removed) model from epidemiology. Based on the literature and the theoretical model, we put forward four hypotheses to be tested. The theoretical model is subsequently estimated through four sets of Ordinary Least Squares (OLS) regressions based on cross-country data covering 80 countries and sourced from the Oxford COVID-19 Government Response Tracker (OxCGRT) (Hale et al., 2020), the Johns Hopkins COVID-19 Dashboard (Dong, Du, & Gardner, 2020), the Economist’s tracker for COVID-19 excess deaths,2 and the World Bank’s World Development Indicators (WDI) Online. We make use of two different measures for COVID-19 fatalities: as officially reported COVID-19 deaths may under-report the true extent of deaths (Adam, 2020), we also employ excess mortality. Finally, we also run regressions using the Shannon-Wiener diversity index as dependent variable, indicating the concentration of fatalities during 2020.

Based on the regression results, we cast doubt on the perception of cities as more deadly places. Countries with a higher population density, where a higher share of the urban population lived in the largest cities, or countries with higher urbanization rates, did not suffer higher COVID-19 fatality rates than more rural countries or countries with a lower population density. Results furthermore suggest that countries with a higher population density and a larger share of the urban population living in the largest city tend to have a lower excess mortality. Using the Shannon-Wiener diversity index as dependent variable, we do not find evidence that higher population densities were associated with a temporal concentration of COVID-19 fatalities. Related to our own findings, we can also point out that the literature on previous pandemics, such as the Medieval Bubonic Plague and the 1918 Spanish Flu, equally leads us to doubt that cities suffered more fatalities during pandemics (Curtis, 2016; Parmet & Rothstein, 2018).

The contribution of this paper is thus to explore the factors associated with COVID-19 fatalities during 2020, focusing on the role of variables that reflect the size, density and compactness of urban areas, controlling for confounding factors. Our study has potentially two important policy implications. One is that identifying in retrospect the factors related to pandemic fatalities may be useful in preparing for, and improving resilience, for future pandemics. As various scientists have pointed out, this is increasingly likely to occur as humans, including their cities, encroach on the natural environment. In fact, the World Health Organization (WHO) detects roughly 7000 signals of potential pandemic outbreaks every month (Acuto, 2020). When the next pandemic will break out is only a matter of time. How many people will get infected and die, will largely depend on the global policy response.

A second potentially important policy implication relates to our finding that lower excess mortality in urbanized areas is associated with economic development and thus, better city organization — which provides resources to manage and maintain stricter lockdowns, and roll out effective pharmaceutical interventions, bringing down transmission and mortality rates. However, not all cities are located in developed economies and equally well-organized, and not all people in cities have equal access to its services. Our paper thus makes a call for accelerated investments in improving planning and governance in cities across the world, particularly in less developed countries where the ability of cities to act as shields against infectious diseases will remain seriously compromised given that “almost one-third of urban dwellers live in informal settlements with limited access to drinking water and safe sanitation” (Sachs et al., 2019, p. 809).

The paper proceeds as follows. In Section 2, the relevant literature on pandemics is surveyed. In Section 3, a theoretical model is presented which is used to estimate the factors related to COVID-19 fatalities. Section 4 puts forth our hypotheses and describes the data. Section 5 sets out the descriptive and regression results, and discusses these. We further derive policy recommendations and take-aways for practice based on our findings. The final section concludes.

2. Literature

The existing literature on the relationship between urbanization and pandemics during COVID-19 suggests that “evidence on the association between density and COVID-19 is contrasting and inconclusive” (Sharifi & khavarian-Garmsir, 2020, p. 10). Several studies did not find any evidence that cities have been worse off in terms of COVID-19 fatalities, e.g., Boterman (2020), Carozzi, Provenzano, and Roth (2020), Gerritse (2020), Jinjarak, Ahmed, Nair-Desai, Xin, and Aizenman (2020), Hamidi et al. (2020), Rader et al. (2020), Ribeiro, Sunahara, Sutton, Perc, and Hanley (2020), and Aizenman, Cukierman, Jinjarak, Nair-Desai, and Xin (2022).

Two studies using cross-country data did not find any evidence for a higher fatality rate in densely populated countries. Aizenman et al. (2022) found, using data of 140 countries across 2020 and 2021, that population density was insignificant once they controlled for vaccination rates, and voice and accountability (measures of governance). They showed instead that the association between the ratio of excess mortality to official deaths and “[…] urban population share is significantly negative” (Aizenman et al., 2022, p. 7). Jinjarak et al. (2020) estimated the determinants of cross-country differences of mortality rate curves, measured by the time it took for mortality rates to peak, and the probability of mortality rates to peak after a specific time period. While they found that non-pharmaceutical interventions had a negative impact on the peak mortality rate, they found no significant effect from the share of a country’s urban population. In fact, they established that a higher population density was associated with a flatter mortality rate curve.

Country-level studies have also failed to establish a positive significant association between population density in cities and COVID-19 fatality rates. Using data from Brazil, Ribeiro et al. (2020) found that small towns were proportionately more affected in terms of COVID-19 fatalities compared to larger cities during the initial stages of the pandemic. They also found that growth in fatalities tended to slow down in large cities, while it increased in smaller towns over time. Using data from 913 US metropolitan counties, Hamidi et al. (2020) showed that urban areas with higher population densities had significantly lower mortality rates, ascribing this finding to better health care systems in cities. Finally, Boterman (2020) reported an insignificant relationship between urban density and COVID-19 mortality in the Netherlands when controlling for age and health service infrastructure.

Using US county-level data, Gerritse (2020) identified a behavioural reason for the lower mortality rates in more densely populated areas. “Mobility responses to shelter from exposure in areas of infection are stronger in densely populated areas: people are more likely to reduce travel (to work and to other destinations) and to stay home more, when their potential exposure to infectious people rises” (Gerritse, 2020, p. 3). Rader et al. (2020) concluded, in line with Gerritse (2020), that people in denser cities reduced their mobility much more during COVID-19. As these behavioural responses take some time to unfold, one may expect that initial mortality rates in cities are higher, after which they decline. This is indeed what Gerritse (2020) and Ribeiro et al. (2020) found. Relatedly, Carozzi et al. (2020, p. 1) found, using US county-level data, that “population density is positively associated with proxies of social distancing and negatively associated with the age of the population”.

While urban density (and connectivity) are the main reasons to suspect that cities will experience relatively more fatalities during a

2 Available on GitHub at https://github.com/TheEconomist/covid-19-excess-deaths-tracker.
pandemic, larger cities may also have more fatalities per capita due to urban scaling. Urban scaling refers to the fact that many city-level outcomes follow a power-law function of its population size. Following Bettencourt et al. (2007, p. 7302), the relationship between city-level output and population size can be written as:

$$Y(t) = Y_0 N(t)^\beta$$

(1)

where $N(t)$ is the population at time $t$, and $\beta$ an exponent reflecting the strength of the power-law. Bettencourt et al. (2007) reported that earlier studies, e.g., on the relationship between new AIDS cases and population size, found $\beta = 1.23$. If this also holds for other infectious diseases, there can be “non-linear health consequences of living in larger cities” (Rocha, Thorson, & Lambiote, 2015, p. 785). In the case of COVID-19, Ribeiro et al. (2020) used Brazilian city-level data to obtain estimates for $\beta$ for infections and fatalities. They obtained an estimate of $\beta = 0.85$ for fatalities, calculated 75 days after the first two deaths. This means that fatalities per million inhabitants decrease with population size. The authors provided a concrete example for Brazil: they expected the city of São Paulo with around 12 million people to have 39 % fewer fatalities per capita than Maringá, a medium-sized city with 420,000 people. They ascribe this to better health care facilities in São Paulo and a proportionally smaller share of people older than 60 years.

Even if large cities have more infections than towns or rural areas, people may still be more likely to survive an infection. A number of mechanisms contributes to this: first, access to medical infrastructure, such as physicians and hospital beds. Second, knowledge and education; it is easier and cheaper to disseminate information about the pandemic in urban areas. In addition, urban populations tend to be more educated and thus more likely to follow the advice of scientists (Alirol, Getz, Stoll, Chappuis, & Loutan, 2011). A third mechanism is the availability of ICT infrastructure in cities. As pointed out by Goldfarb & Tucker (2019, p. 28), “[…] the biggest beneficiaries of digital technologies and data have been in large urban areas”. ICT adoption contributes to the efficiency, productivity and safety of the health care system, and to increasing returns to innovation and optimized delivery of health services (Bettencourt et al., 2007). Just as ICT increases firm performance (Brynjolfsson & Saunders, 2010), it is also assumed to increase the performance of health care systems in terms of savings lives, and in monitoring and surveying health conditions and risks.

To answer the question whether fatalities per capita are higher in cities than in less densely populated locations, a more general question needs to be answered first: which factors are associated with country-level fatality rates stemming from COVID-19? The primary factor is the rate of infection — one has to become infected first to die from COVID-19 (Castex Dechter, & Lorca, 2021; Eichenbaum, Rebelo, & Trabandt, 2020). Thus, countries with higher infection rates per capita will also have higher fatality rates per capita; and it is thus relevant to consider the determinants of infections. Herein epidemiological models have been central to conceptualise susceptibility, proximity and how contagious a virus is as key determinants (Kermack & McKendrick, 1927). Government interventions, consisting of pharmaceutical interventions (PIs), such as vaccines, and non-pharmaceutical interventions (NPIs), such as lockdown and social distancing measures, aim to reduce infection rates. Evidence suggests that NPIs are effective in reducing the spread of COVID-19 infections and thus save lives (Castex et al., 2021). This has been the primary motivation for the adoption of stringent lockdown measures throughout the world in the absence of vaccines (Balmford, Annan, Hargreaves, Altoé, & Bateman, 2020).

Most COVID-19 infections, however, are not fatal. This is clear from the wide heterogeneity in fatalities across the world, and from the fact that infections only explain a proportion of the variation in fatalities. Fig. 1 depicts this relationship, using two measures of COVID-19 fatalities: on the left-hand side excess mortality is used, as measured by The Economist’s tracker for COVID-19 excess deaths; on the right-hand side, official COVID-19 deaths as reported by national health agencies and collected by the Johns Hopkins COVID-19 tracker are shown. The figures show, as expected, a positive relationship between COVID-19 cases and fatalities. The relationship however appears non-linear in the form of an inverted-U relationship — reflecting that not everyone is equally susceptible to die from COVID-19 once infected. COVID-19 cases per million explain around 50 % of the variation in COVID-19 fatalities, and 22 % of the variation in excess mortality.

In addition to the infection case load, various other factors have been found to raise COVID-19 fatalities. These include old age (Avery, Bossert, Clark, Ellison, & Ellison, 2020; Dowd et al., 2020), poor air quality (Conticini, Frediani, & Caro, 2020), and lack of exposure to sunlight (Slusky & Zeckhauser, 2021). Higher economic inequality and, more generally, socio-economic disparities have also been argued to lead to higher fatalities per capita (Ahmed, Ahmed, Pisardies, & Stinglitz, 2020; Hamman, 2021). Vadlamannati et al. (2020, p. 9) found that “equity in healthcare access has a negative effect on COVID-19 deaths […]”. A standard deviation increase above the mean value of the healthcare equity index is associated with a 0.38% decrease in COVID-19 deaths per million”. Indeed, for Duranton & Puga (2020, p. 23) the consequence of urban inequalities is paramount, stating that “the cost of the pandemic has so far been associated more with urban inequalities than with urban density”.

Besides the current COVID-19 pandemic, a number of studies have also scrutinized past pandemics, and similarly cast doubt that densely populated locations have higher fatality rates. Curtis (2016, p. 162), for instance, concluded, using a historical database of mortality from burial records of the 17th century Low Countries (modern day Belgium and The Netherlands), that “mortality crises in plague years were much alike in the cities and the countryside — 20% of rural plagues being severe or extreme and 19% being so in urban environments”. And Parmet and Rothstein (2018) showed that rural and low-density urban areas were even more severely affected than cities during the 1918 flu pandemic.

Based on the review of the relevant literature we already doubt the overall hypothesis that urbanized countries suffer more fatalities, generally and in the case of COVID-19.

3. Theoretical model

The core model used in epidemiology to anticipate the spread, pattern and peak of epidemics and pandemics is the Susceptible-Infected-Recovered (SIR) model, based on Kermack and McKendrick (1927). It classifies the population $N$ of a country $j$ into those who are, at a particular time $t$, susceptible to the infection ($S_j$), those who are...

5 Hamman (2021), however, found no significant effect of lockdowns on mortality across US counties.

6 For example, “94 % of all COVID-19 related deaths [in the Netherlands] are people older than 65” (Boterman, 2020, p. 519). Lockdowns targeted at more susceptible age groups can significantly lower fatality rates (Acemoglu, Chernozhukov, Werning, & Whinston, 2020).

7 “Residents with pre-existing respiratory conditions such as asthma or chronic bronchitis, can be more vulnerable to COVID-19. This may have a more serious impact on city dwellers and those exposed to toxic fumes, than on others” (OECD, 2020, pp. 5-6).
infected \( I_0 \), and those who have recovered \( R_0 \). A key parameter is the transmission rate of the disease, which is denoted by \( \beta \), following Castex et al. (2021). This indicates how fast the disease spreads between infected and susceptible persons in country \( j \) at a particular time. It depends on the proximity (i.e., contact) between persons, and how contagious the disease is. The probability that the infected population spreads the virus, and thus the parameter that determines \( \Delta I_0 \), the growth in infections, is given by \( \beta I_0 N \).

If the recovery rate of infected persons is denoted by \( \gamma \), the growth in the number of infections over time, \( \Delta I_0 \), is determined as follow:

\[
\Delta I_0 = \beta I_0 N - \gamma I_0. 
\tag{2}
\]

At the outbreak of the pandemic \( I_0 = 1 \), and the reproduction rate \( R_0 \), which is the number of persons that an infected person infects before recovery, is:

\[
R_0 = \frac{\beta}{\gamma}. \tag{3}
\]

If \( R_0 > 1 \), the virus spreads exponentially, and if \( R_0 < 1 \), it dampens down the virus. It describes an “epidemiological curve” which is bell-shaped, and which peaks earlier or later, depending on the value of \( R_0 \).

The basic SIR model indicates that to prevent a virus from spreading exponentially and overwhelming the capacity of a country’s health services, bringing down the transmission rate \( \beta \) and increasing the recovery rate \( I_0 \) are imperative. Over time the reproduction rate continuously declines as people build up immunity or benefit from the arrival of a vaccine. These insights lead to the typical ‘best practice’ responses to manage an epidemic or pandemic, pharmaceutical interventions and non-pharmaceutical interventions. PIIs include the testing, tracing and isolation of infected individuals, the development of vaccines and drug treatments, and the utilization of personal protective equipment. NPIs include lockdowns which broadly refer to measures that limit contact between people, such as enforcing social distancing measures, curfews, and closing down schools and businesses where physical proximity cannot be maintained.

The weakness of the standard SIR model as basis for decisions on NPIs is that there is no optimization behavior by individual agents. The impact of NPIs on the transmission rate does not only depend on a central authority laying down regulations, but on optimization behavior from economic agents, given that NPIs carry a cost. To rectify this shortcoming, a number of elaborations of SIR models have been made.

For example, Garibaldi, Moen, and Pissarides (2020) provided a SIR-type model wherein agents optimize their contacts, i.e., they decide how much to social distance (or not) depending on the various benefits and costs associated with such choices. The authors find that a decentralized outcome is sub-optimal, in that private agents will not social distance sufficiently, as they do not take into account various externalities, such as the costs of burdening the healthcare system. Acemoglu et al. (2020) used an adapted SIR model, which they labeled a ‘multi-risk’ SIR model to reflect heterogeneous agents in terms of age. Their model shows that NPIs that impose stricter lockdowns on older people minimize both fatalities and economic costs.

Due to high costs, and compounded by the uncertainty over parameters such as \( \beta \) and \( \gamma \), opposition to NPIs has been widespread. Some have argued that if the virus affects some parts of the population more severely than others, a more targeted approach will be more cost-effective (Eichenbaum et al., 2020). Others have argued that an extensive testing, tracing and quarantining strategy will be just as effective in bringing \( R_0 \) down, but at much less expense (Alon, Kim, Lagakos, & VanVuren, 2020; Dewatripont, Goldman, Muraille, & Plateau, 2020).

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8 See Avery et al. (2020) who provide an introduction to variants of the SIR model, such as the SEIR model that includes an ‘exposed’ state to account for individuals who have been infected with the disease, but are not yet themselves infectious; and the SAIR model that includes ‘asymptomatic’ individuals, i.e., who are infectious, but not showing symptoms.
The point here is not to evaluate this debate, but to illustrate that the basic theoretical SIR model has been influential in shaping policy responses, in particular in how governments resorted to both PIs and NPIs. It also illustrates that a central objective of these interventions has been to reduce the number of infections, and thus mortality. This was supported by emerging evidence in the first quarter of 2020: COVID-19 is more deadly than the common flu and infected persons more often require hospitalization (Petersen et al., 2020; Yang et al., 2020). With more people infected and requiring care in the intensive care unit of a hospital, less medical and healthcare resources will be available to treat all those infected, leading to a higher mortality rate. In addition, there will be also less resources available to treat those with other diseases. Thus, targeting a reduction in infections is justified.

The mortality rate, however, is not only dependent on the number of cases alone. As mentioned in Section 2, there has been substantial heterogeneity within and across countries in COVID-19 mortality rates and excess deaths, often despite similar NPI measures (Adam, 2022; Aizenman et al., 2022). Explaining the factors associated with fatalities across countries can offer useful insights into whether countries need additional interventions to reduce fatalities. Such interventions may, for example, attempt to compensate for some country-specific characteristic which could make a population more susceptible to die from the infection (see factors related to higher mortality in Section 2).

The mortality rate $\delta_j$ from COVID-19 can thus be written as a function of the number of infections ($I_j$), how rapidly it is transmitted, which may depend on spatial patterns of living and working (the variable $T_j$ is used to capture variables that determine the transmission rate, $\beta_j$), the recovery rate ($R_j$ contains variables that determine the recovery rate, $\gamma_j$), and the susceptibility of the population to die from the virus ($S_j$). In reduced form, the mortality rate to be estimated is:

$$\delta_j = \alpha_0 + \alpha_1 I_j + \alpha_2 \sum_{i=1}^n T_{ij} + \alpha_3 R_j + \alpha_4 S_j + \epsilon_j$$  \hspace{1cm} (4)

where $T_{ij}$, $R_j$ and $S_j$ are respectively vectors of variables capturing transmission, recovery, and susceptibility to die from the virus in country $j$ at time $t$. Finally, $\epsilon_j$ is a random disturbance term with the usual properties.

It can be assumed that $I_j$ and $T_{ij}$ reflect NPI policies which are endogenous (see Castex et al., 2021). $T_{ij}$ may also be determined by the extent of urbanization and population density which influences proximity and contact between people and could be a key determinant for higher mortality rates in cities. $R_j$ may be determined by the access to availability and extent of health services and other resources. These can be exogenous over the short- to medium-term, and may be better in urban than rural areas. $S_j$ may be determined by the population share in country $j$ at time $t$ that is above a certain age, and other factors that make the population more susceptible to die from COVID-19. Also these are expected to differ in cities compared to rural areas, with contrasting effects.

4. Research methods

4.1. Hypotheses

Based on the theoretical model, we put forth four testable hypotheses:

**Hypothesis 1.** Countries with a higher population density tend to suffer more fatalities per million from COVID-19 than countries with a lower population density.

**Hypothesis 2.** Countries with a more concentrated urban development pattern, as measured by the share of the population living in the largest city, tend to suffer more fatalities per million from COVID-19 than countries with a smaller share of their population living in the largest city.

**Hypothesis 3.** Countries with a higher share of urban population tend to suffer more fatalities per million from COVID-19 than countries with a smaller share of urban population.

**Hypothesis 4.** Countries with a more concentrated urban development pattern have temporally more concentrated COVID-19 fatalities than countries with less concentrated urban development patterns where COVID-19 fatalities will be more spread out over time.

In the next sub-section we show the data that we will employ for Eq. 4. The selection of variables to include is based on the literature review in Section 2, i.e., on the factors associated with cross-country COVID-19 mortality, and on practical considerations of data availability.

4.2. Data: dependent variables

Our main dependent variable is the fatality rate of COVID-19. There are two measures of fatalities that we use: first, the official COVID-19 fatality reports per million inhabitants from national health departments, as collected by the Johns Hopkins COVID-19 tracker (Dong et al., 2020), and provided by Our World in Data (OWID) on GitHub. The use of the officially reported COVID-19 fatality rates are however expected to be subject to measurement problems: (1) COVID-19 fatality rates are likely under-reporting true fatalities, and (2) comparability across countries is compromised due to differences in criteria for reporting mortality rates of COVID-19 (Adam, 2022; Backhaus, 2020). Such inconsistencies are clearly observed when comparing the officially reported figures with excess deaths (i.e., the number of deaths above the long-term average). Leon et al. (2020) refer to these inconsistencies, pointing out that countries differ in their practices in classifying deaths due to COVID-19 or an underlying pre-existing condition. They therefore recommend to use counts of weekly excess deaths to make comparisons possible, explaining that “the counts would be of deaths by all causes combined, thus side-stepping issues of what is or is not a death attributable to COVID-19” (Leon et al., 2020, p. e81). Based on these considerations, the second dependent variable is thus excess mortality per million inhabitants. The data were obtained from The Economist’s tracker for COVID-19 excess deaths.

A third dependent variable used is the value of a country’s Shannon-Wiener diversity index for COVID-19 fatalities. This variable reflects the extent to which COVID-19 fatalities were temporally more or less concentrated during 2020. We expect more temporal clustering of deaths in countries with a higher share of urbanization. The Shannon-Wiener diversity index in country $j$ is calculated, following Dalziel et al. (2018) and Rader et al. (2020), as:

$$s_j = -\left(\sum_{i=1}^n d_i \ln d_i\right)$$  \hspace{1cm} (5)

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9 The COVID-19 pandemic led to 309 recorded COVID-19 fatalities per million people on average during 2020, with a large standard deviation of 381 fatalities per million, which ranged from as low as zero in Thailand and five in New Zealand, to 1685 in Belgium. Excess deaths were on average 915 per million with a standard deviation of 913.
Where \( d_{ij} \) is the number of new deaths in country \( j \) on day \( i \) during 2020. The lower the value of \( d_{ij} \), the less diversity in fatalities over time, and thus the more temporal clustering of deaths. Conversely, the higher the value of \( d_{ij} \), the more spread out have deaths been across the year. Our interest lies in whether countries which are more densely populated and have a higher urbanization share have a higher temporal concentration of deaths, e.g., at the beginning of the outbreak. Through learning processes, the initial peak would quickly decline, for example, by gaining knowledge on how to treat patients and how to practice social distancing (see e.g. Rader et al., 2020).

4.3. Data: independent variables

The mortality rate \( \delta_j \) from COVID-19 can be written as a function of the number of infections, how rapidly the disease is transmitted and treated, and the susceptibility of the population to die from the virus. As we have argued, population density and urbanization rates will influence these. The independent variables in our regression analyses therefore measure (or proxy) all of these factors: infections, transmission, treatment, and susceptibility. The description and sources of these variables are set out in Table 1. Population density and urbanization, specifically, are captured (or proxied) by three variables, namely (i) the population density of the country, (ii) the share of the urban population living in the largest city, and (iii) the share of urban population in the country.

The number of infections is based on total COVID-19 cases per million, and is likely to be underestimated. Identification of cases has been slow and incomplete in the early days of the pandemic, as testing only became widespread after various months into the pandemic. It nevertheless provides a useful indication regarding the prevalence and spread of COVID-19 within countries.

The speed of transmission depends on behavioural choices and possibilities – for instance, that people are willing and able to maintain social distancing and that they follow public health guidelines. In 2020, all countries in our sample introduced NPIs, such as lockdowns and social distancing requirements. The strength of these interventions can be measured by the Oxford COVID-19 Government Response Tracker (OxCGRT) which is available on GitHub. While NPIs, including lockdowns, saved many lives in 2020 (Flaxman et al., 2020), this measure is endogenous, driven largely by the extent of cases and deaths in a country. The problem in a single-period, cross-country OLS regression is that it will not be able to distinguish the feedback loops that exist between a government’s lockdown measures and COVID-19 deaths. To capture these, we would need a dynamic model, which falls outside the scope of this paper. To overcome this problem, we also proxy NPIs by using a non-endogenous measure, namely trust in government. We assume that with higher levels of trust, people more readily comply with NPIs, so that these have more impact. We use the share of people who trust its government in 2018, an exogenous measure, as it precedes the outbreak of the pandemic.

The measures selected for our susceptibility variables can be motivated with reference to the discussion in Section 3, and include the age structure of the population, income inequality, level of economic development, and environmental indicators of the country. We proxy these with the share of population aged 70 and higher, the Gini-coefficient, GDP per capita, air quality (CO2 emissions), and duration of sunshine hours in the capital city per year. For treatment (and recovery) we use the number of physicians per 1000 people.

5. Empirical evidence

5.1. Descriptive statistics

Our sample consists of 81 countries for which we have data covering most of the variables of interest. The countries included in the analysis, as well as their COVID-19 fatalities and excess death rates (per million) are listed in Table A1 in Appendix A. This table shows the considerable heterogeneity in mortality rates and excess deaths across countries during 2020. Table A2 in Appendix A contains an overview with the summary statistics of all variables.

Table A3 in Appendix A shows the correlation matrix between the variables listed in Table 1. As can be expected, COVID-19 deaths and excess deaths were also significantly and positively correlated with COVID-19 cases. The table further shows that COVID-19 deaths and excess deaths were also significantly and positively correlated with the stringency index, indicating that countries experiencing higher COVID-19 death rates imposed on average more stringent lockdowns. This is confirmed when we regress the stringency index against our dependent variables — see Appendix D. Trust in government is significantly and negatively correlated with COVID-19 deaths and excess deaths. This is expected as we assume that the variable reflects the degree to which people take government-imposed NPIs seriously. Countries with a higher COVID-19 death rate have a significant and positive correlation with the share of population older than 70 years of age, but a non-significant correlation with excess mortality. In contrast, the COVID-19 death rate is not significantly correlated with GDP per capita, but there is a significant and negative correlation with GDP per capita for excess deaths.

The correlation matrix furthermore shows that the Shannon-Wiener diversity index, measuring how spread out (higher value) or concentrated (lower value) COVID-19 deaths occurred in a country over the

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14 We excluded Singapore from the analysis, as this city-state presents a statistical outlier; thus our final sample consists of 80 countries.
year 2020, is significantly and positively correlated with the number of cases, the stringency index, and income inequality. This implies that countries with spread-out patterns of deaths struggled to contain infections and that lockdown measures were (or had to be) more stringent. The significant correlation with income inequality suggests that unequal access to resources (e.g., medical care, income) is associated with a more spread out pattern of deaths over 2020.

All correlations between COVID-19 deaths and excess deaths, and proxies of urbanization are insignificant and small in size. This suggests that more urbanized countries did not suffer more fatalities compared to less urbanized ones. We further hypothesized that pandemic fatalities peak earlier in countries with higher urban development. In other words, we expect that pandemic fatalities in more urbanized countries show an early temporal concentration (spike). The correlation matrix however suggests that the Shannon-Wiener diversity index is not significantly correlated with any of the urban dimensions.

Finally, we can see in the correlation matrix that there is little indication of multicollinearity. The highest correlation values are between COVID-19 mortality and number of cases (0.67), and between COVID-19 mortality and excess death rates (0.63), which can be expected.

5.2. Regression results

The OLS regression results, with robust standard errors in brackets, are shown in Tables 2 to 4. The three regression tables each contain four models. The first model is a baseline specification, including only the number of cases and our urban variables of interest. The second model controls for variables that proxy the susceptibility to infection, such as age, inequality, GDP, air quality, and sunshine hours. The third model controls only for variables that proxy transmission and treatment, such as trust in government (adherence to lockdowns) and the number of physicians per 1000 inhabitants. The fourth model contains all variables.

In Table 2 we show the results for COVID-19 mortality as dependent

Table 2
Dependent variable - COVID-19 deaths per million.

|            | (1)          | (2)          | (3)          | (4)          |
|------------|--------------|--------------|--------------|--------------|
| cases      | 0.017***     | 0.016***     | 0.017***     | 0.017***     |
|            | (8.74)       | (7.11)       | (6.88)       | (6.33)       |
| popdens    | –0.29        | 0.09         | –0.07        | –0.014       |
|            | (–0.54)      | (0.21)       | (–0.18)      | (–0.03)      |
| poplarge   | –3.50        | –2.53        | –2.65        | –1.06        |
|            | (–1.33)      | (–0.88)      | (–0.99)      | (–0.30)      |
| populrb    | –0.45        | 1.62         | 4.15         | 6.21         |
|            | (–0.16)      | (0.41)       | (1.24)       | (1.43)       |
| popage     | 22.50        | 31.6         | (1.57)       | (0.93)       |
| inequal    | 13.34**      | 1.47         | (2.04)       | (0.17)       |
| lngdpwc    | –104.04*     | –85.3        | (–1.85)      | (–1.04)      |
|            | (–1.31)      | (–0.12)      | (–1.37)      |
| airqual    | –0.29        | 0.16         | (–0.10)      | (0.05)       |
| sun        | –0.12        | –0.12        | (–3.58)      | (–1.88)      |
| trustgov   | –6.95***     | –5.80*       | (–3.58)      | (–1.88)      |
|            | (–1.31)      | (–0.12)      | (–1.37)      |
| phys       | –76.93**     | –120.24***   | (–6.95)      | (–5.80)      |
| N          | 269.1        | 495.16       | 542.62       | 584.62       |
| R²         | 0.444        | 0.520        | 0.549        | 0.573        |
| Adj. R²    | 0.410        | 0.439        | 0.494        | 0.458        |

Table 3
Dependent variable — excess deaths per million.

|            | (1)          | (2)          | (3)          | (4)          |
|------------|--------------|--------------|--------------|--------------|
| cases      | 0.025***     | 0.025***     | 0.022***     | 0.023***     |
|            | (5.07)       | (4.57)       | (3.25)       | (3.65)       |
| popdens    | –1.49**      | –1.18*       | –1.09        | –1.38*       |
|            | (–2.11)      | (–1.70)      | (–1.56)      | (–1.78)      |
| poplarge   | –12.12       | –13.61       | –12.31       | –18.0***     |
|            | (–1.90)      | (–1.84)      | (–1.43)      | (–2.22)      |
| populrb    | –20.46       | 4.01         | –16.72**     | 14.28        |
|            | (–4.17)      | (0.40)       | (–2.56)      | 1.23         |
| popage     | 48.35        | 55.17        | (1.51)       | (0.98)       |
| inequal    | 5.69         | –8.70        | (0.37)       | (–0.46)      |
| lngdpwc    | –596.9**     | –840.3**     | (–3.06)      | (–3.01)      |
| airqual    | –3.05        | –1.56        | (–0.45)      | (–0.21)      |
| sun        | –0.12        | –0.21        | (–0.62)      | (–0.94)      |
| trustgov   | –11.32       | 0.59         | (–1.50)      | (0.07)       |
| phys       | –72.64       | 33.6         | (–0.86)      | (0.24)       |
| _cons      | 2357.3***    | 1951.3***    | 2901.9***    | 2613.98***   |
|            | (5.66)       | (2.78)       | (3.96)       | (2.42)       |

Table 4
Dependent variable — Shannon-Wiener diversity index.

|            | (1)          | (2)          | (3)          | (4)          |
|------------|--------------|--------------|--------------|--------------|
| cases      | 0.000596     | 0.000804*    | 0.00104*     | 0.000862**   |
|            | (1.42)       | (2.50)       | (2.55)       | (3.16)       |
| popdens    | 0.0734       | 0.0699       | 0.0838       | 0.0636       |
|            | (1.57)       | (1.76)       | (1.95)       | (1.93)       |
| poplarge   | –0.259       | –0.251       | –0.192       | –0.389       |
|            | (–0.58)      | (–0.70)      | (–0.47)      | (–0.99)      |
| populrb    | 0.330        | 1.206        | 0.438        | 0.427        |
|            | (0.60)       | (1.99)       | (0.74)       | (0.68)       |
| popage     | –1.698       | 4.211        | (–0.74)      | (–0.98)      |
| inequal    | 1.446        | 0.922        | (1.44)       | (0.65)       |
| lngdpwc    | –8.366       | 6.171        | (–9.97)      | (0.55)       |
| airqual    | –0.120       | 0.0164       | (–0.34)      | (0.05)       |
| sun        | 0.00881      | 0.0169       | (0.84)       | (1.72)       |
| trustgov   | –0.749       | –0.395       | (–1.70)      | (–0.65)      |
| phys       | –16.45***    | –3.793       | (–4.03)      | (–0.52)      |
| _cons      | 442.0***     | 347.7***     | 506.5***     | 417.8***     |
|            | (10.87)      | (5.76)       | (9.42)       | (4.08)       |
| N          | 71           | 63           | 56           | 53           |
| R²         | 0.311        | 0.345        | 0.329        | 0.499        |
| Adj. R²    | 0.269        | 0.339        | 0.247        | 0.365        |

The SW diversity index was multiplied by 100 for better readability of coefficients.

t-Statistics in parentheses, based on robust standard errors.

*p < 0.05.

**p < 0.01.

***p < 0.001.

variable. In all regressions, the number of cases is significant and
positive, as expected, and the coefficient sizes stable across regression models. The small absolute sizes of the coefficients are consistent with a low infection fatality risk (IFR).\textsuperscript{15}

The regression in Column (1), the baseline specification, indicates that none of the urban measures are statistically significant, and suggests a rejection of Hypotheses 1 to 3. Before rejecting these hypotheses, however, we need to control for susceptibility, transmission and treatment, as per the theoretical model presented in Section 3. The results in Column (2) show that countries with higher inequality suffered higher COVID-19 death rates in 2020, controlling for other factors. It also shows that richer countries were less susceptible to COVID-19 deaths. In Column (3), we control for treatment and transmission. The results show that countries with higher degrees of trust in government and more physicians suffered fewer COVID-19 deaths. Finally, adding all variables, the regression in Column (4) shows that only the number of cases, trust in government, and number of physicians per 1000 inhabitants are significantly associated with COVID-19 deaths per million in 2020. Thus, countries with better health services and fewer cases, and where people had higher trust levels in government, suffered fewer COVID-19 deaths per million.

In Table 3 the dependent variable is excess mortality per million (see Leon et al., 2020). As in the previous regression table, the number of cases is significant and positive, as expected, and the coefficient sizes stable across regression models.

Column (1), our baseline specification, indicates that population density and the share of urban population living in the largest city are statistically significant and negatively associated with excess deaths in 2020. When we control for measures of susceptibility in Column (2), urban measures remain significant and negative. In addition, GDP per capita is significantly and negatively associated with excess deaths, suggesting that richer countries have more resources to prevent death. In Column (3), controlling for measures of transmission and treatment, a country's urbanization rate is significant and negative. Finally, when controlling for both susceptibility and transmission and treatment in Column (4), population density and the share of urban population living in the largest city remain statistically significant and negatively associated with excess deaths. GDP per capita is also statistically significant and negative, as in Column (2). Overall, the results in Table 3 suggest that countries with more pronounced urban development suffered on average fewer excess deaths in 2020. This leads us to reject Hypotheses 1 to 3, and suggests that the contrary is actually occurring.

Our final set of regression results are contained in Table 4. Here the dependent variable is the value of a country's Shannon-Wiener diversity index for COVID-19 fatalities.

The table shows that the number of cases is significant with a (small) positive coefficient in Columns (2) to (4). This means that a higher number of cases per million is associated with a more spread out duration of the pandemic over 2020. Results in Column (3) indicate that in countries with more physicians per 1000 inhabitants, COVID-19 infections tended to spike earlier on. In Column (4), only the number of cases is significant. More generally, besides cases and number of physicians in Column (3), no other variables are significant. Based on this, we therefore also reject Hypothesis 4. We find no evidence from our regression models that countries with a more concentrated urban pattern have temporally more concentrated COVID-19 fatalities than countries with less concentrated urban development patterns.

We further re-estimate Model (4) of Tables 2 to 4 using lockdown strictness instead of trust in government. The results are contained in Appendix 10. The results show that there is a positive and statistically significant relationship between the stringency of lockdown measures and, respectively, COVID-19 and excess deaths. The results with respect

\textsuperscript{15} Studies using sero-prevalence data established the IFR of COVID-19 at around 0.6 % for the total population (see, e.g., Perez-Saez, Lauer, Kaiser, et al., 2020; Petersen et al., 2020).
to our urban variables of interest are robust to this specification. They are, in their majority, not significant, or negatively associated with excess deaths for the share of urban population living in the largest city.

In conclusion, we reject Hypotheses 1 to 4 and hence the hypothesis that more urbanized countries suffered more fatalities during COVID-19. Our results suggest no relation; or a weak opposite relation in that more densely populated and urbanized countries experienced less excess deaths.

5.3. Discussion and take-aways for policy and practice

The literature review and the empirical analysis presented in this paper do not find any evidence in favor of the hypothesis that urbanized countries suffered more fatalities during COVID-19. The results from various regression models confirm the implications from the theoretical SIR models: The number of cases, the availability of healthcare, GDP per capita (resources), income inequality, and the extent to which a population trusts its government, are the most significant factors related to COVID-19 fatalities. If we use excess deaths per million as dependent variable, countries that are more densely populated, which have a higher share of the urban population living in the largest city, and that have a higher urbanization rate experience fewer fatalities, perhaps due to agglomeration advantages that allow countries to quickly react and reach inhabitants. GDP per capita was also found to be significant and negatively correlated with excess mortality. These findings imply that countries with more concentrated urban development patterns, with a better healthcare system, and which are less unequal and richer, experienced on average fewer COVID-19 deaths per million in 2020, holding other factors constant. Overall, the results for the variables of urban development patterns do not suggest strong associations with COVID-19 mortality.

In 2020, the year that our empirical study covers, no COVID-19 vaccine was available outside of clinical trials until the end of December. The increasing vaccine availability in 2021 therefore offers a provisional opportunity to further scrutinize the suggestion from our findings that countries with higher levels of urban development have suffered comparatively fewer fatalities (as measured by excess deaths), due to the availability of healthcare facilities, and because they are more equal and richer, and thus have more and better resources. If this explanation has some validity, one can expect that vaccination programs are rolled out faster in these countries. Hence, it can provide additional evidence that the same or a lower mortality in more urbanized countries was primarily due to efficiencies in the healthcare system and higher resource availability.

To investigate these speculations, we draw scatter plots of COVID-19 vaccinations as of 15 June 2021, and urbanization rates (Fig. 2) and the Shannon-Wiener diversity index (Fig. 3). Fig. 2 supports this assumption. Countries with a higher share of urban population had on average managed to fully vaccinate a higher proportion of their population by 15 June 2021. On the one hand, because urban centers can reach a higher share of the population within a smaller distance; on the other hand because more urbanized countries tend to be richer, have more resources and thus better access to purchase vaccinations, and have a well-functioning healthcare system that allows for a quick roll-out of vaccinations.

Fig. 3 shows that countries where the Shannon-Wiener diversity index had a lower value (i.e., a spiked temporal pattern in COVID-19 deaths) also managed to fully vaccinate a larger proportion of their population by 15 June 2021. This is in line with our expectation. Thus, having a good healthcare system may have helped urbanized countries to reduce death rates faster once the pandemic started.

Our results thus reflect the fact that urban development is associated with economic development, and that the resources of richer countries facilitate managing and maintaining NPI as well as quickly rolling out effective PL.

There are, however, also various opportunities for developing and emerging economies to learn from these results. First, the significance of trust in government suggests that communication in times of pandemic is paramount. Simple and clearly communicated policies that show transparently how decisions were taken, both at the local and national level, can improve the trust in NPIs, and convince the population to follow these. Policies further need to take into account the realities in which people live and further ensure that people are not pushed into adverse living conditions, making it otherwise impossible for them to follow guidelines. Second, the significant association between number of physicians and COVID-19 mortality shows that medical care matters. Ensuring universal basic health care with equal access to all, also in less developed countries, will save lives. Third, in the longer-term, countries should invest in structures that allow for a fast roll-out of medical programs, for example, vaccines or distribution of medication. Reaching

![Fig. 2. COVID-19 vaccinations and urbanization, 15 June 2021.](https://example.com/fig2)

**Data source:** Authors’ compilation based on the Our World in Data COVID-19 available on GitHub, and World Development Indicators Online.
matter. Finally, only the number of cases were significantly associated with lower numbers of infections (perhaps as a result of better NPI measures) and better medical personnel (more physicians) had on controlling for GDP per capita. This is in contrast to the hypothesis, and estimate a number of regression models to identify the cross-countries factors associated with COVID-19 fatalities and excess deaths. Fatalities from the COVID-19 pandemic in 2020 were measured in two ways: first, by using reported COVID-19 deaths, and second, using excess mortality, given that the former measure may be subject to measurement problems. We also constructed a Shannon-Wiener diversity index for the temporal concentration in reported fatalities. We estimated the factors associated with these three dependent variables based on a theoretical SIR model by running an OLS regression model using cross-country data for 80 countries. The independent variables included three proxies for urban development, namely population density, the share of urban population living in the largest city, and the share of urban population. To these, we added a number of control variables, as specified in the theoretical model.

Our results reject the overall hypothesis that more urbanized countries suffered more fatalities during the COVID-19 pandemic. Countries with lower numbers of infections (perhaps as a result of better NPI measures) and better medical personnel (more physicians) had on average fewer COVID-19 deaths in 2020. Also trust in government was significantly associated with a lower mortality rate, perhaps indicating more confidence in governmental advice. We further found that countries with a higher population density and a larger share of urban population living in the largest city had a lower excess mortality, even when controlling for GDP per capita. This is in contrast to the hypothesis, and suggests that cities are actually safe places. Our results also indicate that richer countries had fewer excess deaths, indicating that resources matter. Finally, only the number of cases were significantly associated with the Shannon-Wiener diversity index, suggesting that more cases are associated with a more spread-out pattern of the pandemic. The coefficient, however, is very small.

Instead, policy responses, the development level, a well-functioning healthcare system, and trust in government are relevant factors in bringing down pandemic fatalities. Well-organized cities can help in this regard, as urbanization and city development are associated with economic development. The resources these countries have, makes it easier for them to manage and maintain stricter lockdowns, or to roll out effective pharmaceutical interventions; especially if their populations have more trust in them. Thus, countries with more pronounced urban development did not suffer more deaths in 2020, and were moreover faster at rolling out vaccination programs. These results lend support to the conclusion of The Economist (2020) that “[h]istory suggests that it is foolish to bet against big cities. Repeated terrible outbreaks of plague and cholera barely delayed the growth of London or Paris.”

In fact, given the benefits of cities for managing pandemics, urban areas may have just become more desirable places to live. This is, however, not a reason to be complacent. It is rather a call for accelerated investments in improving living conditions and governance in cities across the world, particularly in less developed countries (Ahmed et al., 2019). There are still too many slums and areas of neglected urban sprawl where residents have inadequate access to medical facilities, as well as reduced ability to socially distance (Brotherhood, Cavalcanti, Da Mata, & Santos, 2022). Cities’ resilience against infectious diseases are further compromised given that “almost one-third of urban dwellers live in informal settlements with limited access to drinking water and safe sanitation” (Sachs et al., 2019, p. 809), and where they are most often excluded from participation in urban planning.

6. Concluding remarks

Cities have been described as “urban graveyards” (Curtis, 2016, p. 139) during pandemics due to a dense population structure and better connectivity with the outside world. In this paper, we investigate the accuracy of this perception that more urbanized countries suffer more fatalities for the COVID-19 pandemic, focusing on variables that capture urban development. We study the literature on cities and COVID-19, derive a theoretical model of the determinants of the mortality rate, and estimate a number of regression models to identify the cross-countries factors associated with COVID-19 fatalities and excess deaths. Fatalities from the COVID-19 pandemic in 2020 were measured in two ways: first, by using reported COVID-19 deaths, and second, using excess mortality, given that the former measure may be subject to measurement problems. We also constructed a Shannon-Wiener diversity index for the temporal concentration in reported fatalities. We estimated the factors associated with these three dependent variables based on a theoretical SIR model by running an OLS regression model using cross-country data for 80 countries. The independent variables included three proxies for urban development, namely population density, the share of urban population living in the largest city, and the share of urban population. To these, we added a number of control variables, as specified in the theoretical model.

Our results reject the overall hypothesis that more urbanized countries suffered more fatalities during the COVID-19 pandemic. Countries with lower numbers of infections (perhaps as a result of better NPI measures) and better medical personnel (more physicians) had on average fewer COVID-19 deaths in 2020. Also trust in government was significantly associated with a lower mortality rate, perhaps indicating more confidence in governmental advice. We further found that countries with a higher population density and a larger share of urban population living in the largest city had a lower excess mortality, even when controlling for GDP per capita. This is in contrast to the hypothesis, and suggests that cities are actually safe places. Our results also indicate that richer countries had fewer excess deaths, indicating that resources matter. Finally, only the number of cases were significantly associated with the Shannon-Wiener diversity index, suggesting that more cases are associated with a more spread-out pattern of the pandemic. The coefficient, however, is very small.

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CRediT authorship contribution statement

Wim Naudé: Conceptualization, Methodology, Formal analysis, Writing – original draft, Writing – review & editing. Paula Nagler: Writing – original draft, Writing – review & editing, Data curation, Methodology.
Declaration of competing interest

The authors have no conflicts of interest to disclose.

Appendix A

Table A1
COVID-19 and excess deaths per million, 2020.

| Country              | COVID-19 deaths | Excess deaths | Country        | COVID-19 deaths | Excess deaths |
|----------------------|-----------------|---------------|----------------|-----------------|---------------|
| Albania              | 415             | 2087          | Lithuania      | 694             | 2327          |
| Armenia              | 955             | 333           | Luxembourg     | 732             | 366           |
| Australia            | 35              | 160           | Malaysia       | 14              | 76            |
| Austria              | 661             | 908           | Malta          | 408             | 497           |
| Azerbaijan           | 261             | 1900          | Mauritius      | 8               | –281          |
| Belarus              | 42              | 524           | Mexico         | 972             | 2171          |
| Belgium              | 1680            | 1625          | Moldova        | 1130            | 2007          |
| Bolivia              | 855             | 4079          | Montenegro     | 1071            | 1121          |
| Bosnia & Herzegovina | 1227            | 2155          | Netherlands    | 637             | 838           |
| Brazil               | 928             | 1112          | New Zealand    | 5               | –420          |
| Bulgaria             | 1031            | 2463          | North Macedonia| 1374            | 2636          |
| Canada               | 376             | 335           | Norway         | 78              | 13            |
| Chile                | 945             | 823           | Oman           | 310             | 278           |
| Colombia             | 837             | 899           | Panama         | 963             | 680           |
| Costa Rica           | 437             | 184           | Paraguay       | 542             | 257           |
| Croatia              | 1003            | 1497          | Peru           | 1148            | 2627          |
| Cyprus               | 110             | 262           | Philippines    | 79              | –120          |
| Czechia              | 1118            | 1594          | Poland         | 707             | 1616          |
| Denmark              | 201             | –35           | Portugal       | 643             | 1048          |
| Ecuador              | 815             | 2289          | Qatar          | 88              | 130           |
| Egypt                | 66              | 870           | Romania        | 788             | 1899          |
| El Salvador          | 112             | 1175          | Russia         | 385             | 2452          |
| Estonia              | 153             | 319           | Serbia         | 464             | 2049          |
| Finland              | 95              | 123           | Singapore      | 5               | –47           |
| France               | 1002            | 893           | Slovakia       | 324             | 931           |
| Georgia              | 674             | 1295          | Slovenia       | 1221            | 1396          |
| Germany              | 418             | 430           | South Africa   | 496             | 1204          |
| Greece               | 429             | 484           | South Korea    | 19              | –15           |
| Hungary              | 926             | 1220          | Spain          | 1159            | 1486          |
| Iceland              | 77              | –39           | Sweden         | 798             | 831           |
| Indonesia            | 48              | 420           | Switzerland    | 841             | 1007          |
| Iran                 | 290             | 685           | Taiwan         | 0               | –252          |
| Iceland              | 453             | –6            | Tajikistan     | 9               | 932           |
| Israel               | 346             | 315           | Thailand       | 1               | 13            |
| Italy                | 1224            | 1805          | Tunisia        | 381             | 199           |
| Jamaica              | 94              | –155          | Turkey         | 657             | 1037          |
| Japan                | 26              | –179          | Ukraine        | 463             | 1011          |
| Kazakhstan           | 148             | 1595          | UK             | 2253            | 176           |
| Kosovo               | 711             | 927           | USA            | 988             | 1384          |
| Kyrgyzstan           | 206             | 1072          | Uzbekistan     | 18              | 528           |
| Latvia               | 356             | 418           |                |                |               |

Sources: OWID COVID-19 and The Economist's Excess Death Tracker datasets on GitHub.

Table A2
Summary of variables.

| Variable | Observations | Mean       | St. dev. | Min   | Max   |
|----------|--------------|------------|----------|-------|-------|
| Dependent|              |            |          |       |       |
| covmor   | 80           | 558.16     | 459.21   | 0.30  | 2251.49|
| excessd  | 80           | 988.62     | 912.01   | –420.45| 4078.87|
| swindex  | 80           | 4.70       | 0.73     | 1.48  | 5.53  |
| Independent|           |            |          |       |       |
| cases    | 80           | 27,389.90  | 19,480.62| 32.55 | 76,818.85|
| popdens  | 79           | 138.18     | 195.62   | 3.20  | 1454.04|
| poplarge | 71           | 28.32      | 14.22    | 5.53  | 75.22 |
| popurb   | 78           | 70.54      | 15.47    | 27.31 | 99.19 |
| popage   | 78           | 8.72       | 4.17     | 0.62  | 18.49 |
| inequal  | 72           | 35.14      | 7.46     | 24.60 | 63.00 |
| lgdpc   | 79           | 24.23      | 24.00    | 1.12  | 111.06|
| phys     | 66           | 2.94       | 1.37     | 0.43  | 7.12  |
| airqual  | 79           | 30.49      | 14.39    | 6.11  | 93.06 |
| sun      | 80           | 2252.23    | 580.49   | 1230.00| 3542.00|
| Astring  | 77           | 58.72      | 12.55    | 16.69 | 82.50 |
| trustgov | 75           | 51.21      | 18.41    | 10.95 | 99.22 |
We plot, for illustration purposes, the daily COVID-19 fatalities across 2020 for the contrasting cases of Algeria and Mauritius. Algeria is an example of a country with a high value of the Shannon-Wiener diversity index, which means it had a prolonged series of fatalities across 2020, whereas Mauritius had a low Shannon-Wiener diversity index value, meaning that its fatalities were more clustered temporally – after an initial spike the country managed to reduce and keep fatalities low. These patterns are clearly discernible in the two figures.

**Appendix B**

**Fig. B1.** Daily COVID-19 fatalities Algeria, 2020.
Source: Based on the OWID COVID-19 dataset on GitHub.

**Fig. B2.** Daily COVID-19 fatalities Mauritius, 2020.
Source: Based on the OWID COVID-19 dataset on GitHub.

**Appendix C**

**Table C1**
Shannon-Wiener diversity index values for temporal diversity of COVID-19 fatalities, 2020.

| Country     | Top 10 highest | Country                | Bottom 10 lowest |
|-------------|----------------|------------------------|------------------|
| Algeria     | 5.55           | São Tome & Príncipe    | 2.56             |
| Iran        | 5.53           | Papua New Guinea       | 2.20             |
| Belarus     | 5.53           | Mauritius              | 2.03             |
| United States | 5.49        | Barbados               | 1.95             |
| Bangladesh  | 5.48           | Comoros                | 1.89             |
| Brazil      | 5.46           | Equatorial Guinea      | 1.73             |
| Saudi Arabia| 5.45           | Taiwan                 | 1.46             |
| Indonesia   | 5.45           | Burundi                | 0.69             |

(continued on next page)
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Appendix D

This table contains the results of estimating the model specified in Column (4) of Tables 2, 3 and 4 using stringency of lockdown measures in 2020 instead of trust in government. It indicates that stringency of lockdown measures was significantly and positively associated with COVID-19 and excess deaths, suggesting that lockdowns were stricter in countries more severely affected.

| Country       | Top 10 highest | Country       | Bottom 10 lowest |
|---------------|----------------|---------------|------------------|
| Moldova       | 5.42           | Fiji          | 0.69             |
| Panama        | 5.42           | Honduras      | 0.23             |

Source: Authors’ compilation based on the Our World in Data COVID-19 dataset on GitHub.

Table D1
OLS regression results with stringency of lockdown index.

| covmor        | excessd | swindex |
|---------------|---------|---------|
| cases         | 0.0163*** | 0.0164**  | 0.000751*** |
| (6.40)        | (3.03)   | (2.70)   |
| popdens       | –0.284  | –1.626   | 0.0395          |
| (–0.77)       | (–1.92)  | (1.22)   |
| poplage       | –2.110  | –23.45*** | –0.474          |
| (–0.69)       | (–3.69)  | (1.28)   |
| popurb        | 6.121   | 7.488    | 0.250           |
| (1.69)        | (0.77)   | (0.46)   |
| popage        | 62.04*  | 78.57    | –1.964          |
| (2.28)        | (1.83)   | (0.77)   |
| inequal       | 2.478   | –13.55   | 0.753           |
| (0.34)        | (–0.80)  | (0.70)   |
| lngdpcc       | –101.8  | –654.8*** | 8.326           |
| (–1.91)       | (–4.20)  | (1.02)   |
| airqual       | –2.867  | –3.772   | –0.258          |
| (–0.99)       | (–0.57)  | (–0.93)  |
| sun           | –0.109  | –0.193   | 0.0212*         |
| (–1.49)       | (–1.01)  | (2.50)   |
| phys          | –133.8* | 6.373    | –6.122          |
| (–2.50)       | (0.05)   | (1.00)   |
| string        | 15.85*  | 32.27**  | 1.500           |
| (3.14)        | (2.07)   | (1.78)   |
| _cons         | –776.8  | 1067.5   | 314.9***        |
| (–1.53)       | (1.22)   | (3.90)   |
| N             | 53      | 53       | 53              |
| R²            | 0.615   | 0.553    | 0.447           |
| Adj. R²       | 0.512   | 0.433    | 0.298           |

The SW diversity index was multiplied by 100 for better readability of coefficients.

r-Values in parentheses, based on robust standard errors.

* p < 0.05.
** p < 0.01.
*** p < 0.001.

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